Nutrient management in China
Part 1
Nutrient balances and nutrient cycling in agro-ecosystems

Edited by
Rolf Härdter, Jian-Chang Xie
Jian-Min Zhou and
Qin-Zhen Fan

International Potash Institute
P.O.Box 1609
CH-4001 Basel
Switzerland

Nutrient management in China - Part I

Nutrient balances and nutrient cycling in agro-ecosystems

Nutrient management in China

Part I

Nutrient balances and nutrient cycling in agro-ecosystems

Edited by:

Rolf Härdter
Co-ordinator East Asia, International Potash Institute (IPI)
c/o KMA, K+S KALI GmbH, Bertha-von-Suttner-Str.7
34131 Kassel, Germany
Tel. +49-561-9301-2339, Fax. +49-561-9301-1416
E-mail. rolf.haerdter@kali-gmbh.com

Jian-Chang Xie, Jian-Min Zhou and Fan Qin-Zhen
Institute of Soil Science, Academia Sinica,
P.O.Box 821, Nanjing, P.R. China
Tel. +86-25-86881585, Fax. +86-25-86881000
E-mail. jmzhou@ns.issas.ac.cn, fanqinzhen@sina.com.cn.

Institute of Soil Science
Academia Sinica
P.O.Box 821
Nanjing,
P.R. China

International Potash Institute
P.O.Box 1609
CH-4001 Basel
Switzerland

International Potash Institute
Schneidergasse 27
B.O.Box 1609
CH-4001 Basel
Switzerland
Phone: +41-612612922
Telefax: +41-612612925
E-mail: ipi@ipipotash.org
Web: www.ipipotash.org

This Country Report is based, in part, on a workshop that was held on nutrient cycling and management in agro-ecosystems of China, held in Haikou, Hainan, 1999 which has been published as Proceedings in Chinese language by Zhou, J.M., Fan, Q.Z., Xie J.C. and Härdter, R. (2000) (ISBN 7-5630-1553-1/S25). The presented book is an updated translation of the Chinese version, including recent developments in the fertilization practices as described by the various authors.

The editors would like to thank Mr. Wen-Qin Zheng of ISSCAS for his skilful translation of the Chinese papers into English

Layout: Ursula Hartung, K+S KALI GmbH, P.O.Box 102029, 34111 Kassel, Germany

Printing: Druckerei Rindt, Fulda, Germany

Contents

		page
Introduction to the theme		
Härdter, R.	Understanding the nutrient cycles and nutrient balances at different scales to improve nutrient supply and allocation to agricultural systems..................	9
Chapter I	**GLOBAL AND REGIONAL NUTRIENT BALANCES**..	**11**
Krauss, A.	Nutrient cycling and transfers in the global dimension..	13
Uebel, E.	Development in nutrient balances in cropping systems of transitional economies in Central/Eastern Europe..	25
Messick, D. L.	Sulphur balance and sulphur requirements in Chinese agriculture..	35
Zhou, J., Chen, X., Xie, J. and Härdter, R.	Nutrient balance and nutrient management in agro-ecosystems of China....................................	41
Li, J., Lin, B., Liang, G. and Shen, G.	Prospects for mineral fertilizer use in China...........	55
Chapter II	**FARMLAND NUTRIENT BALANCES AND FERTILIZER REQUIREMENT OF NORTHERN CHINA**..	**67**
Jin, J. and Liu, R.	Circulation and regulation of potassium in the soil-plant system under major cropping systems of Northern China..	69
Wu, Y., Wang, Y. and Sun, B.	Nutrient cycle and farmland nutrient balances of the Heilongjiang Province....................................	83
Huang, J. Zhang, J. and Lui, Z.	Analysis of the soil nutrient status of farmland and prediction of the mineral fertilizer demand in the Jilin Province..	89
Lu, Y., Qin, S. and Feng, H.	Nutrient status of farmland soils in the Hebei Province and approaches to its improvement..............	95
Liu, Z., Jiang, L. and Zhang, Y.	Status quo and prospects for the use of mineral fertilizers in the Shandong Province....................	101
Ma, W., Mao, D and Zhang, F.	Allocation of fertilizer nutrients to various crops in the Shandong Province..................................	109

Yan, P. and Mi, Y.	NPK balance in farmland soils and future strategy for fertilization in the Shandong Province.............	117
Jiao, Y., Duan, G. and Qiao, W.	Farmland nutrient balances and prediction of the mineral fertilizer requirement for the 2lst century in Henan..	125
Yang, X., Zhang, S., Wang, X., Tong, Y., Sun, B. and Zhao, H.	Nutrient cycle and nutrient balances in the farmland eco-system of the Shaanxi province.....................	133
Chapter III	**FARMLAND NUTRIENT BALANCE AND FERTILIZER REQUIREMENT OF SOUTHERN CHINA...**	**145**
Dong, Y., Wang, X. and Xu, Q.	Spatial and temporal variation in the nutrient cycle of rice fields in Jiangsu..................................	147
Du, C. and Zhang, Z.	Farmland nutrient balances in the Jiangsu Province...	153
Yin, G., Lui, L., Xu, X., Gao, Q. and Liang, Y.	Changes in soil fertility and prediction of fertilizer demand in Jiangsu...	161
Tian, J. and Wang, Y.	The status quo of and a strategy for farmland nutrient balance in Shanghai..................................	175
Ye, S. and Cao, S.	Fertilization and farmland nutrient balance in Anhui, status quo and outlook..................................	181
Xu, N., Li, J. and Zhang, D.	K cycle and nutrient balance in farmland of the Hubei Province...	191
Dai, P., Nie, J., Liu, X. and Yi, G.	Farmland nutrient cycle and nutrient balances in different eco-regions of the Hunan Province...........	201
Li, Z., Tao, Q., Liu, G. and Liu, Y.	Farmland NPK nutrient balance and management in Jiangxi..	211
Zhang, Y. and Zheng, H	Farmland nutrient balance, a strategy for its improvement and the prediction of future fertilizer demand in the Guangdong Province.....................	223
Feng, W., Tu, S., Fu, T., Chen, Q. and Liao, M.	Farmland nutrient cycle and nutrient balance in Sichuan..	231
Tan, H., Zhou, L. and Xie, R.	Farmland nutrient cycle and nutrient balances in Guangxi..	241
Li, S., Zhang, J. and Huang, S.	Changes in the supply of major nutrients in paddy soils and rational fertilization in Guangxi..............	251
Chen Li.	Trends of changes in the farmland nutrient status in the Hainan Province and suggested methods for improvement..	259

Chapter IV	**ON-SITE STUDIES OF FARMLAND NUTRIENT BALANCES AND RATIONAL FERTILIZATION**	**267**
Witt, C., Wang, G., Dobermann, A., Sun, Q. and Fu, R.	Balanced nutrition and nutrient balances in irrigated rice: a case study in the Zhejiang Province, PR China	269
Xi, Z.	"Cascade" Experiment on fertilizer efficiency and nutrient balance	285
Qin, S., Gu, Y. and Zhu, Z.	Crop response to fertilizer application and nutrient balance in a fluvio-aquic soil	297
Lai, Q., Li, C., Lai, T., Huang, Q. and Yu, J.	Nutrient balance of a rice-rice rotation in paddy fields of a red earth soil of Jiangxi	309
Sun, G.	Residual effects of mineral fertilizers and organic manure and their impact on soil nutrients in a long-term experiment	317
Liu, Y., Zhang, O., He, Y., Li, Z. and Qiao, H.	Soil K status and crop response of wheat to K application in the wheat production area of Southern Shanxi	323
He, C., Sun, X. and Qiu, G.	Effects of K application to a long-term crop rotation of rice, wheat and oilseed rape on yields and soil fertility	331
Chapter V	**NUTRIENT MANAGEMENT IN PERENNIAL CROPS, CASH CROPS.AND IN SPECIAL APPLICATIONS**	**343**
Härdter, R.	Nutrient turnover and requirements in perennial crops using oil palm as an example	345
Magen, H.	Recirculating nutrient solutions in greenhouse production	359
Ruan, J. and Wu, X.	Nutrient input and evaluation of fertilization efficiency in typical tea growing areas of China	367
Zhou, Y., Zhang, J., Huang, F., Zhu, J. and Wang, Z.	Nutrient balances of vegetable cropping systems and their control by fertilization in Tianjin	377
Lin, Z., Li, S., Cha, Z. and Yu, R.	Fertility of soils under rubber plantations and fertilizer application in tropical China	389
Xie, L. Pan. S. and Zhang, W.	Nutrient status and management of tropical fruit crops on Hainan Island	403
Qi, Z. and Tang, S.	Study on sustainable use of tropical forage and grassland in Hainan	413

R. Härdter
Coordinator East/South East Asia,
International Potash Institute,
c/o K+S KALI GmbH, Kassel, Germany

Introduction to the theme

Understanding the nutrient cycles and nutrient balances at different scales to improve nutrient supply and allocation to agricultural systems

Understanding the nutrient cycles and nutrient balances at different scales to improve nutrient supply and allocation to agricultural systems

Rolf Härdter

Coordinator East/South East Asia, International Potash Institute,
c/o K+S KALI GmbH, Kassel, Germany

With the evolution of the farming systems driven by the requirements for food and fibre by a rapidly growing population, the nutrient management practices in China have undergone dramatic changes during the past four decades. The most drastic changes occurred with the improvement of the nutrient availability to agriculture through manufactured mineral fertilizers. This allowed the Chinese growers to shift their nutrient management from a mainly "managing-nutrient-shortages" approach to a more abundant nutrient management in their farms. The former approach was characterized by saving and recycling of nutrients in form of organic manures as well as crops residues or litter, causing that fertility was greatly shifted from one eco-system (e.g. forest) to another (crop- or farmland) and nevertheless was hardly meeting the crop requirements.

On the other hand, the availability of nutrients from mineral fertilizers tends to show a certain affluent use, neglecting important basic principle of good crop husbandry, poor crop residue management, etc. In many cases, the inadequate nutrient management is expressed by a one-sided fuelling of the soil-plant system with nitrogen fertilizer and insufficient replacement of removed potassium. Doing so over years or even decades has led to an accelerated depletion of the soil K reserves. The problems which emerged through this malpractice have not only created concerns of the agricultural researchers and advisors but has also alarmed the decision makers in the agricultural policy and the suppliers of agricultural means of production as well as environmentalist.

Discussions therefore today concentrate very much on issues of how to reduce the so-called oversupply of nitrogen in the crop production in particular. But isn't this just an simplification of the overall problem of inappropriate nutrient management. A reason for this could be that many of the assumptions and conclusions are drawn from simple input : output statistics, indicating that N inputs exceed the outputs by far. Using this approach, however, the various pathways of avoidable and unavoidable nutrient losses from the soil-plant systems are not included. Unavoidable losses are those determined by transformation processes in the soil or the genetically fixed potential of plants to incorporate nutrients and synthesize organic structures, etc. Avoidable losses of nutrients are those occurring through inadequate application (rate, time, etc.) but also through omission or negligence of other important nutrients, especially K, and hence limiting nitrogen uptake. Before these interrelations are not fully understood by the grower but also by other decision makers, the tendency of declining efficiency of applied nitrogen will persist since there will always be an attempt to compensate insufficient crop response or performance by larger application rates.

Only the conceptual approach of a balanced supply of nutrients based on the demand and real removals, including crop residues, can help to alleviate the current problem. Therefore, in order to shed more light into the question how this can be best achieved, the International Potash Institute (IPI) together with the Institute of Soil Science of the China Academy of Agricultural Sciences (ISSCAS) have joint forces by teaming up with a number of Soil and Fertilizer Institutes und the Chinese Academy of Agricultural Sciences (CAAS) to form network that covers the most important cropping system in representative agro-ecosystems of China. The major goal of this network (Figure 1) is to study the current nutrient management practices and their possible improvement through science and good agricultural recommendations. The working principles are that important issues on nutrient management are picked up and intensely studied over a period of three years and results presented during a workshop at the end of each of such a three year cycle, when details are discussed and published to a larger audience in form of proceedings or research topics. The workshops are also the forums, where the focus for the next research cycle in a fast changing environment as affected by crop production and soil fertility management and as it is currently observed in China, is decided.

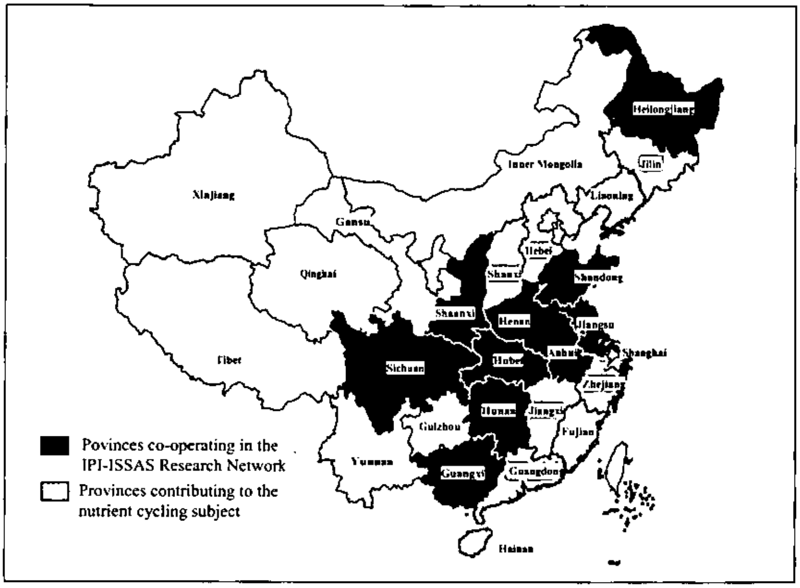


Figure 1. Map of China showing the provinces with typical agro-ecosystems of the "Nutrient management network group" and provinces with close association to the network

In a first approach to improved nutrient management in China, it was decided to analyse in more detail the fate of nutrients entering a cropping system, a farm, a village, county or, at a larger scale, even the province. With these data, it was hoped to obtain a better insight into nutrient fluxes or transfers within a system and from one system to another one. The title of the first part of the work has therefore been under the title "nutrient cycling and nutrient balances in different agro-ecosystems in China". The principles on which the whole work is based are field studies for three years and a study on the quantification of nutrient cycles and transfer within agro-ecosystems at different scales and beyond their borders was initiated.

In this book, the whole subject of nutrient cycling has been divided into five chapters starting with global and regional nutrient balances, followed by analysis and description of the situation in northern China, then by southern China. In the fourth chapter, a closer look at specific on-site studies reveals the current approaches in K crop response studies of annual food crop rotations whereas the last chapter deals with perennial crops and special applications.

Chapter I

Global and regional nutrient balances

Nutrient cycling and transfers in the global dimension

Adolf Krauss

International Potash Institute, IPI, P.O. Box 1609, 4001 Basel, Switzerland

Abstract

Nutrient cycling and transfers occur on different levels of agro-eco systems. This refers in the same way to nutrient cycles in plants and soils, the cycles in farm systems and the transfer of nutrients across national and regional boundaries. An important aspect in nutrient cycling is the balance between input and output. There are substantial differences in nutrient balance between regions, stage of development, economic situation and between nutrients. Potassium is usually in short supply, K balances are mostly negative, which bear consequences for yield formation and yield security.

Contents

- Nutrient cycles in plant and rhizosphere
- Nutrient cycle within a farm system
- Nutrient cycle across national boundaries
- Evolution of regional nutrient balances
- Consequences and conclusion

Nutrient cycling takes place since the beginning of life on earth and the early days of agriculture. Several categories can be distinguished and are different in scale and impact (Figure 1). It ranges from micro levels like in plants or the rhizosphere, to larger scales, e.g. nutrient cycling within a farm system to nutrient transfer across national boundaries. In the following, examples of different categories of nutrient flows in agro-eco systems are discussed.

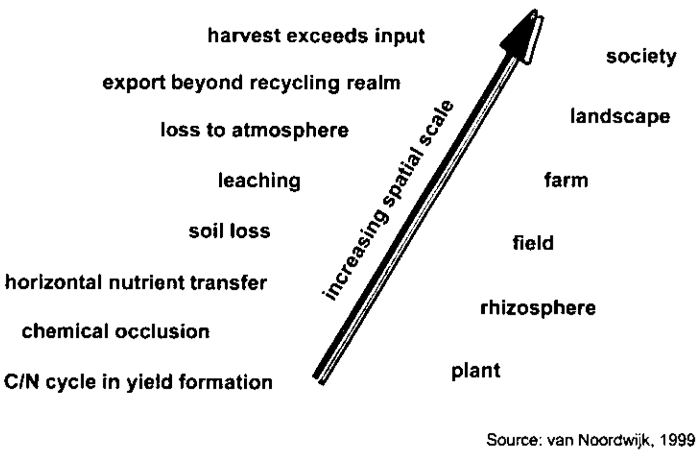


Figure 1. Categories of problems for efficient nutrient flow in agro-ecosystems at different scales

Nutrient cycles in plant and rhizosphere

Apart from the nutrient exchange at the cellular level, the cycling of carbon (C) and nitrogen (N) has an immediate impact on yield formation. As described by Marschner *et al.* (1996), N absorbed by roots is transferred to the shoot and metabolized. In exchange, C deriving from assimilation is re-translocated basipetally to roots and storage organs like tubers, grains, etc. Potassium (K) has a 'motor' function in the C/N cycle. As shown in Figure 2, K moves as counter-ion together with NO_3 in the xylem to the shoot, where NO_3 is metabolized. At the same time, malate, a C-skeleton, is produced in the shoot and part of the malate moves together with K down to the root system where malate is oxidized, yielding $KHCO_3$, where K combines with NO_3 to form KNO_3. Lack of K, therefore, restricts NO_3 transport, leading to nitrate reduction in the roots and accumulation of amino acids. This signals via a feedback effect to roots to restrict further N uptake. Furthermore, C assimilates accumulate in the shoot, which restricts yield formation. Reduced N uptake triggered by K deficiency lowers the N fertilizer use efficiency and thus, N use economy. More N remains in the rhizosphere that might be leached or volatilized, causing an environmental burden. The plant cannot be forced to take up more N if K is in short supply.

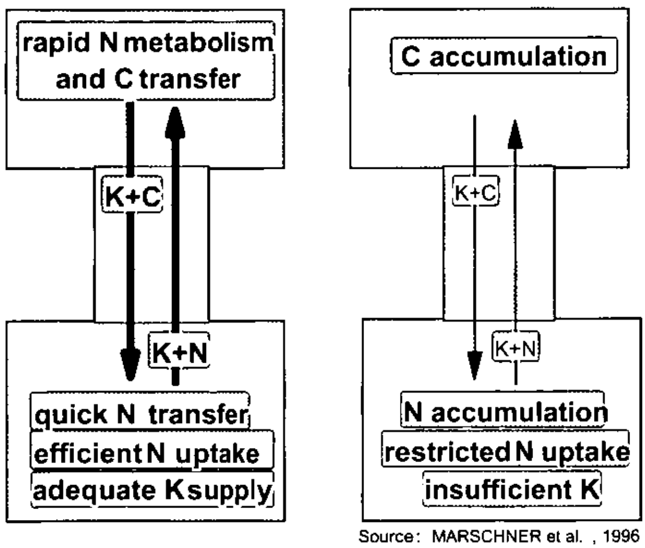
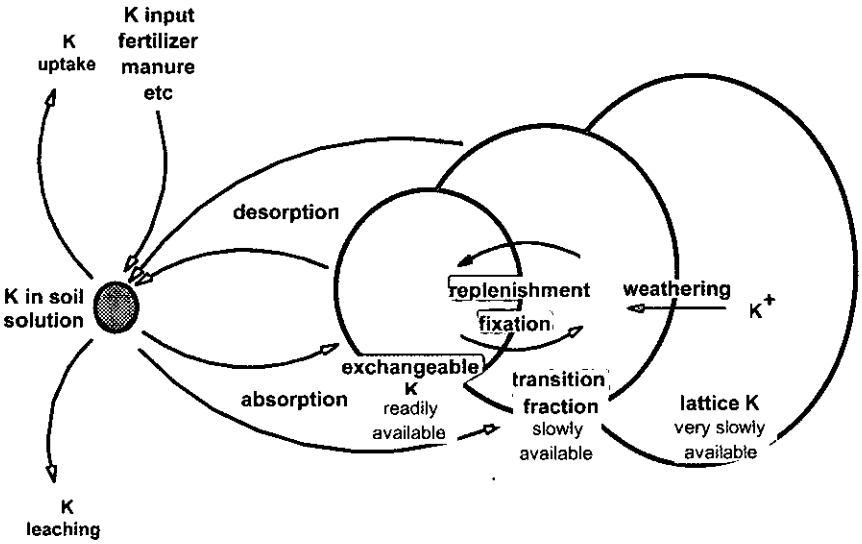


Figure 2. K nutrition and nutrient cycling in plants

A classical example of nutrient cycles on micro level in soils is the exchange process of K between different fractions. Soil K is partitioned between K in solution, K at the cation exchange sites, also called readily available or 'exchangeable' K, the slowly available K fraction or non-exchangeable K and the K in the interlayer spaces of clay minerals, the K reserves (Figure 3). All fractions are interrelated to each other by dynamic exchange processes. K removed from soil solution, either by uptake or leaching, is replenished by K from the exchangeable fraction. Soils well supplied with potassium have a high K release rate, which buffers quickly the K lost from solution, e.g. by plant uptake. With progressing exhaustion of the exchangeable fraction, K supply to the soil solution depends to a larger extend on K released from the slowly available fraction, i.e. from the non-exchangeable K fraction. However, the release intensity of K from the non-exchangeable pool is only a small part compared to that released from the exchange sites. Consequently, with depletion of soil K and thus with the increase of the contribution from the non-exchangeable pool, the yield declines because the release intensity cannot cope with the K demand of a high yielding crop. K from the reserve pool, i.e. from the interlayer space, is released by weathering and hardly contributes to the requirement of a developing crop during the vegetation period. Use of mineral potash and/or organic manure triggers the reverse process: increase of the K concentration of soil solution after fertilizer use initiates absorption processes, which can lead even to K fixation in exhausted soils. The latter is often source of misinterpretation of field trials because crops on K exhausted soils hardly show any yield response to standard K rates when K fixation occurs. To rehabilitate a K exhausted soil is costly. Experiments with Indian soils showed that it requires up to 5 times more units of K to increase the soil K by one unit in contrast to soils with a good K status where 1.2 units of K were enough to increase the soil K (Srinivasa Rao & Khera, 1995).



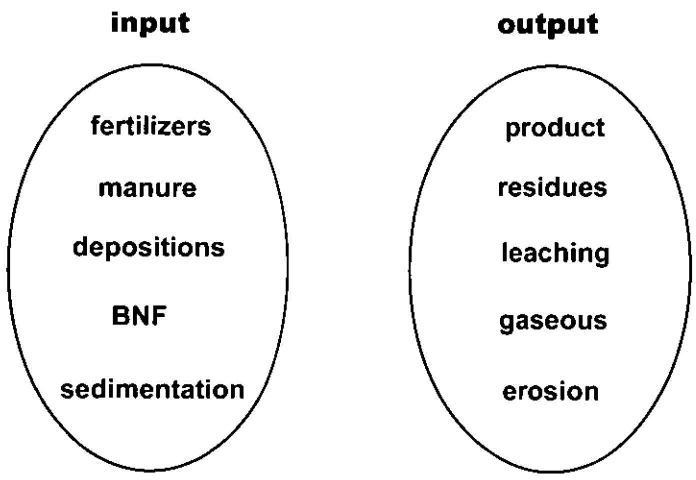
- soil K is partitioned between 4 major fractions
- the different fractions are interrelated to each other through dynamic processes
- unlike N and P, there is no long-lasting slow release organic source

Figure 3. Flow of soil K is subject to dynamic processes

Nutrient cycle within a farm system

The nutrient cycle of a farm is governed by several input and output factors (Figure 4). Nutrients enter the farm with fertilizers, manure, deposition, sedimentation and biological N_2 fixation. Manure as input factor is of particular relevance when feed concentrate is purchased for animals, adding nutrients to the farm system from an

exogenous source. Nutrient input with sedimentation can be an important factor in irrigated agriculture. 1 ppm nutrient per 100 mm irrigation adds 1 kg nutrient ha^{-1}, e.g. 5 ppm K in 600 mm irrigation correspond with 30 kg ha^{-1} K.
Major output factors are nutrient removal by harvested crops, residues if removed, leaching, volatilization and erosion. Nutrient losses through erosion and leaching depend very much on the climatic conditions. In Malawi for instance, which is in the humid tropics, K loss through erosion and leaching represents 69% of the total K loss. In contrast, the major source of K loss in Mali, which is in the arid Sahel zone of Africa, is K removal by crops and residues. Leaching and water erosion in arid climates are naturally of lesser importance.
As a general rule, when nutrient input exceeds nutrient output, the nutrient balance becomes positive. This signals nutrient accumulation in soils and build-up of soil fertility. On the other hand, when nutrient output exceeds nutrient input, then the nutrient balance is negative. A negative nutrient balance indicates soil nutrient mining and loss in soil fertility.



Source: STOORVOGEL & SMALING, 1990

Figure 4. Factors governing the balance in nutrient flow

The economic performance of a particular crop is another important determinant for the nutrient balance. Farms in Kenya, which grow cash crops like tea, have a nutrient balance which is almost in equilibrium. The gross margin of the farm is more than 120'000 KSh (1,580 USD) ha^{-1} yr^{-1}. Farms in Kenya, cultivating only stable crops like maize, which is a less profitable crop (gross margin only 34'000 KSh (448 USD) ha^{-1} yr^{-1}), have a highly negative nutrient balance (Figure 5). Similarly, farmers in Punjab/India invest much more potash and farmyard manure in potatoes, a highly profitable crop compared to wheat and rice. The K balance of potato is positive, that of cereals highly negative (Tandon & Sekhon, 1988). And thirdly, as soon as quality based procurement prices for crops are involved, the K balance improves. Farmers in North India, growing mostly stable crops like rice and wheat, use a very wide N : K ratio of 27:1 in fertilizer application. The unbalanced fertilization indicates a highly negative K balance like shown with the previous example. Farmers in South India grow cash crops like tea, coffee, pepper, cardamom, which are paid according to quality. The N : K ratio of 3:1 in fertilizer use indicates a K balance fairly close to equilibrium.

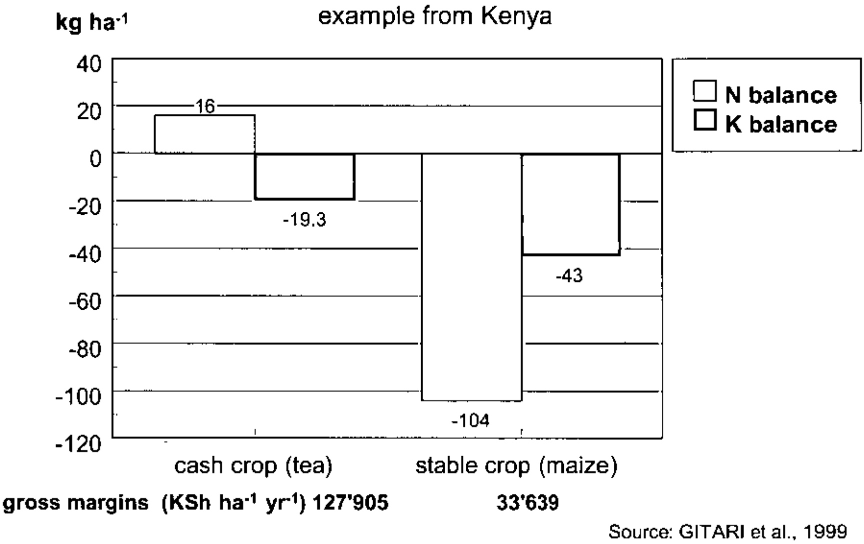


Figure 5. Nutrient balance at farm level as affected by the economic performance

As mentioned earlier, farmyard manure will occupy an important position in the nutrient cycle when purchased feed concentrate adds nutrients from an exogenous source. In Germany for instance, the nutrient balance improves with the intensity of livestock (Figure 6). Arable farms without animals have a nutrient balance rather in equilibrium, though P and K are already in short supply, i.e. showing a slightly negative balance. Crops sold to the market are the major source of nutrient loss. Mixed farms, internally producing fodder, have already a positive nutrient balance because nutrient exports with animal products are much less than with plant products. A very positive nutrient balance is seen in typical livestock farms. Major source of nutrient input is feed concentrate. A comparable situation is experienced in typical dairy farms in Belgium, where in spite of substantially decreased use of mineral fertilizers the nutrient surplus is quite high explained by increasing use of feed concentrate (Michiels *et al.*, 1997). On the other hand, use of farmyard manure, which only recycles farm-borne nutrients, i.e. no additional nutrients from outside, fail to counterbalance nutrient losses. This is the case in countries of Central/Eastern Europe, where farmers can hardly afford to buy feed concentrate. The nutrient content of farmyard manure decreases, as well as the number of animals. The current use of mineral fertilizers represents only one third of the amount used to be applied in the pre-reform period at the end of the eighties. The nutrient balance for instance of the Czech Republic is highly negative (Klir *et al.*, 1998).

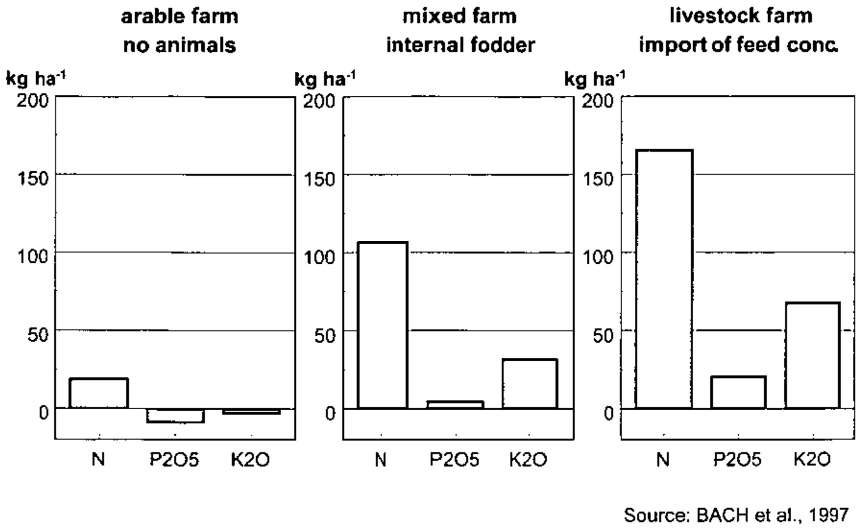


Figure 6. Nutrient balance as affected by the farming system, using the example of Germany

Nutrient cycle across national boundaries

The international transfer of nutrients with commodities is considerable. As shown in Figure 7, North America together with Argentina and Brazil export about 1.2 million tons of K or the equivalent of 2.5 million t potash fertilizers contained in oilseeds and cake, i.e. in feed concentrate. Even India exports nearly 70'000 t K with oilseeds and cake, which is roughly equivalent to 150'000 t of potash. Taking Argentina as an example, the country exported about 3 million t K with oilseeds in the last 10 years but imported, at the same time less than $1/10^{th}$ of the lost potassium, namely 200'000 t for the whole country and all crops (ifc No. 3). Main beneficiaries of the global K transfer with oilseeds and cake are the European Union, which imports some 570'000 t K or 1.2 million t of potash equivalents. China, together with Japan and the Republic of Korea, import around 392'000 t K. A considerable transfer of nutrients also occurs with trade of cereals. The major export countries, Argentina, Australia, Canada, USA and the European Union, transfer with cereals about 1 million t K_2O, mostly to developing countries.

A driving force in nutrient transfer across regional and national boundaries can be seen in urbanization. Currently, more than 3/4 of the population in developed countries live in towns. The same trend appears in developing countries where, within the next 10 years, half of the population will live in towns (Figure 8). Usually, nutrients transferred with food into towns are not recycled to farmers' fields and thus lost from the nutrient cycle because of fear of contamination of sewage sludge with heavy metals and other toxic substances.

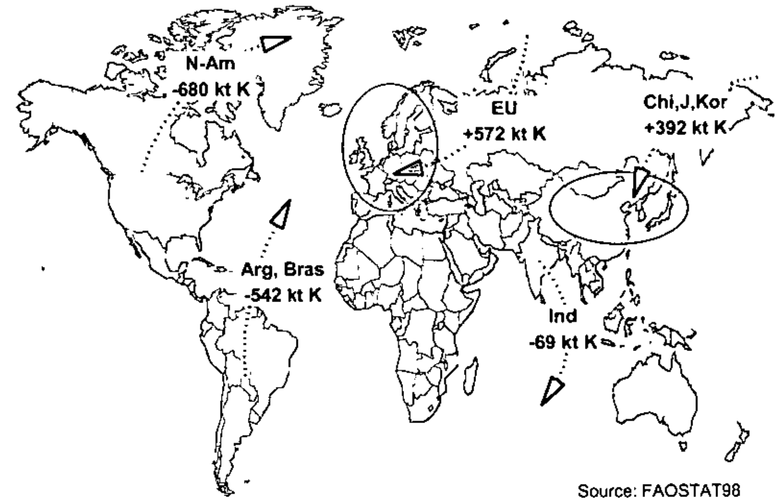


Figure 7. Regional K net transfer with oilseeds/cake figures for 1997

Urbanites eat more meat, fruits and vegetables than their rural counterparts. Export of fruits and vegetables together with stimulants represents about 400'000 t K_2O, most of it being utilized in towns and thus lost for recycling.

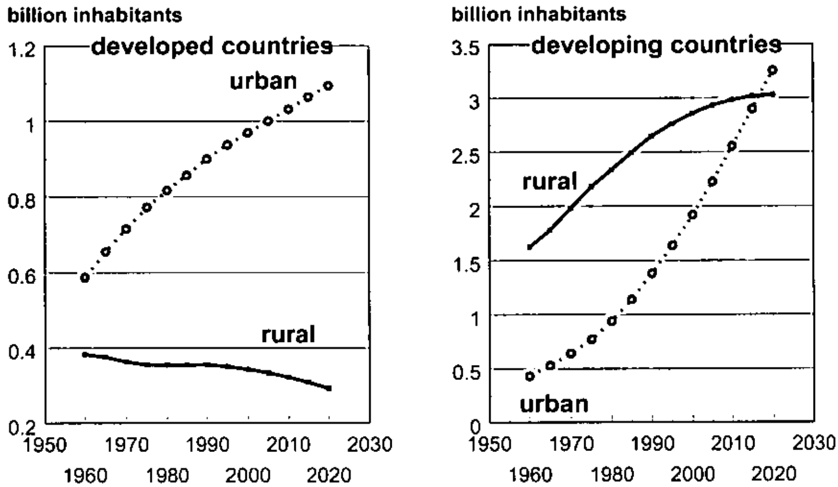


Figure 8. Development of the global population

Evolution of regional nutrient balances

Distinct differences occur in the trend of nutrient balances with respect to the nutrient itself and the region considered. In the nineteen seventies and eighties, fertilizer use in developed countries exceeded the nutrient removal by crops (Figure 9). As mentioned, the deriving positive nutrient balance can be considered as build-up of soil fertility.

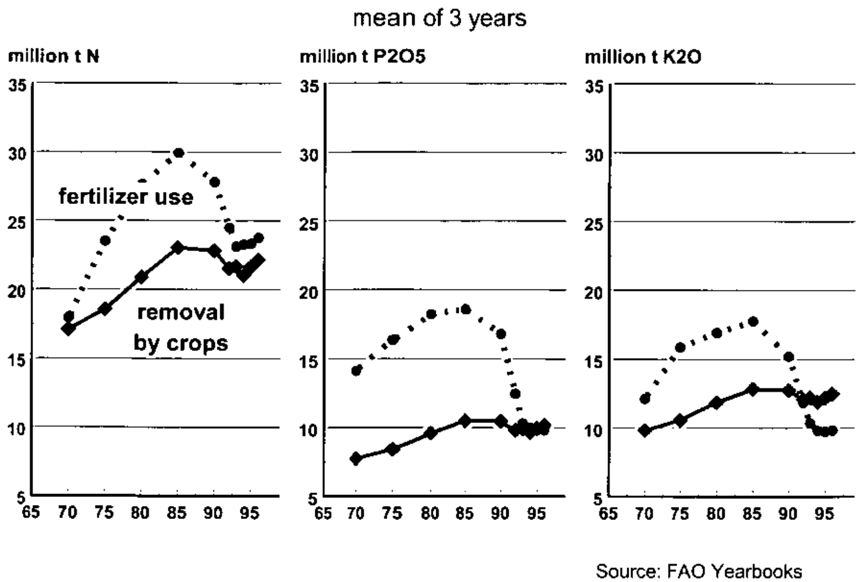


Figure 9. Fertilizer use in relation to nutrient removal by crops in developed countries

However, end of the eighties, the situation changed quite drastically. Fertilizer consumption in developed countries declined sharply for several reasons such as:

a) set-a-side programs, economic and ecological considerations, poor crop prices in 'Western' countries like USA or the European Union;
b) economic reform in Central/Eastern Europe and the Former Soviet Union with the aftermath in form of lack of credits and funds to buy fertilizers and other inputs, unclear land titles, lack of knowledge of new land owners after re-allocating collective land.

In the meantime, nitrogen use seems to revive whereas phosphate and especially potash use lags behind removals by crops.

The evolution of the nutrient balance in developing countries shows a contrasting picture (Figure 10). Use of nitrogen equals or surpasses nitrogen removal by crops. In China for instance, an estimated N removal by crops of about 17 million t is 'counterbalanced' with 23.6 million t N from mineral fertilizers (mean of 1996-98). The trend in phosphorus is comparable to nitrogen although less pronounced. Use of P fertilizers closes progressively more the gap caused by P removal by crops. In China, about 9 million t P_2O_5 are used and about 8 million t P_2O_5 are removed by crops.

The situation of potassium is completely different from N and P. K removal by crops is a multiple of K use with mineral potash. The K balance is highly negative. Some examples (figures represent mean of 1996-98):

- China has a mineral potash input of 3.1 million t K_2O, output with crops of about 17 million t K_2O (Figure 11);
- India uses 1.2 million t K_2O in form of potash, output with crops is 8.8 million t K_2O;
- Sub-Saharan Africa's K input is 0.2 million t K_2O but output with crops is 4.3 million t;

- West Asia North Africa, the WANA region's K input with potash is 0.3 million t and output with crops 4.1 million t K_2O, respectively.

The apparent deficit in K increases in China with a rate of about 250'000 t K_2O and in S-Asia of 180'000 t K_2O annually.

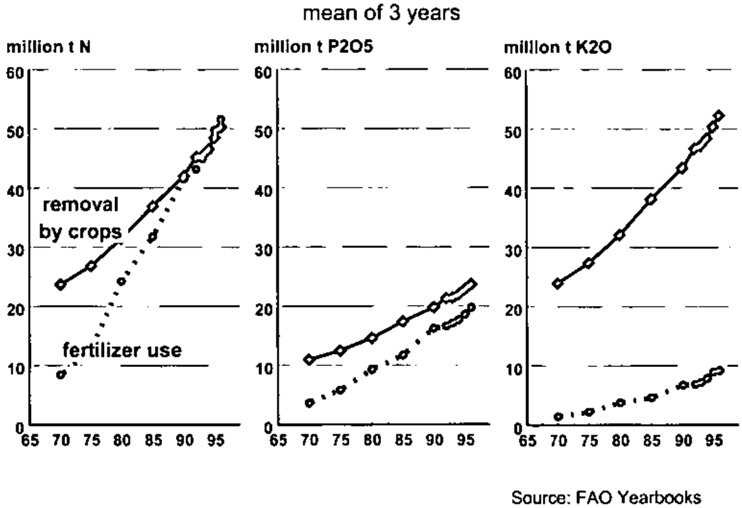


Figure 10. Fertilizer use in relation to nutrient removal by crops in developing countries

Use of organic manure, which is a great tradition especially in China, cannot compensate the huge loss of potassium from soils by harvested crops. Assuming that mineral K represents 30% of the total K use in China, the grand total of about 10 million t K_2O from manure and potash is still far below the total removal of 17 million t K_2O by crops (Figure 11).

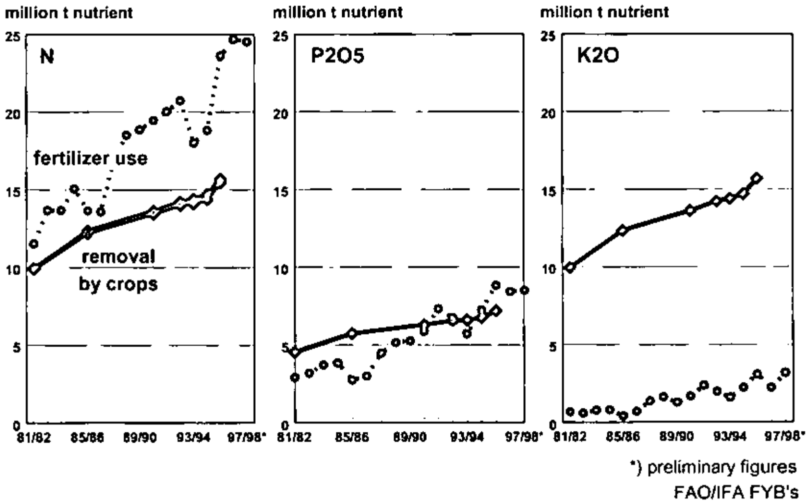


Figure 11. Fertilizer use in relation to nutrient removal by crops in China

The same applies to India. Even with a very optimistic approach, Singh & Biswas (2000) estimate that only 25% of the future nutrient demand in Indian's agriculture can be covered by all kinds of organic manure like FYM, urban/rural waste. Moreover, alternative use of FYM as fuel and building material in developing countries is widespread. Furthermore, the low nutrient content and bulkiness require high labor demand for its mobilization, processing and application. But, labor costs are becoming less affordable to farmers also in developing countries.

Consequences and conclusion

In nature, removing items from a closed cycle either weakens the cycle or it requires compensation to maintain the full strength. This refers also to nutrient cycles. Potassium in comparison to N and P, appears to be in a bad situation, showing that the K deficit is increasing worldwide although with regional differences. Developing countries are badly affected by this aspect.

Why is unbalanced fertilization with emphasis to nitrogen so common in developing countries? It is the immediate and evident effect of nitrogen. At times of economic stress, limited financial resources of the farming community, unclear land title, insecure land tenure systems, etc. are the recognizable effects that make nitrogen to be the most preferred nutrient. In contrast, use of potash commonly results in less spectacular yield effects. The action of potash is more discreet and related to quality, stress tolerance and other traits. Nevertheless, the quantity of potassium that a high yielding plant requires is in the same order of magnitude or even higher than that of nitrogen. What are the consequences of continued soil K mining at negative K balances? Results from long-term experiments conducted in Germany show that with advancing soil K mining and thus declining soil K status the gap between potential and achievable yield increases (Figure 12).

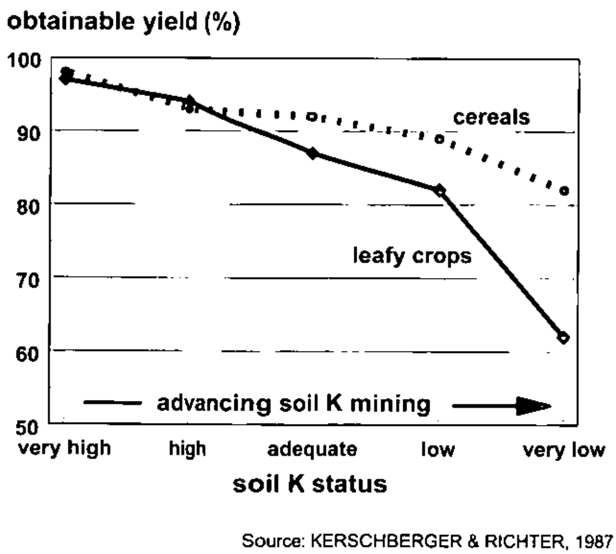


Figure 12. Loss in potential yield at different levels of soil K status

The farmer loses substantial yield opportunity. In this context, long-term experiments in UK showed that with the same amount of 144 kg ha^{-1} N barley yielded only 2 t ha^{-1} on exhausted soil with 68 ppm K, but 5 t ha^{-1} on fertile soil with 329 ppm K (Johnston, 1994). The impact that such unbalanced fertilization has on fertilizer use economy and on the ecology is evident. In addition, K deficient plants are poor in quality, susceptible to stress and therefore a risk in crop production.

The deriving consequences are clear. We have to convince the farmer to invest in soil K capital. The economic returns are good. For example, for each rupee invested in potash, Indian farmers achieve a return of about 5 rupees with higher yields in rice, 8-10 rupees in soybean and more than 15 rupees in potato. There is also a substantial gain in quality and yield security.

We also have to convince the advisors in the extension sector to provide the information to the farmer and the fertilizer sector to provide the potash right in time and quantity. And last but not least, we have to convince decision-makers to provide the policy and economic frame for balanced fertilization.

References

Bach, M., Frede, H.G. and Lang, G. (1997): Entwicklung der Stickstoff-, Phosphor- und Kalium-Bilanz der Landwirtschaft in der Bundesrepublik Deutschland. Gesellschaft für Boden- und Gewässerschutz e.V., Wettenberg, Germany.

Gitari, J.N., Matiri, F.M., Kariuki, I.W., Muriithi, C.W. and Gachanja, S.P. (1999): Nutrient and cash flow monitoring in farming systems on the Eastern slope of Mount Kenya. In: Nutrient disequilibria in agroecosystems (ed. E.M.A. Smaling et al.), CABI Publishing, pp. 211-228.

Johnston, A.E. (1994): The Rothamsted classical experiments. In: Long-term experiments in agriculture and ecological sciences (ed. R.A. Leigh and A.E. Johnston), CAB International, pp. 9-37.

Kerschberger, M. and Richter, D. (1987): Neue Versorgungsstufen (VST) für den pflanzenverfügbaren K-Gehalt (DL-Methode) auf Ackerböden. Richtlinien der Düngung 11, 14-18.

Klir, J., Vostal, J. and Lipavsky, J. (1998): Plant nutrient balances in Czech agriculture. In: Proceedings of the 11th Int. Symposium on Codes of good fertilizer practice and balanced fertilization, September 27-29, 1998, Pulawy, Poland, pp. 428-434.

Marschner, H., Kirkby, E.A. and Cakmak, I. (1996): Effect of mineral nutritional status on shoot-root partitioning of photo-assimilates and cycling of mineral nutrients. J. Exp. Botany 47: 1255-1263.

Michiels, J., Verbruggen, I., Carlier, L. and van Bockstaele, E. (1997): In- and output of minerals in Flemish dairy farming: the mineral balance. In: Proc. 11th Intern. World Fertilizer Congress of CIEC on Fertilization for sustainable plant production and soil fertility, September 7-13, 1997, Gent, Belgium, pp. 695-702.

Noordwijk van, M. (1999): Nutrient cycling in ecosystems versus nutrient budgets of agricultural systems. In: Nutrient disequilibria in agroecosystems (ed. E.M.A. Smaling et al.), CABI Publishing.

Singh, G.B. and Biswas, P.P. (2000): Balanced and integrated nutrient management for sustainable crop production. Fertilizer News, Vol. 45 (5), pp. 55-60.

Srinivasa Rao Ch. and Khera, M.S. (1995): Consequences of potassium depletion under intensive cropping. Better Crops, Vol. 79, pp.24-27.

Stoorvogel, J.J. and Smaling, E.M.A. (1990): Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983-2000. Report 28, The Winand Staring Centre Wageningen, The Netherlands.

Tandon, H.L.S. and Sekhon, G.S. (1988): Potassium research and agricultural production in India. FDCO New Delhi, 144 p.

Development in nutrient balances in the cropping systems of transitional economies in Central/Eastern Europe

Eberhard Uebel

International Potash Institute, Basel, Switzerland (IPI)
Former Coordinator Central/Eastern Europe, Kassel, Germany

Abstract

In Central/Eastern Europe (CEE), a vast agricultural area of about 66 M ha has to produce food for 122 M people and for export. Until the end of the 80's, under conditions of the central planned economy, in most of CEE countries, fertilizers were strongly subsidized by the state. The consequence was agricultural mass production through high fertilizer input, reaching levels of Western European countries and positive nutrient balances. Since the beginning of the 90's with the transition to the market economy, a dramatic decline in mineral (-55 % in N and -80 % each in P and K) and organic (-30 % to -50 %) nutrient consumption set in. Today, agricultural production is carried out at the expense of soil nutrient reserves. Negative nutrient balances led to decreasing soil nutrient contents and loss in soil fertility. Yield levels declined by about 20 to 30 %. However, the agricultural crop production is showing again a slight recovery since the revised increase in fertilizer use in 1993/94. Supportive agricultural policy, regular soil monitoring in farms and relevant strategies for economical, ecological and nutritional balanced fertilization can avoid great losses for farmers and accelerate this starting development.

Introduction

The fertilizer consumption in Central/Eastern Europe (CEE) is characterized by a strong increase from the beginning of the 60's until the end of the 80's and a dramatic decline in mineral and organic nutrient consumption since the beginning of the 90's. In the first period until the end of the 80's, this development was accompanied by an immense growth in crop production fuelled by a fertilizer subsidy through the government under the conditions of central planned economies. In most of the CEE countries, the nutrient balances changed from negative values until the end of the 60's to positive values with an increasing tendency since the beginning of the 70's. The proportion of agricultural land with low soil nutrient contents decreased continuously. Soil fertility was built up. However, in the run of the years, that proportion of soils with high and very high nutrient contents increased partly to an undesirable extent. In the second period, since the beginning of the 90's with the transition of the CEE countries to the market economies, the farmers had to fight for economical survival and were forced nearly to abstain from the use of yield increasing means of production, especially from fertilizers. Agricultural production was carried out at the expense of nutrient soil reserves. Negative nutrient balances led to decreasing soil nutrient contents and losses in soil fertility. Since 1993/94, a renewed slight increase in fertilizer consumption set in. In this paper, the consequences of different fertilizer consumption practices for nutrient balances, soil fertility and crop production are analyzed, using typical examples. Conclusions for future economical and ecological relevant fertilizer strategies are drawn.

Methods

The development of fertilizer consumption, the nutrient balances, development of the nutrient supply status of soils and crop production of selected countries of the CEE were analyzed on the basis of statistical data from FAO, publications of scientists from universities and other sources. Typical tendencies were characterized and needs for future development discussed.

Results and discussion

Importance of agriculture in the economies of CEE

Agriculture has a much greater importance in the national economies in CEE countries than in the countries of Western Europe (WE). An average share of 7 % of GNP (European Union 1,7 %) is assigned to agriculture of CEE and the share of employees in agriculture reaches 23 % (EU 5,1 %) of total employees. An agricultural area of about 66 M ha has to produce food for 122 M people and to earn revenue from export.

Development of fertilizer consumption

In view of the importance of agriculture in CEE, it is mandatory to maintain soil fertility and agricultural production at a high level. But with the economic transition since the beginning of the 90's, fertilizer consumption, the most important means of production declined at the most by –51 % in N use, by –78 % in P and -76 % in K use in terms of mineral sources and by –30 % to –50 % in terms of organic manure compared to the 1988/89 level. Only in 1994/95, a renewed slight increase in total fertilizer consumption set in (Tab. 1).

Table 1. Development in mineral fertilizer consumption (1000 t) in CEE 1992/93 until 2001/02 and absolute and relative changes 1988/89 to 2001/02

Year		N	P_2O_5	K_2O	NPK*
1992/93		1,827	614	518	2,959
1993/94		1,946	584	492	3,022
1994/95		2,160	615	523	3,298
1995/96		2,144	655	599	3,398
1996/97		2,402	693	650	3,745
1997/98		2,227	646	699	3,572
2001/02		2,270	577	600	3,447
change 88/89	**absolute**	**-2,373**	**-2,079**	**-1,854**	**-6,316**
to 01/02	**relative**	**-51.1**	**-78.3**	**-75.6**	**-64.7**

* $N + P_2O_5 + K_2O$

(Source: FAO)

The level of mineral fertilizer consumption which reached 3,447,000 t NPK in 2001/02 equals a fertilizer input of 32.5 kg ha^{-1} N, 9.5 kg ha^{-1} P_2O_5 and 10.2 kg ha^{-1} K_2O, respectively, or 52.2 kg ha^{-1} NPK. This low level in fertilizer use does not form a basis for a high agricultural production intensity.

Nutrient balances in agriculture

The dramatic decline in fertilizer consumption led to a change in the agricultural nutrient balances in the CEE. The strongly positive nutrient balances in the period 1986-90 changed to negative values in the period 1991-1995 as the examples of the Czech Republic, Hungary and Poland indicate (Tab. 2).

Table 2. Nutrient balance of selected CEE countries in kg ha^{-1} agricultural area

Period	Nutrient	Czech Republic	Hungary	Poland	**Mean**
1986 – 90	N	+ 39.9	+ 32.0	+ 14.6	**+ 28.8**
	P_2O_5	+ 40.3	+ 24.0	+ 29.4	**+ 31.2**
	K_2O	+ 10.4	+ 14.0	+ 14.7	**+ 13.0**
1991 - 95	N	- 10.7	- 30.0	- 9.6	**- 16.8**
	P_2O_5	- 13.6	- 13.0	- 1.1	**- 9.2**
	K_2O	- 51.6	- 28.0	- 19.8	**- 33.1**

(Source: Vostal, 1996; Kadar, 1997; Fotyma, 1997)

In Bulgaria the nutrient balance was also negative for all three main nutrients in the period 1991 to 1995 and amounts to – 40,000 t N, - 79,000 t P_2O_5 and – 224,000 t K_2O per year (Nikolova and Samaliova, 1998), describing the huge nutrient losses in the agriculture of Bulgaria.

Nutrient balances and soil fertility

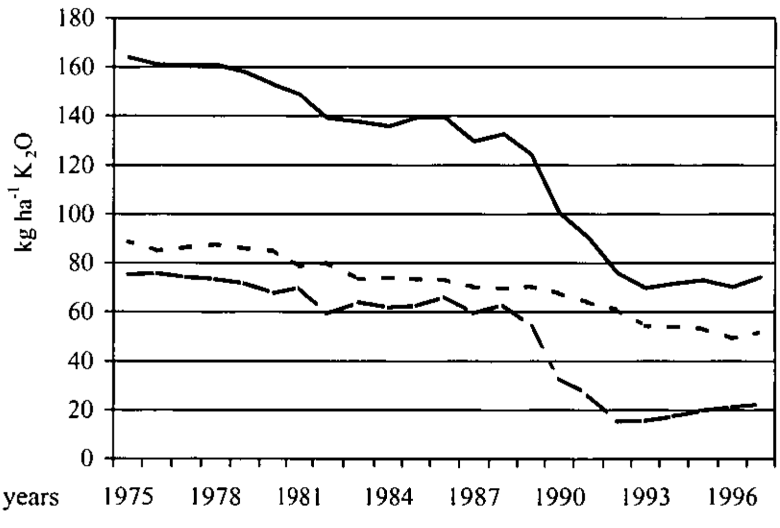
The negative nutrient balances in CEE led to an agricultural crop production at the expense of the soil reserves and hence to a continued depletion of soil nutrients as the example of K for Hungary and the Czech Republic is showing (Table 3).
The decline in the proportion of soils with the supply class "high" would not cause any problem as long that of soils with the supply class "medium" increase. Problems for soil fertility are due to the increasing proportion of soils classified as supply class "low" and "very low". The quick change from the supply class "high" to "low" needs soil monitoring to avoid yield losses for the farmers.

Table 3. Shift in K status of arable soils in % of the area in Hungary and the Czech Republic based on K supply classes

Country	Period	K supply class		
		low	medium	high
Hungary	1986 – 90	15	25	60
	1991 – 95	20	35	45
	shift	**+ 5**	**+ 10**	**- 15**
Czech Republic	1986 – 90	4,7	70,9	24,3
	1991 – 95	7,9	71,9	20,1
	shift	**+ 3,2**	**+ 1,0**	**- 4,2**

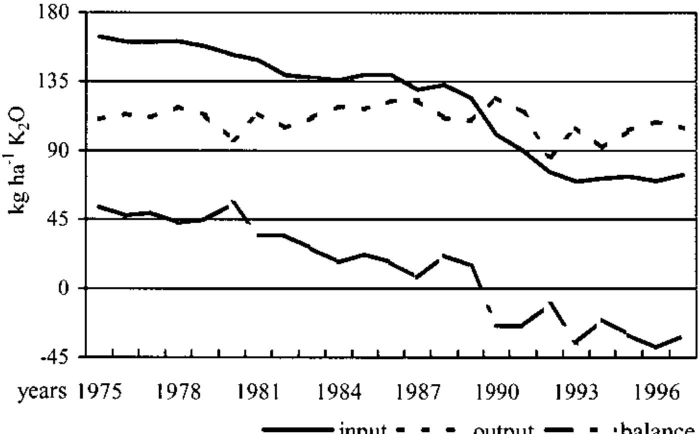
(Source: Kadar, 1997; Travnik et. al., 1996)

Results from Poland (Gosek and Fotyma, 1998) give an insight into the dynamics of the interrelation between the level of fertilization, the nutrient balance and the status of soil nutrient supply using the example of potash (Fig. 1 – 3).



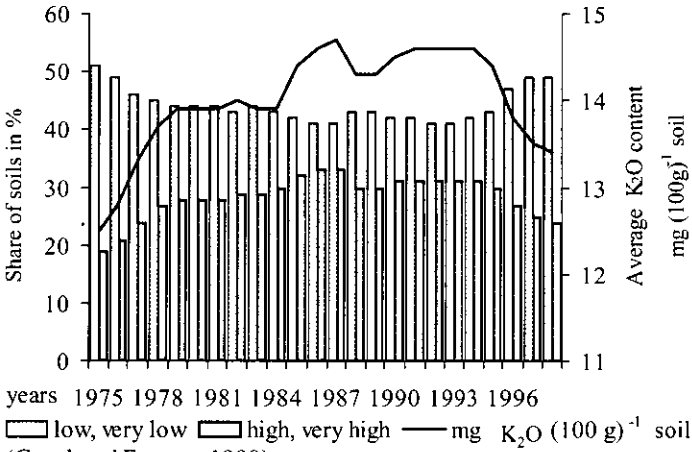
(Gosek and Fotyma, 1998)

Figure 1. Development of potash fertilization in Poland (kg ha^{-1} K_2O)



(Gosek and Fotyma, 1998)

Figure 2. Potassium input : output balance (kg ha^{-1} K_2O) in Poland



(Gosek and Fotyma, 1998)

Figure 3. Change in potash supply of soils in Poland 1975 to 1997

For the Polish agriculture with its high proportion of light soils, the data convincingly show that positive potash balances led to an increase of potash contents in the soil and a proportional decrease in soils with low and very low K content (1975 – 1990). In case of negative K balances, in a range of –20 to –40 kg ha^{-1} K_2O per year, since the beginning of the 90's, the soil K content remained for a certain time at the same level, depending on the buffering capacity of soils. After this period, the potash content declined rapidly. The proportion of soils with low and very low K contents increased, indicating the decline in soil fertility.

The latest data of a soil survey in Poland carried out in 1999 reveal that 48 % of the soils belong to the K soil supply class "low" and "very low". This may threaten the Polish agricultural production as K deficient plants are more susceptible to climatic calamities like droughts, frost, heat and to pests and diseases. Insufficient K supply also reduces the efficiency of other fertilizers, especially of N. This reduces the fertilizer use economy, the production costs and causes the risks of environmental pollution to increase. Despite the low level of fertilizer input in the CEE, this problem is of current importance since N has been the preferred nutrient when fertilizer use picked up again. The nutrient balance for the main crops of Bulgaria shows the already existing one-sided use of nitrogen in 1996 (Tab. 4). On average of all crops tested, only the nitrogen balance is positive.

Table 4. Nutrient balances for the main crops of Bulgaria (1996)

		Nutrient balances (in tons)		
Crops	Balance sheets	N	P_2O_5	K_2O
Wheat	Crop removal Fertilizer input Balance	46,442 62,926 +16,484	19,649 6,920 –12,729	**41,083** **230** **–40,852**
Barley	Crop removal Fertilizer input Balance	9,576 10,695 +1,119	5,016 487 –4,529	**10,945** **48** **–10,897**
Maize	Crop removal Fertilizer input Balance	28,301 11,220 –17,081	9,797 435 –9,362	**30,478** **0** **–30,478**
Sunflower	Crop removal Fertilizer input Balance	13,247 5,902 –7,345	13,777 1,504 –12,273	**40,800** **295** **–40,505**
Sugar beet	Crop removal Fertilizer input Balance	208 30 –178	173 17 –156	**736** **8** **–728**
All crops	Crop removal Fertilizer input Balance	120,404 151,883 +31,479	69,582 12,824 -56,758	**210,736** **187** **-210,548**

More emphasis has to be laid on the promotion of balanced fertilization to increase the fertilizer use efficiency and to avoid environmental pollution. Nutrient balances can help to find the way to a more precise fertilizer management.

Fertilization and crop production

Under European conditions, mineral fertilizers contribute on average 35 to 40 % and in special cases even more to the final yield. They are a very important factor for crop production and crop quality. The dramatic decline in fertilizer consumption in agriculture of CEE with its losses in soil fertility was therefore strongly connected with the yield decline by about 20 % to 30 % since the beginning of the 90's (Tab. 5). The slight recovery in fertilizer consumption since 1993/94 (Table 1) correspondingly led to an increase in the average crop production indices of CEE countries (Figure 4). How strongly yield levels depend on the amount of fertilizer input is shown in Figure 5.

Table 5. Crop production indices of CEEC (1989 – 91 = 100 %)

Country	1992	1993	1994	1995	1996	1997	1998
Bulgaria	82.1	60.4	71.0	81.4	55.9	70.3	66.9
Croatia	68.5	75.0	72.3	77.1	80.0	84.4	94.0
Czech Republic	88.0	91.5	82.7	86.8	87.9	85.5	87.9
Hungary	72.0	64.9	76.2	74.4	73.4	85.8	83.7
Macedonia	112.8	81.0	93.6	96.8	97.8	101.8	108.1
Poland	75.7	99.1	77.1	89.7	91.0	83.5	92.9
Romania	76.3	98.3	93.6	103.4	94.6	110.6	88.7
Slovakia	88.0	84.9	88.8	85.5	88.1	91.1	83.0
Slovenia	90.0	93.9	113.2	108.0	120.0	111.4	119.7
Yugoslavia	77.2	76.4	83.7	86.5	87.1	99.0	93.5
Mean	**83.1**	**82.5**	**85.2**	**89.0**	**87.6**	**92.3**	**91.8**

(Source: FAO)

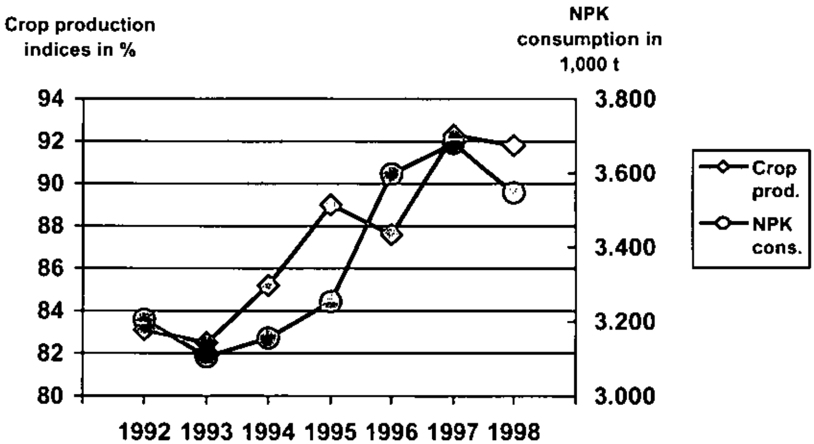


Figure 4. Development of fertilizer use and crop production indices in CEE

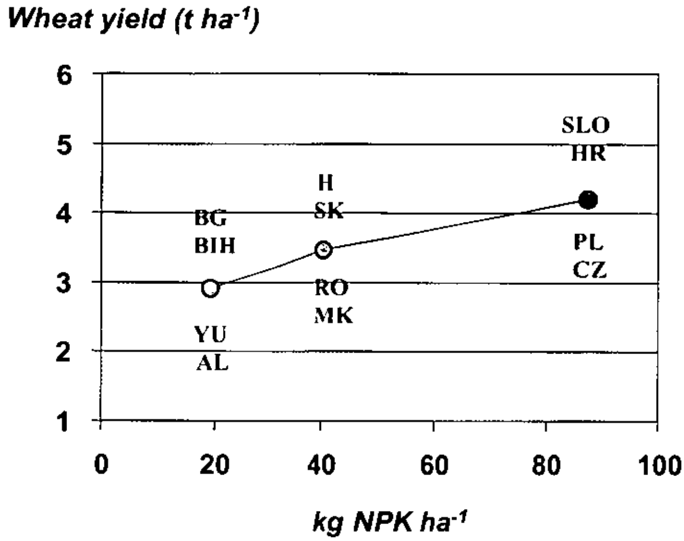


Figure 5. Relationship between fertilizer use and yield of wheat in the CEE, 1998

The countries with the largest fertilizer inputs per unit area like Slovenia, Croatia, Poland and the Czech Republic have reached the largest average wheat yield with about 4.2 t ha^{-1} in 1998. The countries with the lowest level of fertilizer use like Albania, Yugoslavia, Bosnia and Herzegovina and Bulgaria harvested only 2.9 t ha^{-1} winter wheat in 1998. This shows the huge reserves which can be mobilized by the agricultural potential of CEE by appropriate fertilization practices.

Conclusions

The CEE countries have a great agricultural potential. At present, agricultural production is mainly carried out with negative nutrient balances and hence at the expense of soil reserves. To maintain all chances for sustainable agricultural production, losses in soil fertility have to be avoided by increasing fertilizer use in mineral as well as in organic form on the basis of regular soil monitoring and harmonious nutrient balances. For economic farm management and sustainable production the "medium" or "optimum" nutrient fertility class is recommended. Farmers with an increasing share of low supply class soils have the wrong fertilization strategy. Such farms are likely to encounter losses in yield and quality, because nutrient release, especially of potassium, from the soil reserves will be limited and the soils will lose the capacity to buffer stress situations like drought, etc.

On the other hand, there is no need to accumulate available phosphate and potash reserves in the soil above the optimum level as the costs for the farmers increase and usually only insignificant yield increases are obtained. However, the possibilities of balanced fertilization must be fully exploited to ensure high yields and good quality products. Farming must be environmentally friendly but at the same time profitable.

In view of the coming membership in the European Union, the CCE countries have to transform their agriculture into productive and competitive systems for which a sustained high soil fertility is a prerequisite. It is necessary to find a political frame in agriculture towards a better price/cost ratio in production, access to credits, etc. to enable the farmers to replenish the nutrients removed from the fields and to guarantee a harmonized nutrient balance in agricultural production.

References

FAO: Yearbook "Fertilizer" and "Production", Food and Agriculture Organization of the United Nations, Rome / Italy, various years.

Gosek, S., Fotyma, M., 1998. Long term potassium balance in Poland, 11th International Symposium on Codes of Good Fertilizers Practice and Balanced Fertilization, Pulawy, 443-453.

Fotyma, M., 1997. The present and the future of Polish agriculture. IFA production and international trade committee meeting, Warsaw, 1-4.

Kadar, I., 1997. Talajaink tapelemgazdalkodasa az ezredfordulon. Növenytermeles, Tom 46, (1), 73-84.

Travnik, K., Cermak, P., 1996. Porovnaní vysledku kontroly urodností pudy za období 1990-1991 a 1993-1995. Ustrední kontrolní a zkusební ustav zemedelsky v Brne, 20.

Vostal, J., 1996. The impact of fertilization intensity on fertility and returns of selected plants in Czech Republic after 1990. IXth International Colloquium for the optimization of plant nutrition, Prague, 580-584.

Nikolova, M., Samalieva, A., 1998. Economic potential of fertilizer use in Bulgaria with particular reference to potassium. 11th International Symposium on Codes of Good Fertilizer Practice and Balanced Fertilization, Pulawy, 416-422.

Sulphur balance and sulphur requirements in Chinese agriculture

Donald L. Messick

The Sulphur Institute, 1140 Connecticut Ave, NW Suite 612, Washington, DC 20036, USA,

Abstract

The difference between sulphur supply and removal determines the soil sulphur fertility status. The components of sulphur supply and demand in the soil-plant-atmosphere system are conceptualised in Figure 1. The relative importance of each of these components varies from one system to another, but, generally, sulphur supply depends on native sulphur content and sulphur addition from external sources, such as precipitation, irrigation water, manure, crop residues and the addition from chemical sources, such as sulphur-containing fertilizers and other chemicals. These supply sources vary with locality, level of industrialization, environmental considerations and stage of economic development. On the other hand, sulphur is taken up by the plant, fixed in the soil system and lost through leaching or volatilization. Again, the relative importance of each of these pathways depends on soil, crops and sulphur sources. Available data suggest that most soils in China have low total sulphur reserves, because of low organic matter content, intensive cultivation and crop production, as well as leaching losses in the humid areas. Moreover, not all the sulphur supplied to the soil is taken up by the plant. A large share of it may be lost or may become fixed in the soil in compounds from which the sulphur is not readily available as the use efficiency of sulphur is rather low. Consequently, depending on the use efficiency, the amount of sulphur that needs to be added to the soil may be two to four times that of sulphur removed by crops.

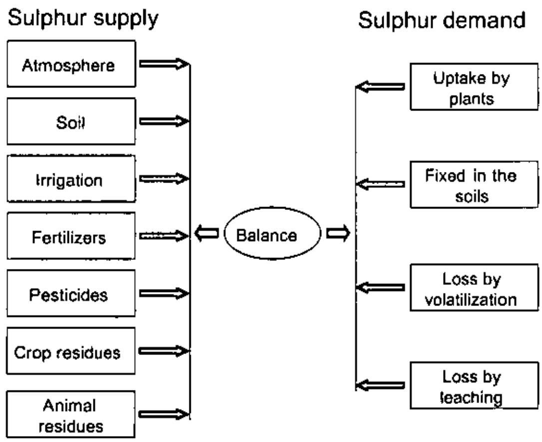


Figure 1. Components of sulphur supply and demand in soil-plant-atmosphere system.

In the last two decades, China has experienced several changes in agriculture and fertilizer sectors that have had a major impact on sulphur availability and sulphur requirements. As discussed before, with the introduction of intensive agricultural technology, especially the high yielding varieties and fertilizer use, the requirements for sulphur increased dramatically with the increase in crop yield and multiple cropping. On the other hand, sulphur availability has been declining with less sulphur supply to soil through changes of fertilizer materials; the fertilizer industry bas been replacing slowly the sulphur-containing fertilizers with sulphur-free fertilizers, mainly because of high distribution costs, and farmers use less organic manure because of high labour costs and low nutrient content. The net result of increased requirements and declining sulphur availability is that the sulphur deficiency is getting bigger over time, and the sulphur deficiency problems in agriculture are becoming widespread.

The atmosphere is an important component of the sulphur cycle in the agricultural system. Sulphur gases, mostly sulphur dioxide (SO_2) and sulphate aerosols, generated naturally or artificially, enter the air, soil, rivers and the ocean by rain and become a main source of sulphur supply to the environment. The combustion of sulphur-containing fossil fuels (coal, oil and gas) is by far the greatest source of anthropogenic sulphur emissions and also a principal sulphur source for most soils in China. The total sulphur deposit from the atmosphere deposited through precipitation annually was 6.51 million tons in China, which included 0.64 million tons of sulphur on arable land (about 10% of the total land area) (Yang and Gao, 1998). In addition, a considerable amount of sulphur may be absorbed by both plants and soils as SO_2 from air. These atmospheric additions could meet the sulphur demand of the crops, but unfortunately the sulphur emissions and depositions are not equally distributed, and the amount of SO_2 returned to the soil in the form of rain depends on the location of the industrial activities; hence sulphur deficiencies in certain areas, particularly those that are in rural areas away from industrialized complexes, are more common. For example, according to the data reported by the Chinese environmental agency (Figure 2), the industrial areas receive high sulphur deposition (>20 kg ha^{-1} yr^{-1}) because of the higher population density and the use of coals with higher sulphur content, such as Tianjing (66.7 kg ha^{-1} yr^{-1}), Beijing (41.3 kg ha^{-1} yr^{-1}), Shandong (33.2 kg ha^{-1} yr^{-1}), Jiangsu (28.9 kg ha^{-1} yr^{-1}), Henan *(25.5* kg ha^{-1} yr^{-1}), and Shanxi (24.8 kg ha^{-1} yr^{-1}). In most of the agricultural provinces, the sulphur depositions from atmosphere are low between 0 to 20 kg ha^{-1} yr^{-1}, averaged at 6.78 kg ha^{-1} yr^{-1}. Especially in remote agricultural provinces, the sulphur depositions are very low, such as Qinghai (0.3 kg ha^{-1} yr^{-1}), Xinjiang (0.5 kg ha^{-1} yr^{-1}), Heilongjiang (1.6 kg ha^{-1} yr^{-1}), Gansu (2.3 kg ha^{-1} yr^{-1}), Hainan (2.7 kg ha^{-1} yr^{-1}), Yunnan (3.5 kg ha^{-1} yr^{-1}) and Jilin (4.1 kg ha^{-1} yr^{-1}) provinces.

The sulphur deposition is well reflected in the soil sulphur availability. According to the results of a soil sulphur fertility survey, the soil available sulphur contents in these provinces are also very low; they have been classified as most sulphur deficient areas

(Figure 3). Even within the same province, there is a very wide range in the amount of sulphur received in rainfall at the various sites (Zhang, et al. 1997). According to the results of sulphur accessions in rainfall collected with the cation/anion rainfall collection device at 30 locations along the Yangtze river catchment through Jiangsu, Anhui and Hubei provinces, the three sites with lowest recordings (1.5 to 4.4 kg ha^{-1} yr^{-1}) were located in rural areas in Anhui province, and the site with the highest recording (54 kg ha^{-1} yr^{-1})

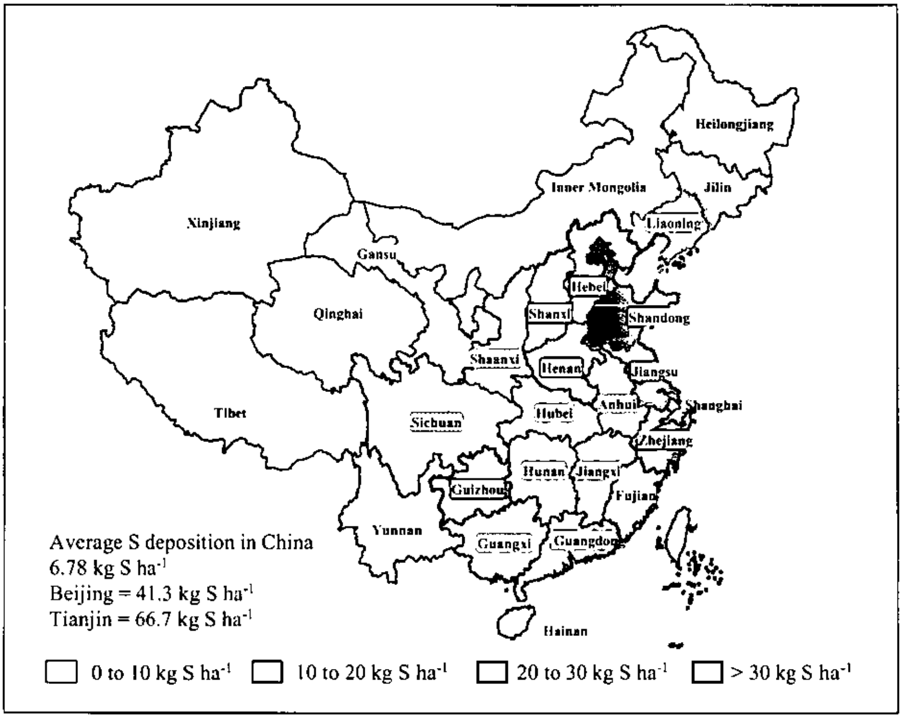


Figure 2. The distribution of sulphur deposition from precipitation in China.

was in Tongling, an industrial city in southern Anhui province. Southern Jiangsu province, which is more industrialized than the northern part, has an average sulphur deposition of 32 kg ha^{-1} yr^{-1}, while the average sulphur deposition in rainfall in northern Jiangsu province is 17.8 kg ha^{-1} yr^{-1}. The sites near Shanghai also received high accessions of sulphur. Generally, sulphur deposition from rainfall is many times higher within a 5 to 10 kilometres radius of the industry than away from it because the SO_2 and sulphate aerosols cannot be transported far due to heavy density. Thus, the amount of atmospheric sulphur added to the soils in the rural areas of the industrialized provinces varies between 5 to 10 kg ha^{-1} yr^{-1} and between 0 to 5 kg ha^{-1} yr^{-1} for most rural areas in agricultural provinces. However, the total amount of SO_2 emitted to atmosphere and returned to the soil in rain will decrease because of regulations to control air pollution. Liu (1995) studied the sulphur input and output in paddy fields of southern China. The amounts of sulphur added annually to the soil from fertilizers, precipitation and irrigation water were 16.99 kg ha^{-1}, 6.88 kg ha^{-1} and 3.90 kg ha^{-1}, respectively. However, sulphur removal by crop uptake and leaching were 19.06 and 10.50 kg ha^{-1}, respectively, which produced a 1.79 kg ha^{-1} sulphur deficit.

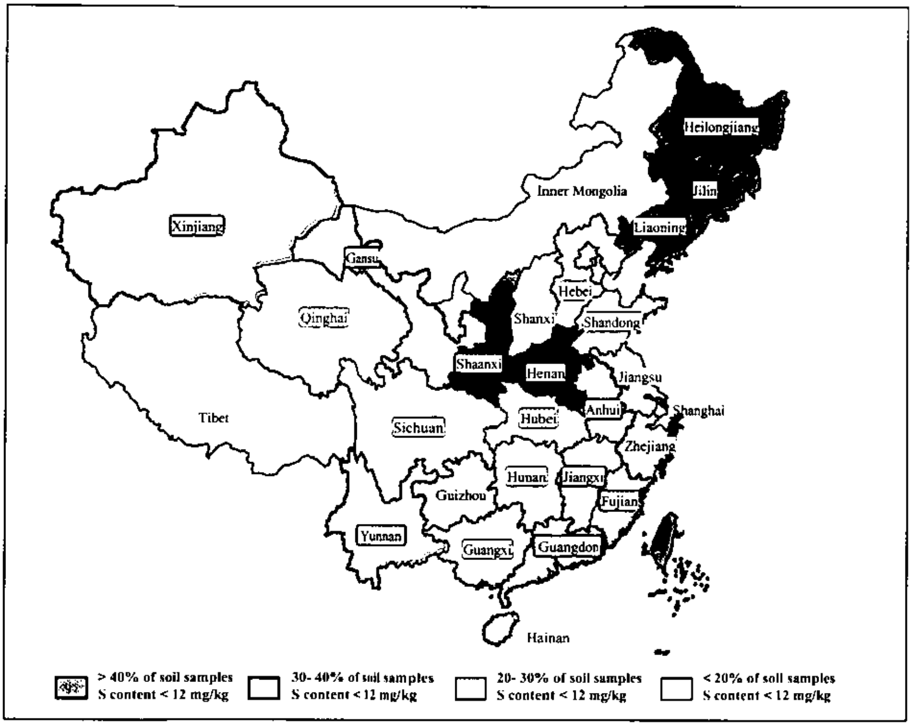


Figure 3. Distribution of soils with low sulphur content (S < 12 mg kg^{-1}) in China

These data indicate that the amount of sulphur through precipitation and irrigation water was almost equivalent to the amount of sulphur lost through leaching. Therefore, the sulphur balance in the soil depends greatly on fertilization and crop removal.

In 1995, the total amount of sulphur uptake by crops in China was 1.98 million tons (Table 1). Considering the fertilizer use efficiency (35%) of applied sulphur, the total plant nutrient sulphur requirement was estimated at 5.66 million tons sulphur. However, the total amount of sulphur added as fertilizer, farm manure and straw in 1995 was 4.77 million tons, of which 3.1 million tons were from SSP, 1.3 million tons from manure, 0.32 million tons from crop straw and 0.15 million tons from ammonium sulphate. This produced a deficit of 0.9 million tons sulphur or about 16% of the total requirement, clearly indicating the serious sulphur deficiency emerging in Chinese agriculture and the need for effective sulphur supply strategies. Moreover, the most popular sulphur-containing fertilizers like SSP are not uniformly distributed in China; SSP has been mostly used in southern and central China, such as Jiangsu, Sichuan, Hubei, Hunan, Yunnan, Guizhou, Zhejiang, Fujian, and Anhui provinces, where it is produced. While the rest of the provinces, especially in northern China, mainly use either fused calcium-magnesium phosphate or high-analysis phosphate fertilizers like TSP, MAP/DAP or nitro-phosphate, which has further accelerated soil sulphur deficiency and increased the magnitude of response to sulphur fertilizers in various agricultural systems of these areas.

Table 1. Estimated sulphur balance in Chinese agriculture in 1995 (1000 tons).

Crop	Sulphur removal	Sulphur source	Sulphur input
Grain crops	1100	SSP	3100
Cotton	136	Ammonium sulphate	150
Oil crops	188	Potassium sulphate	85
Vegetables	310	Organic manure	1200
Soybean	88	Straw	235
Sugar	60		
Fruits	51		
Others	50		
Total	1983		4770
Total demand: 1983/0.35 (Efficiency factor) = 5660			
Total Input: 4770			
Deficit: 890			

The intensification of agricultural production per unit area, coupled with an expanding use of high-analysis, sulphur-free fertilizers or low-sulphur fertilizers, such as urea and ammoniated phosphates, is causing sulphur deficiencies to spread rapidly throughout China. The problem could be exacerbated further as sulphur dioxide emissions are increasingly controlled. If this problem is neglected, the inevitable consequences will be decreased yields and reduced efficiency of other inputs, which will, in turn, result in higher production costs. According to TSI, the current annual deficit for sulphur fertilizers in China will increase to 1.5 million tons by 2005 and to 2.3 million tons annually by 2010 unless corrective measures are taken (Table 2) (Messick and Fan, 1999). The challenge is clear: to develop sustainable Chinese agriculture, the major strategy is to promote the balanced and efficient use of plant nutrients from both organic and inorganic sources at farm levels to intensify agriculture in a sustainable manner. Whatever strategies are developed, they must consider the essential role of sulphur for future crop production and quality. It is expected that the sulphur fertilizer use in China will significantly increase over the coming decade and make a greater contribution to the increase of Chinese agricultural production through value-added balanced fertilization, including sulphur. Based on the results in sulphur research conducted in China, including sulphur fertilizer into the fertilization program could increase yield by an average of 10% in sulphur deficient soils (0.6 ton ha^{-1}). By extrapolation, this would amount to a total grain yield increase of 18 million tons in China every year, and an estimated increase in economic returns at approximately 36 billion yuan (4.4 billion USD) for farmers.

Table 2. Sulphur demand and supply in Chinese agriculture (million tons).

Year	Grain Yield	Sulphur demand [a]	Sulphur supply [b]	Sulphur deposit form atmosphere [c]	Sulphur deficit
1997	470	4.2	3.3	13	0.9
2005	520	4.6	3.1	11	1.5
2010	560	5.0	2.7	10	2.3

a. Sulphur demand is estimated from all major food production and sulphur fertilizer use efficiency.
b. Sulphur supply is estimated from SSP, ammonium sulphate and potassium sulphate consumption.
c. Sulphur deposit from atmosphere is estimated from the governmental report on SO_2 emissions in China.

References

Liu Chongqun, 1995. Importance of sulphur fertilizer and sulphate fertilizer requirements in China. p. 1-9. Proc. National Workshop on Phosphate Fertilizer and Sulphuric Acid Production in China, Luoyang, Henan, China. May 1995.

Messick, D.L. and Fan, M.X. 1999. An overview of global agricultural requirements for plant nutrient sulphur. Sulphur No. 260. pp. 26-33. January-February 1999.

Yang, X. and Gao, Q. 1998. Sulphur transportation and precipitation from atmosphere in China. Chinese Environmental Science. 11(4): 27-34.

Zhang Jizhen, Hu Zhengyi, Ma Youhua, Zhu Weimin and Zhang Ligan. 1997. Soil sulphur situation and crop responses to sulphur application in Anhui province. Proc. Nat. Workshop on Sulphur for Chinese Agriculture: Agronomic Progress and Strategies for Meeting Future Requirements, Nanjing, China. 2-3 May 1997. TSI, Washington, DC, United States; PRISM, Sulphur Corporation, Calgary, Alberta, Canada; ACAR, Armidale, New South Wales, Australia and Academia Sinica, Nanjing, Jiangsu, China.

Nutrient balance and nutrient management in agro-ecosystems of China

Zhou Jianmin[1], Chen Xiaoqin[1], Xie Jianchang[1], and Rolf Härdter[2]

[1]Institute of Soil Science, Chinese Academy of Sciences, Nanjing, P. R.China, 210008
[2]International Potash Institute, c/o K+S KALI GmbH, Kassel, Germany

Introduction

Since Liebig put forward the mineral element theory, it has been recognized that the returning of nutrients is the key for maintaining soil fertility and plant production. Without the scientific foundation, Chinese ancestors had already realized this importance long time ago and put returning of nutrients into practice much earlier. China, being a country with thousands of years of tillage history, realized the miracle to keep the soil productive for such a long time without mineral fertilizer, just by efficient recycling of residues and applying organic manure. Before 1950, all of the applied nutrients originated from organic manure. In the 1950's, manufactured nitrogen fertilizer appeared in the agricultural practice. With the improvement of crop cultivars, the development of the chemical fertilizer industry and the progress of tillage methods, mineral fertilizers gained increasing importance in returning nutrients to the soil. Nitrogen fertilizer use gradually increased in 1960's whereas phosphorous fertilizer use only took off at the end of 1960's. Potash use started only at the end of the 1970's. The fertilizer input from that time onwards increased year by year (Table 1). In 2001, the total N fertilizer input was as much as 21,641,000 t (of N), the P fertilizer input was 7,060,000 t P_2O_5, K fertilizer was 3,998,000 t K_2O, not including the nutrients contained in 9,842,000 t compound fertilizer (Table 1).

Table 1. Input of mineral fertilizer in China,1000 t

Year	Total ($N+P_2O_5+K_2O$)	N	P_2O_5	K_2O	Compound fertilizer
1957	373	320	53		
1965	1,447	1,331	108	3	5
1975	5,211	3,309	1,463	113	326
1980	12,694	9,342	2,733	346	273
1985	17,758	12,049	3,109	804	1,796
1990	25,903	16,384	4,629	1,479	3,416
1995	35,936	20,219	6,324	2,685	6,708
1996	38,278	21,452	6,584	2,908	7,347
1997	39,807	21,717	6,891	3,220	7,981
1998	40,856	22,344	6,828	3,463	8,222
2001	42,254	21,641	7,060	3,998	9,842

The application of mineral fertilizers resulted in an increase of grain yield, which in recent years has stagnated in many places, despite of further increase in fertilizer input. Though this observation is found in all crop production systems once a certain level of production is reached, there is no doubt that in China this stagnation is also related to the unbalanced and the inappropriate ratio of nutrient input. This has been proved by the eutrophication of waters and the reduction in soil productivity. Therefore, it is necessary to investigate and evaluate the nutrient balance of farmland, in order to improve and maintain soil productivity and to develop sustainable systems. This must provide the necessary guidance for the improvement of fertilization strategies in the agricultural practice, and assist the fertilizer policy for a national program for improved fertilizer production, importation, exportation and distribution.

Forms and pathways of major nutrients in farmland ecosystems

The diagram of a typical nutrient cycle in the field is presented in Figure1. The main nutrient input in the farmland ecosystem include: mineral fertilizer, organic fertilizer (nutrient reuse from agricultural by-products, e. g. residues from animal husbandry and crops), biological nitrogen fixation, wet and dry deposition, irrigation, etc.. The pathways of output of nutrients mainly comprise removal with crop harvest, runoff, leaching, ammonia volatilization, denitrification, nitrogen gas released directly by crops, etc. Irrational fertilizing techniques and measures can accelerate the unproductive loss of nutrients, i.e. those which are not removed by harvest, resulting in low use efficiency of fertilizer.

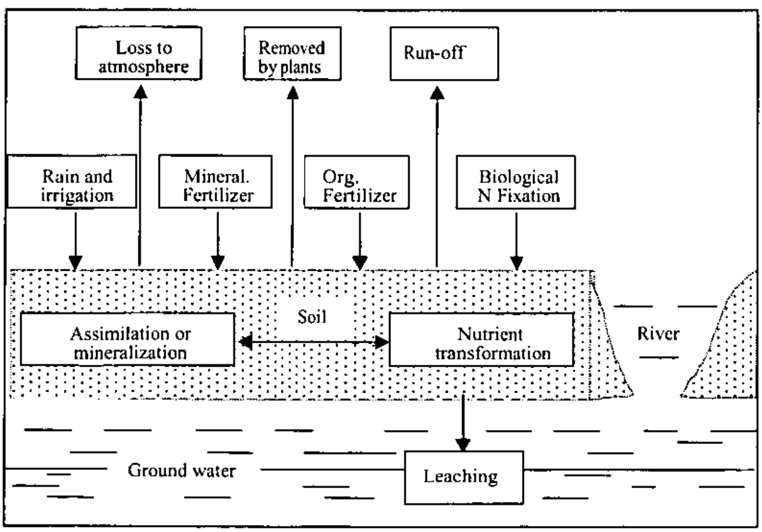


Figure. 1 Nutrient cycling in farmland production systems

Generally, the amounts of nutrients from inorganic and organic fertilizers constitute the inputs, those in the harvested crops are the main outputs. These data can be easily assessed.

Nutrient management in Chinese farmland varies distinctly between the different periods. Before the 1970's, the input of nutrients mainly relied on organic manure. With the development of the mineral fertilizer industry the ratio of mineral fertilizer in agriculture increased continuously from then onwards. Since 1975, the nitrogen from mineral fertilizer was larger than that from organic manure. Since the beginning of 1980's, the same is observed for phosphorus (Figure 2). On the other hand, until today the largest proportion of applied potassium comes from organic sources. With the rapid increase of mineral fertilizer use, the ratio of nutrients from organic sources in the total input decreased significantly. But because organic sources mainly comprise nutrients reused and recycled from crop production, the absolute amount has still factually increased with the increase in biomass due to larger input of inorganic fertilizers. On average, the proportion of nutrients applied from organic sources amounts to 36.7% whereas for potassium in 1990, it was in the region of 77% (Lin, 1998).

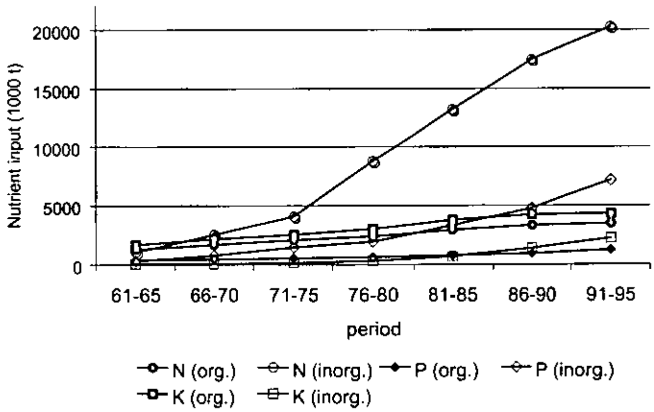


Figure 2. The input of N, P_2O_5, K_2O from organic and inorganic sources in Chinese agriculture during different periods (Source: Shen, 1988, Chin. Yearbook of Agriculture, 1995, 1996)

There is a certain area planted to leguminous crops and green manure in China. Therefore, the symbiotic nitrogen fixed by the rhizobia of legumes is an important source of nitrogen input into farmland. The cumulative amount of nitrogen fixed by leguminous crops during 5 years since the 1950's in China is shown in Figure 3. There was little variation in the total amount of nitrogen fixed since the 1970's, fluctuating around 5,500,000 t. However, this estimate didn't include the amounts fixed by horse bean, cowpea, red bean, pea and mungbean, thus the data in Figure 3 slightly underestimate the real N inputs.

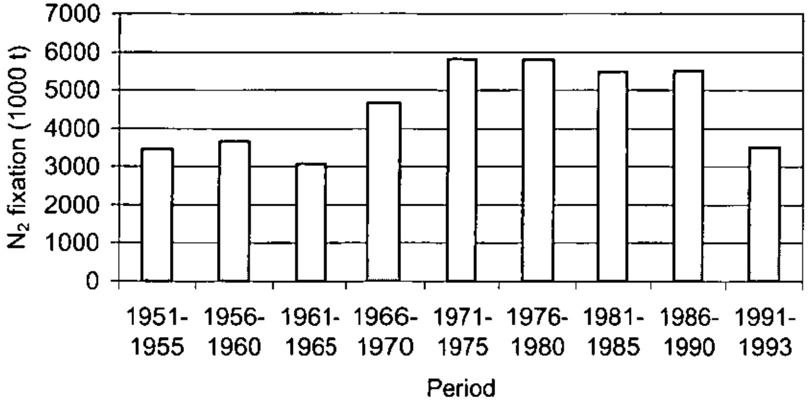


Figure 3. Amounts of symbiotically fixed nitrogen by leguminous crops in different periods in China (1000 t) (Source: Shen, 1998)

Water circulation is closely related with the nutrient cycle. Wet deposition (rain), irrigation, flowing water, seepage, leaching, etc., all of which are the inputs and outputs concerned with water, are the main constituents of farmland ecosystem, especially of paddy field ecosystems (Table 2).

Table 2. Nutrient inputs from irrigation and rainfall (Source: Qin et al. 1989)

Site	Water	Cropping system	N	P	K	Ca	Mg
			kg ha^{-1}				
Wuxi	Irrigation	2 seasons / year	8.92	0.038	17.4	227	56.0
		3 seasons / year	12.8	0.054	25.0	327	80.4
	Rain		12.0	-	3.44	44.3	1.2
Wujin	Irrigation	2 seasons / year	3.06	3.12	26.3	184	48.9
		3 seasons / year	4.22	4.31	36.3	253	67.3
	Rain		25.9	0.59	8.36	27.7	2.10

Table 2 and 3 show that losses through water either by leaching or runoff are largest for potassium followed by nitrogen and phosphorus. Irrigation or rain contribute different amounts of nutrients, which also vary between different regions and cropping systems. The nutrients imported or exported by the four pathways in Taihu Lake region are shown in Table 4. Based on these data, the calculations show that inputs of N, P and K through irrigation and rain water slightly exceeded the losses by runoff and leaching. In the double cropping system, the inputs from rainfall and irrigation exceeded those of the N losses by 20 kg ha^{-1} and those of the K losses by 11 kg ha^{-1} and in the triple cropping system by 22 kg N and 17 kg K_2O ha^{-1}, respectively. Therefore, the contribution of the water cycle to the nitrogen and potassium supply can be substantial. This could partially explain why in certain areas only small amounts of mineral K are applied. However, the contribution of the rain and irrigation water to the N supply is obviously not taken into account by the farmers as it is indicated by the generous use of N despite substantial deposition through the water supply (Table 4).

Table 3. Nutrient loss by leaching or runoff from a paddy field soil of south China (Source: Lu, 1996)

Region	Pathway	Loss of water	Nutrient concentration mg kg^{-1}			Loss of nutrients kg ha^{-1}		
		t ha^{-1}	N	P	K	N	P	K
Mountain	Leaching	1650	3.0	0.05	5.03	5.1	0.15	17.0
	Runoff	1050	1.8	0.02	2.9	3.9	0.45	10.2
Alluvial paddy field	Leaching	1800	2.0	0.04	3.5	6.9	0.15	12.2
	Runoff	675	1.41	0.02	2.3	2.0	0.30	3.2
Acid red soil region	Leaching	1650	2.0	0.02	2.8	6.8	0.06	9.6
	Runoff	450	1.4	0.01	1.9	1.5	0.015	2.0

Table 4. Nutrient balance in water circulation under different cropping systems (kg·ha^{-1}) n=3 (Source: Xu et al., 1998).

	N	P	K
		2 crops $year^{-1}$	
Irrigation	6.45 ± 3.0	1.16 ± 1.70	23.56 ± 5.35
Rain	18.23 ± 7.1	0.59	5.28 ± 2.68
Runoff	2.86 ± 1.42	0.204 ± 0.167	7.46 ± 1.78
Leaching	1.86 ± 0.37	0.247 ± 0.215	10.66 ± 5.45
Balance	19.96	1.299	10.72
		3 crops $year^{-1}$	
Irrigation	9.07 ± 4.40	1.61 ± 2.34	32.86 ±6.83
Rain	18.23 ± 7.1	0.59	5.28 ± 2.68
Runoff	2.32 ± 1.64	0.274 ± 0.228	6.71 ± 3.54
Leaching	2.60 ± 0.66	0.343 ± 0.298	14.4 ± 6.22
Balance	22.38	1.58	17.03

In general, the amount of nutrients imported or exported by water in comparison to fertilizers or harvested crops was small. Furthermore, the estimation of the amount of input and output by water was very difficult in practice. However, this part is very often neglected when estimating the macro-balance of nutrients in a farmland ecosystem.

Many studies were carried out on nitrogen loss through ammonia volatilization, denitrification and other nitrogen containing gases. And the results indicate that the percentage of nitrogen lost by ammonia volatilization was less than 10% of the total application. However, under conditions favoring ammonia volatilization, the percentage can rise to 40-50%. This would then be the main pathway of losing nitrogen (Cai and Fan, 1998). The proportion of nitrogen lost through denitrification is estimated to be at 2.5%-6.6% (Zhu, 1998a). Zhu compiled many studies in different regions and anticipated that the average loss of nitrogen from fertilizer was about 45%. This rounded figure was calculated from estimated average losses of 50% in paddy fields, 40% in maize and about 30% in wheat (Zhu, 1992) and is hence very rough. It may vary by several orders of magnitude from side to side and for a good fertilizer management should be assessed for each particular conditions.

The development of nutrient balances for N, P, K in Chinese farmland ecosystem

The nutrient balance of N, P, K in different periods in China

There are different methods to evaluate the nutrient balance in farmland, such as the nutrient input/output ratio, including the rate of nutrient returned and calculating the coefficient of balance. Some authors used the permitted efficient or deficient ratio considering the real soil fertility in China based on the criteria that crop yield is not affected under a certain level of deficiency and nutrients are not wasted within a certain range of sufficiency. Figure 4 shows the nutrient balance for N, P, K which has been calculated by comparing inputs and outputs based on existing statistics.

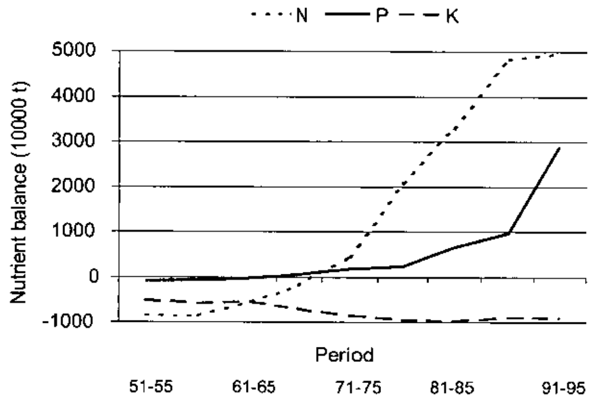


Figure 4. The development of the nutrient balances for N, P_2O_5, K_2O in Chinese farmland (Source: Shen, 1998; Chinese Yearbook of Agriculture, 1995, 1996)

Before the 1970's nitrogen had been deficient because only small amounts were applied by inorganic fertilizers. Since the 1970's nitrogen became more and more sufficient due to large amounts of inputs from inorganic sources. However, the nitrogen content in farmland wasn't increased to a measurable extent, which may be explained by the fact that applied N remains mobile, is not incorporated into soil constituents and hence all what is not absorbed by the plants is lost from the soil again. Before the 1970's phosphorus was also deficient, but since 1980's it has accumulated greatly in the soil, mainly because of relatively small P removals in comparison to the amounts applied. It was calculated by Lu (1998) that P fertilizers (P_2O_5) imported to farmland had been up to 100 Mt during the past 50 years. Considering the current and residual use efficiency of P fertilizer, 50% being regarded as taken up by crops, the accumulated P in the soil would be over 50 Mt P_2O_5, equal to 375 kg P_2O_5 accumulated per hectare. If 5% - 10% of the above P would be in the available form, the availability should be 4-8 mg kg^{-1} greater than that in 1949. Potassium has always been deficient, although the input of K fertilizer has gradually increased. With larger yields, the potassium removed by crops has also increased. From Figure 4 it is evident that the current input of potash is by far insufficient.

The nutrient balance of N, P, K in China at present time

Helongjiang, Shaanxi, Henan, Jiangsu, Sichuan, Hunan and Guangxi provinces represent typical agro-ecoregions of 1 season / year, 2 seasons / year, 3 seasons / 2 years, 5 seasons / 2 years, 3 seasons / year cropping systems. Therefore, the nutrient balance of these provinces may be representative for the variation found in the whole country. The nutrient balance in all of these 7 provinces was surveyed and the results are presented in Table 5.

Table 5. Nutrient budget of farmland in seven agro-ecological-regions in China (kg ha^{-1})

Province	N			P_2O_5			K_2O		
	Input	Output	Balance	Input	Output	Balance	Input	Output	Balance
Helongjiang	108.2	102.4	5.9	46.8	10.8	36.0	27.3	47.3	-20.1
Shaanxi	194.4	122.8	71.7	23.1	11.5	11.6	33.1	44.2	-11.2
Henan	136.2	122.9	13.3	75.5	50.4	25.1	70.1	117.7	-47.6
Jiangsu	481.1	394.3	86.8	154.9	91.4	63.5	162.6	195.9	-33.3
Sichuan	322.5	·249.0	73.5	121.5	67.5	54.0	75.0	196.5	-121.5
Guangxi	416.1	504.0	-87.6	150.6	84.2	66.4	285.4	443.5	-158.1
Hunan	582.7	253.2	329.5	188.0	155.8	32.3	318.1	360.7	-42.6

Note: "-" indicates nutrient depletion.

The results presented in Table 6 indicate that N and P were sufficient and K was deficient in all provinces except that N was deficient in the Guangxi Province. A comparison between irrigated lowlands and uplands in Guangxi showed that although upland occupies only a little less land, the input of mineral fertilizer in upland was much lower than that in irrigated lowland. Thus N was especially and seriously deficient in the upland, which caused that the overall N supply to the cropping systems of the province was deficient (Tan et al., 2000). In this investigation N losses were accounted as 45% of the application, though Wang et al. (2001) found much lower recovery of applied N in farmers fields, indicating N losses of up to 70-75% and larger. Large and partly unavoidable losses of N maybe to a great extent a reason for excessive N application in China, which influences the quality of product and also the environment. Surplus application of phosphorus was also observed in every region of China. Although phosphorus is generally fixed in the soil and little lost, large amounts applied especially to sandy soils may increase its mobility, and also result in losses which then affect the environment. Furthermore, the poor nutrient use efficiency of both N and P directly affect the economic returns from their application.

The causes of nutrient imbalance in Chinese farmland

Many factors caused the nutrient imbalance. One of the major reasons is deeply rooted in the perception of many farmers. For a large number of them mineral fertilizer means nitrogen and vice versa. This is due to the significant and quick action of nitrogen fertilizer which farmers could rely on. It will need a long time to change this perception among users, though scientists have done a lot of research on balanced fertilization in recent years, proving the essentiality of all nutrients. It may be mainly because of inadequate education of the farmers which limits the spread of a new approach to fertilization. It may be also due to the fact that the development of a service system for agricultural means of production in China lags behind so that farmers can't get the type of fertilizers and the appropriate recommendations required. Too much nitrogen fertilization became a common and serious problem. In the South Jiangsu Province, the nitrogen input was as much as 600-750 kg per hectare N (Li et al., 1998). Undoubtedly such high input of nitrogen seriously influences the economical and ecological impact of farming. The use efficiency of phosphorus fertilizer in the current cropping seasons is very low, between 10%-25% (Lu and Jiang, 1990). The poor mobility of phosphorus caused that large amounts of phosphorus were fixed in the soil. Certain soils, however, need large amounts of phosphorus to saturate the soil matrix and make enough P available to meet crops' requirements. This usually led to the observation that the input surpassed the requirement, and large amounts of phosphorus accumulated in the soil. The low use efficiency of phosphorus fertilizer, however, also depends on the type of P fertilizer. After introduction of highly concentrated water-soluble P fertilizers, sources with low phosphorus content, low solubility, low prices and low use efficiency followed. These fertilizers, easily accepted by farmers for their low prices, resulted in the large amount phosphorus being applied every year and even during each cropping season.

Besides the good mobility of potassium in the soils responsible for losses especially through leaching, the observed K deficit in China is mainly due to the current K fertilization policy. This comprises the fertilizer supply structure, people's perceptions, and fertilization measures/techniques in the field, etc.. This altogether caused that on one hand, a serious imbalance in fertilizer consumption of N, P, K developed. The application ratio of N to K_2O which in plants is about 1 : 1 was less than 1 : 0.2 (Xie et al., 1998; Xie, 1998), which certainly led to the exhaustion of the soil K reserves. On the other hand, the ratio of organic manure input, which for a long time had been the only potassium source for farmland, decreased significantly with the increasing use of mineral fertilizer, enhancing the imbalance of N, P, K. Potassium deficiency not only limits the yield and quality of agricultural products, but also restricts the use efficiency of N and P fertilizer, intensifies the environmental problems caused by the loss of N and P. Long periods of exhaustion of soil K reserves resulted in a degradation of soil fertility. The latter couldn't meet the requirement of a sustainable agricultural development. In addition, the introduction of high yielding cultivars and the increase of multiple cropping boosted the tendency of imbalance. Consequently the K deficient areas in China are expanding.

Returning straw to the field is an important way to reduce the strain on soil K. Not only the amount but also the way it is returned can have a distinct impact. A long-term experiment on returning straw from 1979-1993 in blue and purple soil in the suburb of Shanghai (Table 6) showed that if straw (2,100 kg ha^{-1} in each cropping season) was returned together with inorganic N, P and K, hardly any deficiency occurred. This experiment also showed that returning of straw as much as 4,200 kg ha^{-1} per year was not adequate to compensate the K deficit in these soils. In general, the fertilization practice,

Table 6. The nutrient balance with returning straw for 15 years (kg ha^{-1}) in the suburb of Shanghai (Source: Wang et al., 1994)

Treatment	Uptake			Input			Nutrient balance		
	N	P	K	N	P	K	N	P	K
Control	1298	335	1142	0	0	0	-1298	-335	-1142
Straw	1425	337	1319	384	52	771	-1041	-285	-548
Straw +NP	2909	566	1734	6429	1021	771	3521	454	-964
Straw +NPK	2876	591	2061	6429	1021	1895	3554	429	-166
NPK	2634	475	1844	6045	969	1307	3411	494	-528

combining organic manure with inorganic fertilizers has positive effects on the potassium balance. Table 7 shows the soil K balance under different fertilization schemes in several experiments conducted in the provinces of Hebei and Shandong. It also confirms that the input of only organic manure could not overcome the deficiency of potassium. It is therefore necessary, to apply adequate inorganic K fertilizer to increase the K supply up to the sufficiency level.

Table 7. Soil K balance in the 5 years experiments conducted in the provinces of Hebei and Shandong (Source: Wang et al., 1994)

Site	Soil	Cropping seasons	Treatment	Removal	Input K, (kg ha^{-1})	Balance
Hebei, Yutian	Fluvio-aquic soil	10	NP	381	0	-381
			NPK	702	935	232
			NPM	418	51	-367
			NPKM	734	986	252
Shandong, Laiyang	Brown soil	10	NP	599	0	-599
			NPK	913	935	21
			NPM	670	183	-486
			NPKM	977	1118	141
Hebei, Yutian	Fluvio-aquic soil	7	NP	175	0	-175
			NPK	521	561	40
			NPM	259	142	-117
			NPKM	570	702	133
Hebei, Yutian	Cinnamon soil	9	NP	711	0	-711
			NPK	1357	841	-516
			NPM	920	126	-794
			NPKM	1593	967	-626
Shandong, Laiyang	Brown soil	7	NP	446	0	-446
			NPK	712	654	-58
			NPM	526	349	-177
			NPKM	829	1003	174

Consequences of nutrient imbalance in farmland

Economical losses

The mineral nitrogen applied in the form of urea, ammonium and nitrate, etc. undergoes transformations in the soil which depending on site specific conditions, may lead to large N losses into water or air. This, besides the environmental impact also leads to substantial economic losses. According to the statistics, 21,164,110 t (elemental N) nitrogen fertilizer was applied to farmland in 2001. If the loss of nitrogen fertilizer is in the region of 45% as estimated by Zhu, the total annual loss is as much as about 9,522,000 t N from China's farmland. This amount is equivalent to 20 Mt of urea. At a price of 2,000 RMB Yuan/t urea, the total loss is 40 billion RMB Yuan (4.9 billion USD) (Chinese Agricultural Yearbook, 1998; Zhu, 1998b).

Waste of energy and resources

Production of N, P, K fertilizers is generally a natural resource and energy consuming process. Hence it is a perpetual loss to the development and utility of the non-renewable resources in the future.

Environmental problems

Surplus application of nitrogen does not lead to an accumulation in the soil, but is generally lost through different pathways into the atmosphere or water. The increase of ammonia flux in the atmosphere leads to soil acidification followed by a replacement of vegetation, e.g. forest decline, etc., affecting whole ecosystems. In addition, the discharge of N_2O and other NO_x gases destroy the ozone layer. As to water, the nitrate content in surface and ground waters may be increased. Efflux of excessive P into water, furthermore, leads to an eutrophication so that with increasing attention paid to the control of industrial pollutants in sewage, more and more importance has also to be attached to the potential pollution caused by agriculture.

Decline in soil fertility

Large supplies in nitrogen and phosphorus and inadequate supply of potassium leads to an imbalance between N, P and K. This means that the crops' demand for normal growth cannot be met, and the potential crop yields cannot be fully exploited. In contrast, imbalances between these nutrients will accelerate the exhaustion of soil potassium at the same time. This will surely result in a further decrease in the use efficiency of NP fertilizers, thus the sustainable soil productivity and development of agriculture will be threatened.

Strategy to resolve the current nutrient imbalance in China

The limited farmland resources and the strong population pressure make it necessary to continuously improve crop yield per unit area. For China, this situation will persist for quite a long time in the future. Increasing the fertilizer input will still be the key method to supply the food demand. But the nutrient imbalance in current farmland and the serious maladjustment of N, P, K ratios in fertilization, if not corrected in time, will inevitably lead to further decline in quality of farm products and increase in cost of production. Together with a poor fertilizer use efficiency, the threat to the environment, the decrease of soil fertility, etc., will affect China's food security and sustainable development of agriculture in the 21st century. It's a great challenge for Chinese soil and fertilizer scientists to achieve high efficiency, high yield and high quality of agricultural products as well as to improve soil fertility and to maintain environmental quality.

Principles to improve the balance situation of nutrient in fertilization

The major causes which led to the nutrient imbalance are evident from the results of the above investigation on the current nutrient utilization practice in China. Thus the general principles in fertilization can be summarized as 'economizing N, activating P, and supplementing K'.

'Economizing N' refers to improvement of nitrogen input towards better techniques and smaller quantities. It could be carried out by improving the adjustment of N fertilizer amount according to the requirement of crops. Using new fertilization application techniques to minimize nitrogen losses and increase use efficiency of N fertilizer, e.g. by better splitting the application. The application of new type of release-controlled and slow-release fertilizer will play an important role in this field. "Activating P" refers to reduce the fixation of P from fertilizer and activate P accumulated in soil through new techniques by employing soil organisms which are capable to mobilize this fractions. Furthermore, using appropriate fertilizer varieties and methods of fertilization according to the cultivation systems and soil conditions has a great potential in this respect. The application of many kinds of synergistic agents for phosphorus fertilizers will hence have promising prospects. The strategy of 'supplementing K' is rather simple, which means to increase the application of K fertilizer to a large extent. Besides maintaining high crop yield, the potential with larger K application lies in increasing product quality and maintaining soil fertility. Since this is the tendency of the agricultural development, a further increase of K fertilizer application is of utmost importance

Application of organic manure will constitute an important component to maintain a balance in soil fertility

As outlined, application of organic manure has been well recognized in China for centuries. The returning of most of the organic matter to farmland is a need to an efficient utilization of nutrient resources. Returning nutrients from organic residues to the field can also help to reduce the mineral fertilizer input and may as well reduce environmental pollution caused by excessive one-sided application of especially N fertilizer. Organic manure is generally characterized by a complete and balanced ratio of nutrients, thus, could well contribute to an alleviation of the nutrient imbalance situation in China. Taking K as an example, the ratio of potassium applied by organic manure to the whole potassium input is up to 70%. But the organic manure is also characterized by low nutrient concentrations and slow release combined with inconvenient handling of bulky material. Therefore, improved techniques for the application of organic fertilizer have to be developed, including the returning of straw and the commercial manufacturing of organic fertilizers from organic residues.

Supplement of micronutrients should not be neglected in the nutrient balance.

The application of macronutrients and the increasing of crop production inevitably leads to the exhaustion of micronutrients and some other beneficial elements, which will result in the decrease of crop yield and quality. Thus it is necessary to supplement these elements to keep nutrient balance in farmland. Application of organic manure and returning of straw has long been the best way to supplement nutrients not yet recognized for being limiting production at a site.

Strengthening the macro-control of fertilizer distribution.

The agricultural service system in which the official advisory service together with the fertilizer Industry advise farmers, has not been well developed in China. The influence of governmental intervention will therefore play a continued role in the nutrient supply to farms. This means that government services improve the advices on appropriate fertilizer use to farmers and at the same time care is taken of that the serious imbalance of nutrients is reverted in the importation and production of fertilizers so that the required nutrients are available on the market. The new approach should also pay attention to the distribution of various fertilizers. Fertilizers should be allocated to the regions of higher production potentials, i. e. where the return from fertilizer is higher and should be reduced in regions, where already excessive fertilizer use and comparatively smaller potentials exist. The basis for putting high-efficient utilization of fertilizer resources and maintain nutrient balances in future into practice is to build and develop an agro-technical service system.

References

Cai, G. X., Fan, X. H., 1998. Soil nitrogen and the efficient application of N fertilizers. In: Lu, R. K., (ed.), Theories of Soil and Plant Nutrition and Application of Fertilizer. Chemical Industry Press, Beijing, pp. 112-151. (in Chinese)

Chinese Yearbook of Agriculture. 1995. Chinese Agricultural Press, Beijing. (in Chinese)

Chinese Yearbook of Agriculture. 1996. Chinese Agricultural Press, Beijing. (in Chinese)

Chinese Yearbook of Agriculture. 1998. Chinese Agricultural Press, Beijing. (in Chinese)

Li, Q. K., Zhu, Z. L., Yu, T. R., (eds.), Fertilization Problems in Sustainable Development of Chinese Agriculture. Jiangxi Science and Technology Press, Nanchang, P. R. China. (in Chinese)

Lin, B., 1998. Problems and management in the development of fertilizer structure and effect in China. In: Li, Q. K., Zhu, Z. L., Yu, T. R. (eds.), Fertilization Problems in

Sustainable Development of Chinese Agriculture. Jiangxi Science and Technology Press, Nanchang, P. R. China, pp. 12-27. (in Chinese)
Lu, R. K., Jiang, B. F., 1990. Phosphorus in Soils. In: Hseung, Y., Li, Q. K. (eds.), Soils of China (2th edition). Science Press, Beijing, pp. 486-501. (in Chinese)
Lu, R. K., Liu, H. X., Wen, D. Z., Qin, S. W., Zheng, J. Y., Wang, Z. Q., 1996. Studies on nutrient cycle and equilibrium in a typical agroecological system in China: I. Parameters of nutrient output in field systems. Chinese J. of Soil Sci. 27(4): 145-151. (in Chinese)
Qin, Z. P., Xu, Q., Hseung, Y., 1989. Nutrient cycling in wheat-rice and barley-rice-rice rotation systems of the Tai Lake region: II. Cycling of five major nutrients in normal paddy field ecosystems. Acta Ecologica Sinica. 9(3): 245-252. (in Chinese)
Shen, S. M., 1998. The cycle of carbon and main nutrients in the agricultural system and the soil nutrient balance in China. In: Shen, S. M. (ed.), Soil Fertility in China. Chinese Agricultural Press, Beijing, pp. 57-110. (in Chinese)
Tan, H. W., Zhou, L. Q., Xie, R. L., 2000. Studies on the cycling and balance of field nutrients in Guangxi Province. In: Zhou, J. M., (ed.), Nutrient Cycling and Management in Chinese Agro-ecosystems. Hehai University Press, Nanjing, pp. 220-225. (in Chinese)
Wang, G., Dobermann, A., Witt, C., Sun, Q. and Fu, R. 2001. Performance of site-specific nutrient management for irrigated rice in Southeast China. Agron. J. 93, 869-878.
Wang, Z. L., Jin, J. Y., Wang, L. C., Gao, G. L., 1994. K balance and preliminary studies on potash requirement of some soils in the North areas of China. In: Chinese Academy of Agricultural Sciences, the Beijing Agency of PPIC, (eds.), Soil potassium and effect of potash application in the North areas of China. Chinese Agricultural Press, Beijing, pp. 17-25. (in Chinese)
Wang, Y. H., Ke, F. Y., Zhang, M. Z., Gu, Y. M., Chen, C. H., 1994. The overall effect of long-term turning over straw into soils. Chinese J. of Soil Sci. 25(7): 53-56. (in Chinese)
Xie, J. C., 1998. The use and requirement of potash and management in China. In: Li, Q. K., Zhu, Z. L., Yu, T. R. (eds.), Fertilization Problems in Sustainable Development of Chinese Agriculture. Jiangxi Science and Technology Press, Nanchang, pp. 69-85. (in Chinese)
Xie, J. C., Xing, W. Y., Zhou, J. M., 1998. Current use of and requirement for nutrients for sustainable food production in China. In: Johnston, A. E., Syers, J. K. (eds.), Nutrient management for sustainable crop production in Asia. The University Press, Cambridge, UK, pp. 267-277.
Xu, Q., Yang, L. Z., Dong, Y. H. (ed.), 1998. The rice field ecosystem of China. Chinese Agricultural Press, Beijing. (in Chinese)
Zhu, Z. L., 1992. Processes of nitrogen loss and management in the field system. In: Zhu, Z. L., Wen, Q. X. (eds.), Nitrigen in Soils of China. Jiangsu Science and Technology Press, Nanjing, pp. 213-249. (in Chinese)
Zhu, Z. L., 1998a. The fertility and management of soil N in China. In: Shen, S. M. (ed.), Soil Fertility in China. Chinese Agricultural Press, Beijing, pp. 160-211. (in Chinese)
Zhu, Z. L., 1998b. Problem and management in the use of nitrogen fertilizer in China. In: Li, Q. K., Zhu, Z. L., Yu, T. R., (eds.), Fertilization Problems in Sustainable Development of Chinese Agriculture. Jiangxi Science and Technology Press, Nanchang, pp. 38-51. (in Chinese)

Prospects for mineral fertilizer use in China

Li Jiakang, Lin Bao, Liang Guoqing and Shen Guiqin

Soil and Fertilizer Institute of CAAS, 100081

Abstract

In the recent 20 years, the application pattern of mineral fertilizer in China has changed with the development of a market economy and the concomitant adjustment of plant production. The mineral fertilizer applied to commercial crops has increased year by year. The acreage under fertilizer application increased from 22.0% of the total in 1980 to 31.5% in 1997 whereas the applied amount accounted for 42.6%, excluding forestry and grassland. Considering this situation, it became necessary to re-evaluate the prospects for mineral fertilizer use in China.

Application of mineral fertilizer and nutrient balance of farmland in China

Current situation of mineral fertilizer use in China

The use of mineral fertilizer gained immense momentum only during the recent 20 years, which is confirmed by the fact that the consumption of mineral fertilizer in 1980 was 12.69 million tons (nutrient units) and increased to 40.80 million tons in 1998, which means that it more than tripled within only 18 years. The average increase of mineral fertilizer use was 1.56 million tons annually (Table1).

Table 1. Consumption of mineral fertilizer in China in recent years*

Year	Consumption (thousand tons)					$N:P_2O_5:K_2O$**
	Total	N	P_2O_5	K_2O	Compound	N=100
1980	12,694	9,342	2,733	346	273	100:31:4.0
1985	17,758	12,049	3,109	804	1,796	100:33:7.8
1986	19,306	13,126	3,598	774	1,808	100.34:7.0
1987	19,993	13,268	3,719	919	2,087	100:36:8.1
1988	21,416	14,171	3,821	1,012	2,412	100:35:8.4
1989	23,571	15,368	4,189	1,205	2,809	100:36:9.2
1990	25,903	16,384	4,624	1,479	3,416	100:38:10.5
1991	28,051	17,261	4,996	1,739	4,055	100:40:11.6
1992	29,302	15,761	5,157	1,960	4,624	100:42:12.8
1993	31,519	18,351	5,751	2,123	5,294	100:45:13.3
1994	33,181	18,820	6,007	2,348	6,006	100:47:14.5
1995	35,936	21,209	6,324	2,685	6,708	100:47:15.1
1996	38,280	21,453	6,584	2,896	7,347	100:46:15.3
1997	39,805	21,713	6,894	3,220	7,978	100:48:16.7
1998	40,854	22,335	6,841	3,459	8,220	100:47:17.2
2001	42,254	21,641	7,060	3,998	9,842	100:53:20.3

* The consumption of mineral fertilizer was cited from *China Agriculture Yearbooks*.
** N, P_2O_5 and K_2O in compound fertilizer was converted on the basis of a 3:6:1 nutrient ratio in the imported and domestic compound fertilizers.

Calculated on the basis of 133.33 million ha of farmland and 208.00 million ha of acreage under crops due to a 1.56 multiple cropping-index, the average amount of mineral fertilizer applied in 1998 was 306 kg ha^{-1} farmland and 196 kg ha^{-1} per crop, respectively.

Table 2 indicates that world-wide there is a good relationship between the fertilizer applied per unit area and the general stage of economic development as well as between fertilizer application and the average of farmland per person. Generally speaking, the application level of fertilizer in developed countries was higher than that in developing countries. The application rate of fertilizers in those countries with more available arable land per capita was less than in countries with limited availability of arable land, showing that intensity of agriculture increases with scarcity of land.

Table 2. Comparison of fertilizer applied per unit area between China and some countries or regions of the world

Region or country	Fertilizer application (kg ha^{-1})			Farmland for each person (ha $person^{-1}$)
	1989	1994	1997	
World	98.7	90	97.1	0.239
North America and Central America	83.7	97	97.1	0.589
Asia	114.8	129	141.1	0.129
Europe	229.4	163	85.1	0.242
All the developed countries	124.6	-	-	-
All the developing countries	76.8	-	-	-
U.S.A.	93.6	104	108.8	0.713
Russia	117.0	20	14.1	0.879
India	65.2	124	88.0	0.181
Japan	415.0	442	396.3	0.032
France	311.5	280	277.0	0.316
Germany	411.3	248	238.2	0.144
Netherlands	649.6	587	569.5	0.059
United Kingdom	345.7	339	364.7	0.104
China*	306.0	216	267	0.114
China**	196.0	139	171	0.168

* Calculated on 133.33 million ha of arable land.

** Calculated on 133.33*156%=208.00 million ha of arable land.

The total amount of fertilizer applied in China was larger than in the average of the developed countries world-wide. But compared with Germany and the United Kingdom with similar farmland availability per capita, China's total fertilizer consumption is still less.

During the course of increasing the consumption of mineral fertilizers, China had to adjust the ratio of N : P : K in the fertilizers. Whereas in 1980, this ratio was 100:31:4, it steadily improved to a ratio of 100:53:20 in 2001. In the current situation, the application ratio between N and P is more according the plants' requirements whereas the proportion of potassium applied is yet far from matching the crop removals. This causes a continuous depletion of soil K reserves.

Nutrient balance of farmland in China

For several decades, our agricultural production was depending on the input of organic sources, mainly crop residues, animal and human wastes, which caused that all nutrients without exception became the main production limiting factor. Since the 1980's, this situation greatly changed with increasing the input of mineral fertilizer. In 1995, Chinese farmers applied 28.35 million tons of N, 13.65 million tons of P and 10.96 million tons of K, including organic and inorganic fertilizer with a ratio of 100:48:48 of N : P_2O_5 : K_2O. The nutrients removed by crops were 13.73 million tons of N, 5.77 million tons of P and 14.55 million tons of K at a ratio of 100:42:106 of N : P_2O_5 : K_2O. The balance between inputs and outputs shows that N was sufficient with 3.50 million tons, P sufficient with 4.89 million tons and K was deficient with 3.55 million tons. This situation further worsened until 2000 (Table 3).

According to the nutrient balance of farmland, Chinese farmers applied much more nitrogen fertilizer and less potassium fertilizer before. Although an excess in phosphorous was applied because in the beginning our soil was widespread deficient in P, and owing to the behavior of P in the soil not being leached, it was necessary to keep a high application level over a long time, to develop the soil fertility of farmland. It then became essential for us to adjust the application ratio of N and K and improve the potassium status in both soil and crop.

Table 3. Input and output of nutrient of farmland in China (thousand tons)

Year			1949	1957	1965	1975	1980	1985	1990	1995	2000
Input	Organic Fertilizer	N	1620	2490	2930	4100	4160	5030	5260	6110	6520
		P_2O_5	790	1230	1380	1940	2060	2560	2800	3300	3440
		K_2O	1870	2860	3060	4620	5090	6210	6930	7600	8320
	Inorganic Fertilizer	N	6	316	1210	3640	9430	12590	17400	22240	22480
		P_2O_5	-	52	550	1610	2900	4190	6680	10350	8410
		K_2O	-	-	3	130	370	980	1820	3360	3350
Output		N	2910	5110	5220	7490	8670	11140	12790	13730	16620
		P_2O_5	1380	2360	2370	3340	3780	4790	5590	5770	6640
		K_2O	3060	5620	5600	8130	9330	12080	13750	14550	17390
Balance		N	-1290	-2460	-1690	-1570	210	190	1170	3500	1140
		P_2O_5	-590	-1100	-600	-280	310	710	1890	4890	1000
		K_2O	-1190	-2760	-2540	-3380	-3870	-4890	-4990	-3550	-5720

Note: Use efficiency of N applied was calculated as 50% (including after effect), P 70% (including after effect), organic fertilizer and K as 100%, assuming minimum losses as residual effects over the years are included.

Developing trend of mineral fertilizer use in China

Change of fertilizer application pattern of China during the past 20 years

With the development of a market economy, the adjustment of plant production, an increase in tea, fruit, mulberry, tropical commercial trees and popularization of fertilizer use, the pattern of fertilizer consumption in China greatly changed. According to the statistical information from the *China Agriculture Yearbooks*, in the period from 1980 to 1997, the acreage under crop for grain was stable at around 0.11 billion ha. The increase of total grain production was achieved by raising the per unit-area yield which depended on the increase of fertilizer application. During the same period, the acreage under commercial crops increased rapidly by 2.13 times for melon, 3.85 times for fruit trees, 4.93 times for tobacco, 56% for oil seeds, 108.6% for sugar. The total acreage for commercial crops, receiving fertilizer increased from 14.93 million ha in 1980 to 16.47 million ha in 1997 whereas the proportion of acreage under grain crops, receiving fertilizer declined from 78% in 1980 to 68.5% of the total in 1997, down 10% (Table 4). Moreover, the fertilizer applied per unit-area to grain crops was smaller than that applied to commercial crops. According to the results from a survey covering 1958 farmers from the Jilin, Shandong, Shaanxi, Sichuan, Hubei, Guangxi, Jiangsu provinces or municipalities, the average amount of mineral fertilizer applied to grain crops in 1996 was 273 kg ha^{-1} and 441 kg ha^{-1} to commercial crops (Table 5). The fertilizer applied to commercial crops was 61.5% larger than that applied to grain crops. If calculated on crop area basis, using the data from *China Agriculture Yearbook* and the information from the above described survey, 40% of mineral fertilizer was applied to commercial crops in 1997 (Table 6). Even though the data of the survey indicate a 35 % larger application than what is actually applied according to the statistics, it revealed an apparent insight into the application pattern of China during the past 20 years.

Furthermore, according to the survey with 1958 farmers, comparing the fertilizer application in 1996 and 1994, the fertilizer applied to commercial crops raised by 53 kg ha^{-1} and only 13 kg ha^{-1} to grain crops (Table 7), or 13.6% and 5%, respectively. Underestimating the proportion of fertilizer applied to commercial crops in the past and overestimating that applied to food crops, could be a reason for the observation that the grain yield of China in recent 20 years could not catch up with the increase of mineral fertilizer application. The discussion above did not include the fertilizer application to forestry and grass.

Table 4. Area of various crops in China, receiving fertilizers in recent 20 years (1000 ha)

Crop variety	1980	1985	1990	1995	1997
Grain	116472	108845	113467	110061	112913
Cotton	4920	5140	5588	5421	4491
Oilseed	7929	11800	10900	13101	12380
Crude fiber	314	1231	495	376	327
Sugar	922	1525	1679	1820	1923
Tobacco	397	1313	1593	1470	2353
Melon and vegetable	4021	5673	7059	10616	12591
Other crops	10642	8097	7583	7013	6991
Tea tree	1041	1045	1061	1115	1076
Fruit tree	1783	2736	5179	8098	8649
Mulberry	287	413	484	(484)	(484)
Tropical crops	(588)	588	698	668	685
Total	149315	148407	155785	160244	164864
Grain (%)	78.0	73.3	72.8	68.7	68.5

Note: cited from *China Agriculture Yearbook*. Mulberry lacked the information of 1995 and 1997 so that data of 1990 were used. The information of 1980 on Tropical crops was used instead of that of 1985.

Table 5. Fertilizer applied to each crop based on a survey with 1958 farmers in 1996 (kg ha^{-1})

Crop Type	N	P_2O_5	K_2O	Total	Acreage applied (ha)
Wheat	171	80	20	277	318.2
Corn	203	70	27	300	411.7
Rice	196	51	55	302	364.5
Root crop	104	36	15	155	63.8
Bean	34	28	21	83	76.7
Others	132	38	7	177	15.1
Average of grains	177	64	32	273	1250
Melon and Vegetable	263	237	121	721	51.6
Cotton	215	79	57	351	50.1
Crude fiber	159	55	84	298	2.2
Sugar	304	112	208	624	21.1
Oil seed	114	56	27	197	76.1
Tobacco	119	91	71	281	11.7
Fruit tree	326	197	73	596	57.9
Tea tree	448	19	12	479	2.2
Mulberry	251	21	14	286	3.3
Others	145	65	38	248	9.3
Average of commercial crops	240	126	75	441	285.5

Note: cited from the survey carried out by SFI of CAAS and PPIC.

Table 6. Proportion of fertilizer applied to grain and to commercial crops of China in 1997

Total mineral fertilizer applied (mill. tons)	Grain crop			Commercial crop		
	Acreage (1000 ha)	Application (mill. tons)	Of total (%)	Acreage (1000 ha)	Application (mill. tons)	Of total (%)
53.75	112913	30.82	57.4	51951	22.91	42.6

Note: 1. The mineral fertilizer application was calculated, using the information in Table 4, namely 273 kg ha^{-1} for grain crop and 441 kg ha^{-1} for commercial crop.
2. The actual mineral fertilizer applied in 1997 was 39.80 million tons.

Table 7. Comparison between the application of mineral fertilizer of 1958 farmers in 1984 and 1996

Crop type	1994				1996				Change
	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total	
Grain crop	172	62	26	260	177	64	32	273	13
Commercial crop	216	112	60	388	240	126	75	441	53

Note: cited from the survey carried out by SFI of CAAS and PPIC.

Fertilizer application to forestry

Since 1979, three surveys on forestry were carried out and a fourth is in progress. The information on area development of commercial forest, bamboo and seedling nurseries are shown in Table 8. According to this, commercial forest and bamboo production developed very fast, increasing 89.0% and 18.5% in the period of 14 years from 1979 to 1993. Fast-growing forest was not surveyed and an amount for 2000 was anticipated. Commercial forest refers to those forests planted for dry fruit, oil seed, beverage, flavoring agents, raw industrial material and drug production excluding fruit, mulberry and tea, which are listed separately in the *China Agriculture Yearbook*. Generally speaking, fast-growing forests, commercial forests, bamboo and seedling nurseries have to receive mineral fertilizers.

Table 8. Artificial and grown forest resource in China (1000 ha)

Period of survey	Fast-growing forest**	Commercial forest*	bamboo	Seedling nursery
1979-1981	-	6259	3200	-
1984-1988	-	8722	3546	184.5
1989-1993	800	11830	3791	114.9

* Commercial forest was referred to those forest planted for dry fruit, oil seed, beverage, flavoring agents, raw industrial material and drug production.

** Fast-growing forest was not surveyed and 8 million ha were anticipated for 2000.

In recent years, considerable research on the fertilizer application to forestry was carried out. Some of the results are shown in Table 9, in which 3 groups can be distinguished as fast-growing forest, commercial forest and bamboo. Fast-growing forest included 49 varieties, e.g. fir, red pine, slash pine, other pines, eucalyptus and poplar, etc., The results revealed that fast-growing forest needed mainly nitrogen and phosphorous fertilizer whereas potassium was not essential at this stage. However, based on a calculation, using 17 field trials in commercial forests, including fruit, flavoring agents and oil seed, the application of fertilizer should be 200 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 150 kg K_2O ha^{-1}.

11 trials on bamboo were carried out and the results show that the application of fertilizer should be 212 kg N ha^{-1}, 77 kg P_2O_5 ha^{-1} and 68 kg K_2O ha^{-1}.

Furthermore, the trials above indicated that the fertilizer application to forestry was generally larger than that to grain crops and the fertilizer applied to commercial forest was even much greater.

Table 9. Fertilizer application to forestry (from 1989 to 1997)

	Variety	Trial amount	Application (kg ha^{-1})*			Trial location
			N	P_2O_5	K_2O	
Fast-growing forest	Fir	12	53(7)	61(11)	31(5)	Jiangxi, Fujian, Yunnan, Guangxi, Guangdong, Jiangsu, Zhejiang, Hunan
	Masson Pine	7	94(5)	119(7)	54(4)	Guangxi, Guizhou, Sichuan, Hunan, Anhui
	Slash Pine	7	39(4)	67(6)	14(2)	Jiangxi, Hunan, Anhui, Guangdong
	Other pines	7	76(6)	51(5)	21(2)	Guangdong, Liaoning, Fujian, Heilongjiang
	Eucalyptus	6	50(5)	84(6)	53(4)	Guangdong, Guangxi, Fujian, Yunnan
	Poplar	10	126(10)	72(9)	14(4)	Shandong, Hebei, Hunan, Gansu
Commercial forest	Jujube	5	116(5)	75(4)	34(2)	Shandong, Hebei
	Chestnut	5	264(5)	110(5)	30(1)	Zhejiang, Liaoning, Henan, Hebei
	Chinese Gooseberry	1	150	100	120	
	Persimmon	1	200	150	150	
	Hawkthorn	1	150	150	150	Liaoning
	Hickory	1	207	67.5	67.5	Zhejiang
	Cashew	1	160	40	70	Hainan
	Pepper	1	570	304	375	Hainan
	Tung tree	1	120	71	78	Zhejiang
Bamboo		11	212(11)	77(9)	68(8)	Zhejiang, Sichuan, Guizhou, Anhui

* Average of all trials and ( ) indicates the current recommendation.

Fertilizer application to grassland

According to the statistical information from Stockbreeding and Veterinary Department of MOA in 1994, the reserved acreage for managed grassland was 6.0876 million ha scattered mainly in the border provinces (Table 10).

Table 10. Acreage under natural and seeded grassland in China (1000 ha)

Region	Natural grass	Seeded grass	Region	Natural grass	Seeded grass
Country	392832.6	6087.6			
Hebei	4712.1	233.7	Sichuan	22538.8	272.7
Shanxi	4552.0	205.8	Shannxi	5206.2	477.3
Inn.Mongolia	78804.5	2414.0	Gansu	17904.2	762.3
Liaoning	3388.8	149.7	Qinghai	36369.7	219.4
Jilin	5842.2	109.9	Ningxia	3014.1	136.4
Heilongjiang	7531.8	235.7	Xingjiang	57258.8	500.5

Source: *Grass Resource in China*, 1994, Stockbreeding and Veterinary Department of MOA.

Table 11. Fertilizer application to grassland

Grass Variety	Trial Location	Trial Variety	Fertilizer recommendation (kg ha^{-1})				Remarks
			N	P_2O_5	K_2O	Total	
Grasses of garmineae species	Yunnan		161	92	53	306	Zhao Junquan 1991
	Jiangsu	Flattened hemarthria	375	32	45	452	Zhu Xueqian 1991
	Gansu	Oat	100	150	120	370	Li Zhihua 1994
	Fujian	Dallis Grass	207	54	-	261	Lin Zhirong 1995
	Gansu	Clover	16.5	16.5	-	33	Jiang Danlan 1995
	Shannxi	Alfalfa	69.0	52.5	-	121	Liu Fengxian 1992
	Jiangxi	White Clover	-	63.0	62.0	125	Jin Yimei 1994
	Ningxia	Alfalfa	-	180	-	180	Peng Wendong 1994
Bird's food grass	Yunnan	White Clover	-	70	40-55	120	Huang Bizhi 1992
	Guizhou	White Clover Ryegrass	138	135	-	273	Chen Minghua 1994
	Sichuan	Orchardgrass	138	42	-	180	Fan Jiangwen 1996
Mix-seeding grass	Yunnan	White Clover Green Bristlegrass	-	35	25	60	Huang Bike 1992

Combining some trial results from each province, it was concluded that grasses and seeded grass mixtures mainly needed nitrogen and phosphorous fertilizers whereas pure stands of bird's food grass need mainly phosphorous fertilizer only. The amount of fertilizer applied to grasses was the largest among all varieties, with an application of about 300 kg ha^{-1} of mineral fertilizer. The second important mineral fertilizer consumer was seeded grass mixture with 200 kg ha^{-1}. Bird's food grass received only about 100 kg ha^{-1} (Table 11).

Table 12. Fertilizer recommendation for grassland on soils of southern China (kg ha^{-1})

Grass variety	N	P_2O_5	K_2O	Total
Gramineae	100-120	40-60	40-50	180-230
Bird's food	-	40-50	30-40	70-90
Mix-seeding	30-40	40-50	35-40	105-130

Source: Xu Minggang 1978

Evaluation of the mineral fertilizer requirement of China

In the past, when fertilizer requirements for China were estimated, much emphasis was laid particularly on grain crop production only. So the estimated requirements were often smaller than the actual application, particularly as long as no distinction was made of how much fertilizer is needed for crop production, forestry and grassland.

China's population is still growing and will reach 1.6 billion in 2030. Because of limited land resources, the total agricultural production needs to be increased by raising the per unit-area yield of crops. Moreover, China's forestry and grassland production was backward and there is a large scope for intensification. On the basis of above described conditions the demand of mineral fertilizers has been re-evaluated.

Fertilizer requirement for grain crops

If the future population of China stabilizes at around 1.6 billion people, the total need for food would be 0.64 billion tons of grain equivalents which means an increase of 0.14 billion tons of food compared to the current production of 0.5 billion tons. According to trial results from the *National Mineral Fertilizer Network*, each ton of mineral fertilizer can increase the grain output by 8-10 tons which means that 14.00-17.50 million tons of additional mineral fertilizers would be needed to achieve above goal.

Fertilizer requirement for commercial crops

The actual cropped area in China is around 208 million ha, of which commercial crops account for 27%, i.e. 56.16 million ha. The area under other crops besides vegetables and sugar crops was kept constant. In 1997, the area under perennial commercial cropping was 10.89 million ha with no apparent adjustment besides fruit trees. But considering the development of fruit trees, we suppose the acreage under perennial commercial cropping was 11.89 million ha. Together these two crops account for 68.05 million ha. Under the condition of keeping the area under commercial crops unchanged, we could increase the per unit-area yield of crop by applying more mineral fertilizers. It is estimated that additional 6.80 million tons of mineral fertilizer would be needed in 2030 if the fertilizer applied increased by 100 kg ha^{-1}.

Fertilizer requirements by forestry

According to the results of the third forestry survey (1989-1993), the forestry area, including fast-growing forest, commercial forest, bamboo and seedling nurseries was 23.74 million ha.

1) Fast-growing forest: The area under this type of forest was supposed to be 8.00 million ha. The production cycle of fast-growing forest is 15 to 20 years. Generally, fertilizers should be applied 3 to 4 times, including a basal dressing. According to the recommendation, 70 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} (Table 9) are needed for each application. Calculated on a 20 years production cycle and 3 applications, the average fertilizer needed for each year would be around 0.20 million tons.

2) Commercial forest: This type of forest, including bamboo and seedling nursery covers together an area of about 15.74 million ha. According to the recommendation (Table 9) based on an application of 400 kg ha^{-1}, the fertilizer needed for each year is in the region of 6.30 million tons. The fertilizer needed by forestry together is therefore 6.50 million tons of nutrients.

Fertilizer requirement by grassland

According to the statistics of Stockbreeding and Veterinary Department of MOA in 1994, the reserved needed grassland area in China was 6.087 million ha. Assuming that fifty percent of the grassland is fertilized, using the recommendation in Table 11 and Table 12 (namely 200 kg ha^{-1} per application), the mineral fertilizer needed by grassland is about 0.6 million nutrient tons.

According to the above estimated results, the additional fertilizer needed together would be 27.90-31.40 million tons, including 14.00-17.50 million tons for grain crop, 6.80 million tons for commercial crops, 6.50 million tons for forestry and 0.60 million tons for grassland. In 2001, the application of fertilizer in China was 42.20 million tons. Together with the additional increase, the total amount of fertilizer needed is in the region of 68.70-72.20 million nutrient tons, which means that the fertilizer requirement has to increase by approximately 70% until 2030. The actual total cropping area in China is approximately 208.00 million ha. Based on this area the fertilizer application would be 330-347 kg ha^{-1} (similar to that of the United Kingdom). The evaluation is preliminary, its suitability in the reality of China needs further discussion and research.

Summary

1) In 2001, the total application of fertilizer in China was 42.25 million nutrient tons. Calculated on 133.33 million ha of farmland and 208.00 million ha of annually cropped

area in China, the application of mineral fertilizer was 316 kg ha^{-1} and 203 kg ha^{-1}. During recent years (1995 to 2000) the farmland received annually 2.55 million tons of surplus N (in excess of the amount removed by the crops), 4.58-4.89 million tons of surplus P_2O_5 and was under-supplied by 2.89-3.55 million tons of K_2O.

2) During the recent 20 years, the fertilization pattern changed greatly. The proportion of acreage under commercial crops increased from 22.0% in total in 1980 to 31.5% in 1997. According to the survey, the fertilizers applied to commercial crops accounted for 40% of the total application, which was discussed as the main reason for the observation that crop yield did not increase at the same rate as the mineral fertilizer consumption during the past 20 years.

3) The total supply of mineral fertilizer in China is apparently insufficient. In order to satisfy the future need for agricultural products to supply 1.6 billion people, the input of mineral fertilizer has to be further increased. It is estimated that the upper limit of total mineral fertilizer needed is around 70.00 million tons, including the nutrients applied to forestry and grassland.

4) The estimation for mineral fertilizer consumption by agriculture is mainly based on the development of agriculture, forestry and stockbreeding, using the average input of mineral fertilizer to achieve a certain yield target. So, the aspects of natural resource and economy for reacting to this amount of mineral fertilizer was not considered. Furthermore, the economic benefits of fertilizer application was also not discussed. In a market economy, farmers' choice, how much fertilizer and what kind they want to apply to which crop, depends on the returned profit from fertilizer application.

Chapter II

Farmland nutrient balances and fertilizer requirement of Northern China

Circulation and regulation of potassium in the soil-plant system under major cropping systems of Northern China

Jin Jiyun and Liu Rongle

PPI/PPIC Beijing Office, SFI of CAAS 100081

Abstract

Potassium supply of soils in China follows a clear zonal pattern. Compared with the soils in Southern China, the potassium content and its availability in the soils of North China are regarded as being higher. Referring to the distribution of major clay minerals and the results of bio tests, the potassium supply potential of soils in China can be divided into 7 classes, from very low to very high, using the fraction of slow-release potassium. Meanwhile, a Sketch Map for Soil Potassium Supply Potential in China was drawn, showing an increasing trend from North to South. This was used as the scientific basis for the reasonable distribution and use of potassium fertilizer in China.

The National Chemical Fertilizer Network carried out more than 5000 experiments with N, P and K on 18 crop species in the whole country and analyzed the concentration of numerous soil fertility parameters. The results show that potassium deficiency mainly occurred south of the Changjiang River whereas in the three largest agricultural regions of the north, most of the soils had a high to medium potential to supply potassium, except for some sandy soils and brown soils in Jiaodong Peninsula and Liaodong Peninsula. Trial results showed also that there were no yield-increasing effects of potassium applied to grain crops in Northern China during this period.

In the 1980's, a number of reports appeared, showing potassium deficiency and the yield promoting effect of potassium increased steadily. Then in the 1990's, with the increase in the use of nitrogen and phosphorous and the consequently larger yields, response to K application in Northern China became more evident. This caused that the consumption of potassium also increased steadily. Even in the northwest of China, where soils are generally known for their inherent abundance in potassium reserves, farmers began to apply potassium to K-responsive crops.

To better understand these observations and to describe the interaction between crop production, nutrient uptake/removal and replacement, studies were undertaken on the potassium cycling in the soil-plant system under major cropping systems in Northern China. Led and organized by the Ministry of Agriculture in co-operation with PPI//PPIC and all the Soil and Fertilizer Institutes (SFI) of the Chinese Academy of Agricultural Sciences (CAAS), a so-called "Sino-Canada Potassium Agronomic Development" project was initiated which has now completed its third phase (1993-1998). One of the main objectives of this project was to study the K supply potential of various soils and the efficiency of K application. Since 1992, representative cropping systems on major soil types in the northern 13 provinces (or cities) of China were selected and 25 fixed location trials were set up. Using these results, this paper focuses on the cycle and balance characteristics as well as regulation mechanisms for the potassium supply under the major cropping systems in Northern China.

Materials and methods

Trial locations

Starting in 1993/1994, 25 field experiments were set up in 13 provinces, such as Shandong, Henan, Hebei, Tianjin, Liaoning, Jilin, HeilongJiang, Shanxi, Shaanxi, Ningxia, Gansu, Qinghai and Xinjiang. Considering the local conditions of agricultural production, representative cropping systems were chosen, such as winter wheat-maize, winter wheat-soybean, maize, rice, wheat-soybean, winter wheat-spring wheat, wheat-cotton and multiple-season vegetable. Most trial results were recorded except for some trials which had to be discontinued because of changing ownership of the fields (Table 1).

Table 1. Description of sites selected for the long-term fixed location trials on potassium response in the northern part of China

Province	Location (City)	Soil type	Cropping system	Period
Shandong	Daling of Linyi	Brown soil	Wheat- maize	1993-
	Sunlou of Linzi	Drab soil	Wheat- maize	1993-1997
Hebei	Chenchun of Luancheng	Chao drab soil	Wheat- maize	1993-
	Leitou of Xinji	Drab soil	Wheat- maize	1993-
Henan	Luoyang	Chao drab soil	Wheat- maize	1993-
	Luohe	Chao soil	Wheat- maize	1993-
	Hexing of Shuiping	Shajiang black soil	Wheat- maize	1993-
Tianjin	Zhangwo of Xiqing	Chao soil	Wheat- maize	1993-
	Shuigao of Xiqing	Chao soil	Wheat- maize	1993-1996
Heilong-jiang	Hongxinglong Farm	Meadow soil	Vegetable rotation	1993
	Shuangcheng	Black soil	Wheat to soybean	1993-
	Zhaodong	Chernozem	maize	1993-
Jilin	Liufangzi of Gongzhuling	Black soil	maize	1993-
	Taojia of Gongzhuling	Black soil	maize	1993-
Liaoning	Farm of LAAS	Meadow soil	maize	1993-
	Shahe of Hancheng	Paddy soil	rice	1993-1997
Ningxia	Daxin of Yinchuan	Anthropogenic-alluvial soil	Wheat with maize interplanting	1993-
Qinghai	Mayingkala of Ledu	Chestnut soil	Wheat	1993-
	SFI of QAAS	Chestnut soil	Wheat	1993-
Shanxi	Qiaoli of Linfen	Drab soil	Wheat	1993-
Shannxi	Yangling of Xian	Lou soil	Wheat-maize	1994-
Gansu	Farm of GAAS	Anthropogenic-alluvial soil	wheat	1994-1995
Xinjiang	Shangong of Changji	Gray desert soil	Wheat-maize	1994-1997
	Saili of Zepu	Anthropogenic-alluvial soil	Wheat-maize to cotton	1994-1997

Fixed location trials were arranged on soils which were widespread and which had a representative fertility. The major soils used included the most common soil types in the northern part of China.

Trial design

Considering the possibility of returning crop residues to the field, two programs were adopted in the trials. The first program consisted of four treatments of NP, NPK, NPSt and NPKSt, designed in accordance with the cropping systems including wheat, where St means that wheat residues were returned (Table 2). The second program consisted of three treatments including NP, NPK_1 and NPK_2 (Table 3).

Table 2. Design and treatments of fixed location trials (first program)

Trial location	Crop	Plot (m^2)	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K application in each treatment (K_2O, kg ha^{-1})			
					NP	NPK	NPSt	NPKSt
Luancheng and	Soybean	50	180	150	0	150	0	150
Xinji of Hebei	Maize		180	180	0	150	0	150
Luoyang and	Wheat	30	150	180	0	150	0	150
Luohe of Henan	Maize		225	150	0	150	0	150
Shuiping of Henan	Soybean		60	180	0	150	0	150
	Wheat		150	180	0	150	0	150
Linyi of Shandong	Wheat	13	150	112.5	0	150	0	150
	Maize		150	112.5	0	150	0	150
Linzi of Shandong	Wheat	33	112.5	112.5	0	56.25	0	56.25
	Maize		112.5	112.5	0	56.25	0	56.25
Xiqing of Tianjin	Wheat	45	225	150	0	150	0	150
	Maize		225	150	0	150	0	150
Hongxinglong of	Wheat	21	120	240	0	240	0	240
Heilongjiang	Maize		300	240	0	240	0	240
Yinchuan of	Wheat	34	406.5	104.7	0	150	0	150
Ningxia	Maize		406.5	104.7	0	150	0	150
Yangling of	Wheat	12	187.5	187.5	0	150	0	150
Shannxi	Maize		187.5	187.5	0	150	0	150
Linfen of Shanxi	Wheat	33	172.5	105	0	150	0	150
Lanzhou of Gansu	Wheat	27	150	75	0	112.5	0	112.5
Ledu of Qinghai	Wheat	25	110	55.2	0	150	0	150
Xining of Qinghai	Wheat	25	147	73.5	0	150	0	150

Table 3. Design and treatments of fixed location trials (second program)

Trial location	Crop	Plot (m^2)	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K application in each treatment (K_2O, kg ha^{-1})		
					NP	NPK_1	NPK_2
Shuangcheng of Heilongjiang	Maize	30	375	240	0	187.5	375
Zhaodong of Heilongjiang	Maize	30	375	240	0	187.5	375
Gongzhuling of Jilin	Maize	40	225	112.5	0	112.5	225
LAAS	Maize	30	300	150	0	112.5	225
Sujia of Liaoning	Rice		360	180	0	112.5	225
Sujia of Liaoning	Maize		300	150	0	112.5	225
Changji of Xinjiang	Wheat	30			0	112.5	225
	Maize	40			0	112.5	225
Zepu of Xinjiang	Cotton	30			0	112.5	225
	Wheat	40			0	112.5	225
	Maize	40			0	112.5	225
Xiqing	Vegetable	22	300	225	0	112.5	225

All plots received abundant nitrogen, phosphorous and other nutrients in order to avoid other yield limiting factors than potassium and crop residues. The plots' sizes varied between 13 m^2 and 15 m^2 and the treatments were randomly arranged with 4 replications. High-yielding crop varieties, popular in the local agricultural production, were planted.

Harvest and soil analysis

The crop in each plot was harvested separately and analyzed for yield parameters. At the same time, grain and straw were collected and analyzed for potassium and water contents. After the harvest of each autumn crop grown in a two crop per season cropping system or after harvest of the single crop grown in the one-crop per season cropping system, soil samples from 0-20 cm and 20-40 cm depth were taken and analyzed for readily available and slow-release potassium. Conventional methods were adopted for the extraction and analysis of soil potassium.

Results and discussion

Characteristics of potassium cycling in the soil-plant system under different cropping systems

The potassium in the soil-plant system could be divided into two pools, namely the soil potassium reserve and the crop potassium sink. A transfer of potassium occurred between the two pools by crop uptake from the soil and return from crop roots and residues back to the soil. The potassium removed from the system by straw was the typical exportation whereas the application of potassium reflected the importation.

Characteristics of the crop as potassium sink

For the soil-plant system, the crop potassium sink could be divided into 3 parts. The first are the residues in the soil after harvesting, which include the potassium in plant roots; the second is the removal from the system by the harvested parts, which include the potassium in the grain and/or the harvested plant parts meant for consumption. The third is the removal or residues depending on the field management technologies, which includes the potassium in the straw, where it is found as one of the major nutrient elements. The difference in soil potassium reserve, crop type as well as variety affects the crop potassium sink and the proportion of each part. The results show that there is a significant difference among crop potassium sinks under different cropping systems in different regions. The average absorption of potassium by the crops in 5 years for the three major agro-ecological regions is summarized in the Tables 4, 5 and 6.

Table 4. Comparison between potassium sinks of various wheat and maize cropping systems in the north of China (kg K_2O ha^{-1}, average of 5 years)

Location	Crop	NP	NPK	NPKSt	NPSt
Luancheng of Hebei	Wheat	150.7	165.4	169.1	144.3
	Maize	107.8	141.3	166.9	117.1
	Total	258.3	306.7	336.1	261.4
Xinji of Hebei	Wheat	145.7	194.6	194.3	143.3
	Maize	66.5	137.9	146.7	91.5
	Total	212.2	332.4	340.9	234.8
Linyi of Shandong	Wheat	111.4	174.5	205.5	145.8
	Maize	77.5	134.3	148.7	87.7
	Total	188.9	308.8	354.2	233.5
Linzi of Shandong	Wheat	98.7	154.6	182.4	133.1
	Maize	74.6	119.7	135.0	87.1
	Total	154.6	244.3	283.6	198.4
Linfen of Shanxi	Wheat	195.3	205.2	247.0	203.2
Zhangwo of Tianjin	Wheat	143.5	138.9	24.2	20.8
	Maize	106.2	131.6	139.2	100.4
	Total	243.4	262.5	154.4	113.9
Mean (locations)	Wheat	142.1	179.9	200.4	154.8
	Maize	82.4	134.8	150.9	96.8
	Total	224.4	314.7	351.3	251.6

In Northern China with the prevailing wheat-maize rotations (Table 4), the plots without K and no straw application showed an average potassium absorption of 142 kg K_2O ha^{-1} for wheat and 82 kg ha^{-1} for maize. On average, both crops together absorbed 209 kg K_2O ha^{-1}. There was a significant difference in the K absorption between locations within the same cropping systems and crops. In the wheat-maize cropping system in the north of China, the potassium absorption by wheat in Hebei and Tianjin was 140-150 kg K_2O ha^{-1} and that in Shandong was 100-110 kg K_2O ha^{-1}. The 5 year average of potassium absorption by maize was 105 kg K_2O ha^{-1} in Luancheng of Hebei and Tianjin whereas in other regions it was 66-78 kg K_2O ha^{-1}. Improving the K supply by mineral fertilizer application (NPK) increased K absorption by wheat and especially maize at all locations. On average over all locations, K absorption by the crops increased by 38 kg K_2O ha^{-1} for wheat and 52 kg K_2O ha^{-1} for maize. Further increase in K uptake by both crops was obtained in treatment NPKSt with additional 21 kg and 16 kg K_2O ha^{-1} for wheat and maize, respectively. With recycling of crop residues (NPSt), total K absorption of both of each individual crop was much reduced, indicating that best K absorption is obtained in the combination of NPKSt, followed by NPK.
In contrast to the two-crops per season cropping systems of the north, the potassium absorption by the single-crop per season maize in the northeast of China was comparatively small (Table 5). The average of potassium absorption in the plots without K application over all locations was in the region of 92 kg ha^{-1}. This amount dramatically increased with the application of K, showing that the first rate (K_1) had the strongest effects whereas after application of the 2^{nd} rate (K_2) K response was much less significant. Differences in K absorption between locations were significant in the NP plots, reflecting mainly the differences in K availability. At the higher rate of K application (NPK_2), only the location Liufangzhi considerably exceeded the K uptake, which otherwise was in the region of 160 kg K_2O ha^{-1}. This could reflect the greater maize production potential due to better growth conditions (climate) at this location.

Table 5. Comparison between potassium sinks of maize in the northeast of China (kg K_2O ha^{-1}, average of 5 years)

Location	NP	NPK_1	NPK_2
Shuangcheng of Heilongjiang	70.7	111.6	159.0
Zhaodong of Heilongjiang	88.9	115.1	155.5
Liufangzi of Jilin	101.3	149.1	195.5
Taojiatun of Jilin	84.4	153.0	160.3
Shuizhong of Liaoning	108.9	123.2	151.8
Mean (locations)	91.7	150.5	164.4

In the northwest of China with the prevailing cropping system wheat-maize-(cotton), the annual potassium absorption by the crops largely depended on whether cotton was included in the rotation (Table 6). In comparison to the wheat-maize cropping system the cotton-wheat-maize rotation had a larger K absorption of 200-400 kg additional K_2O. Greatest differences in K absorption between these to basic crop rotations occurred in the NPKSt treatment, where K uptake was obviously not limited by the supply from the soil. On the other hand, smallest differences between the cropping systems occurred in the NP treatment, where K supply by the soil was obviously limiting. It is interesting to note that the K sink for maize was larger than for wheat when the rotation system included cotton whereas it was vice versa when the cropping system consisted of wheat-maize only. Dramatic effects of absorption by each crop and by the whole cropping system were observed through mineral K application and the additional recycling of wheat straw (NPKSt).

Table 6. Potassium sink of a wheat-maize-(cotton) rotation in the northwest of China (kg K_2O ha^{-1}, average of 5 years)

Trial location	Crop	NP	NPK	NPKSt	NPSt
Yinchuan, Ningxia	Wheat	129.6	175.6	168.5	155.1
	Maize	188.1	253.3	258.4	232.0
	Total	317.7	428.9	426.8	387.1
Xining, Qinghai	Wheat	199.7	268.0	233.7	241.8
	Maize	231.2	310.8	279.2	308.1
	Total	430.8	578.8	512.9	549.9
Changji, Xinjiang	Wheat	167.9	199.6	219.5	
	Maize	272.2	330.3	388.7	
	Total	440.1	529.9	608.1	
Zepu, Xinjiang	Cotton	370.4	479.4	532.5	
	Wheat	141.6	152.0	166.7	
	Maize	119.7	129.7	158.4	
	Total	631.7	761.0	857.6	
Mean (locations)	Cotton	370.4	479.4	532.5	
	Wheat	169.7	206.5	206.6	198.4
	Maize	207.7	256.9	275.4	270.0

The potassium distribution within the plant among grain and straw at harvest showed that it was affected by the crop species, trial location and fertilization practice. This was revealed by calculating the potassium absorbed by either grain or straw and expressing it as percentage of the total K uptake by the crop. The results show that the proportion of potassium allocated to the grains was larger in maize and rice than in wheat (Table 7). There was also a significant difference in the K distribution within the plant between the fertilizer treatments of the same crop at the same location. The application of potassium decreased the percentage of potassium in the harvested grain. For example, in Xinji of Hebei and Hongxinglong of Heilongjiang, the proportion of K in the grain was 13.7% and 12.4%, respectively, without potassium application and with returning of residues, respectively. K application alone and K application plus returning of residues led to a decline in the proportion of K in the crop. A similar observation was made for maize. It can be concluded that the application of potassium increased the total potassium absorption by the plants and enlarged the crop potassium sink. However, it decreased the proportion of potassium in the grain as a potassium sink in the plants, showing that under low K supply the plant gives priority to the K allocation to the generative parts (seeds, grains).

Table 7. Potassium absorption of wheat and maize grains in different trial locations expressed as percentage of total K uptake by the crop (average of 5 years)

Trial location	NP	NPK	NPK_1	NPK_2	NPKSt	NPSt	Average
			Wheat				
Gansu	9.5	8.3		8.0	9.0		8.5
Hongxinglong, Heilongjiang	12.4	12.5			10.7		11.8
Xinji, Hebei	13.7	9.7		12.9	11.2		11.8
Tianjin	15.5	18.7			15.7		16.6
Changji, Xinjiang	12.2		12.3	11.4			12.0
Zepu, Xinjiang	24.1		23.2	22.5			23.3
			Maize				
Luancheng, Hebei	22.2	14.7			12.9	12.7	15.6
Xinji, Hebei	21.8	17.2		15.5	15.9	16.5	17.4
Shuangcheng, Heilongjiang	51.0		37.3	25.3			37.9
Zhaodong, Helongjiang	48.0		49.9	30.0			42.6
Taojiatun, Jilin	33.8		22.8	21.5			26.0
LiuFangzi, Jilin	33.1		25.5	19.8			26.1
Tianjin	32.2		17.4	30.4		37.2	34.1
Zepu, Xinjiang	19.1		14.8	16.1			17.5
			Rice				
Liaoning	23.4			12.6			17.5

Characteristics of soil potassium reserve

The soil potassium reserve constitutes an important K source in the soil-plant system for crop production and is the basis for the potassium cycle. The concentration of the various K fractions in the soil can be directly used to evaluate the soil potassium reserves in different soils of different locations.

With respect to the total potassium, soils in the north of China were considered abundant in this nutrient in the past. The readily available potassium and slow-release K in the potassium cycle of the soil-plant system varied to a great extent, but on average, soils were classified as well supplied in the nutrient K. The summarized results show that the average of readily available potassium of 25 soils was 158 mg K kg^{-1} and 983 mg K kg^{-1} for the slow-release potassium. Largest concentrations of slowly available K were found in the soils of the northwest of China with 809-1805 mg K kg^{-1}. In the northwest, soils contained 344 mg K kg^{-1} and 569 mg K kg^{-1} more K than in the north and northeast of China, respectively. The slow-release potassium in soils of the north of China was 600-999 mg K kg^{-1} and the average was 959 mg K kg^{-1}, 225mg K kg^{-1} larger than that in the northeast of China. The readily available soil potassium in the north was 97-168 mg K kg^{-1} and on average 31 mg K kg^{-1} smaller than that in the northeast. It was obvious that the concentration of slow-release potassium in soils of the north was much larger than that in the northeast. The concentration of readily available potassium in soils of the northwest was much larger than that in the north.

Table 8. Concentration of various soil potassium fractions of 25 fixed location trials in the north of China

	Total potassium (%)	Slow-release potassium (mg kg^{-1})	Readily available potassium (mg kg^{-1})
Northwest (5 provinces)	2.02	1303	174
Northeast (3 provinces)	2.01	734	164
North*	1.90	959	133
Average for 13 provinces	1.97	983	158

* Not including the vegetable soil of Shuigao village, Xiqing district of Tianjin.

Soil samples of long-term fixed location trials were taken and analyzed for potassium after the harvest of the last crop each year. The results show that because of variable climatic conditions, soil sampling, analytical procedures to analyze readily available and slow-release K, the measured soil K concentrations differed greatly among years. However, certain principles among the treatments in the same location could be observed. The results of soil analysis from each trial showed that the readily available potassium in soil increased in the treatments with potassium application and where both mineral K was applied and crop residues returned to the field. In the treatment without returning residues, the application of potassium also increased the soil K concentrations, however, to a lesser degree (Figure 1). On the other hand, the results of two fixed location trials in Shandong, however, showed that the concentration of readily available K in the soil of NP and NPSt decreased by 5.2 mg kg^{-1} and 4.7 mg kg^{-1} each year.

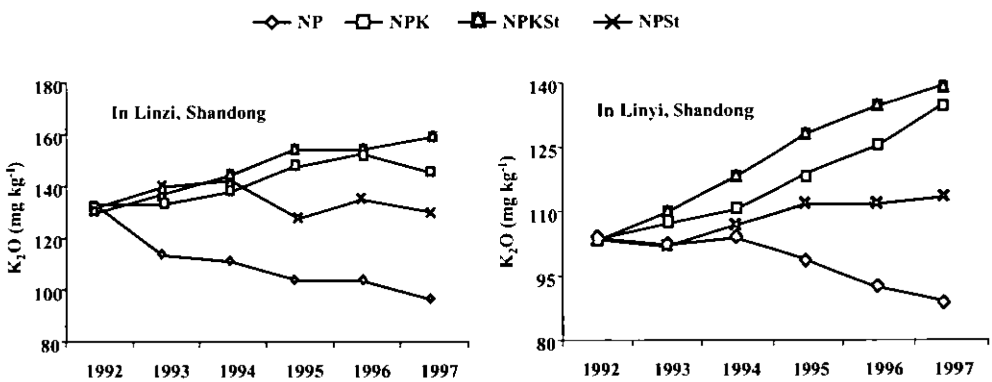


Figure 1. Change of available potassium in soils at different locations

In the Chaozongrang soil, which was classified as medium in K and characterized by sandy texture, the available K decreased by 0.5 mg kg^{-1} per year which was slower than that of the brown soil with higher fertility. Potassium application alone, returning residues and potassium application plus returning residues increased the concentration of soil K to a different extent. With respect to readily available potassium a similar situation was found in the vegetable soils of Tianjin.

The results of fixed location trials in Heilongjiang showed that readily available potassium decreased by 2.48 mg kg^{-1} annually when potassium was applied continuously for 5 years. The concentration of potassium increased by 4.34 mg kg^{-1} yearly in the K_1 and 11.32 mg kg^{-1} in the K_2 treatment (Figure 2). The application of potassium also reduced the decline in slow-release potassium, but the effect was not significant (results not shown). The slow-release potassium decreased continuously for 5 years by 47.8 mg kg^{-1} in the treatment without potassium application, by 44.6 mg kg^{-1} in the K_1 and by 31.4 mg kg^{-1} in the K_2 treatment. Two fixed location trials in Jilin showed similar trends.

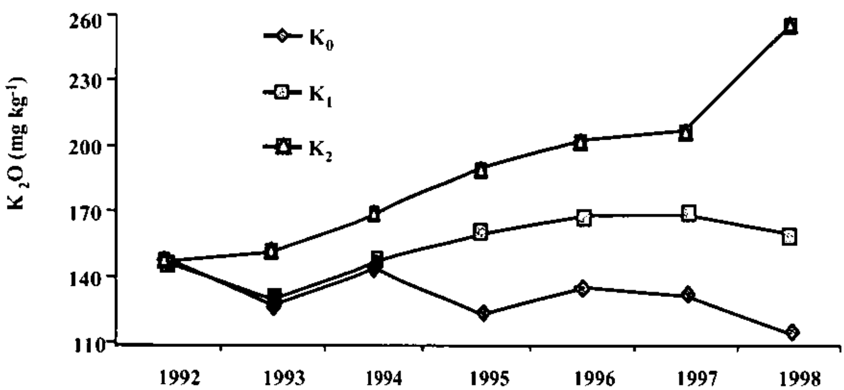


Figure 2. Change of available potassium in soils of Heilongjiang (0-20cm depth of soil)

Potassium balance in the soil-plant system in different cropping systems

The nutrient balance of the soil-plant system was calculated as K surplus or deficit in the various cropping systems by using four parameters, including K removal by grain (harvested product) and removed crop residues (straw) as output, K fertilizer application and returned residues as input. The results show that without potassium application and returning of residues a yearly loss of 134-258 mg K_2O kg^{-1} was observed in the north. In all treatments without K application (NP, NPSt), the balances were negative in all locations, reaching from –63 kg K_2O ha^{-1} yr^{-1} in NPSt at Linfen (wheat only) to -258 kg K_2O ha^{-1} yr^{-1} in Luancheng (Table 9). At all locations, with the exception of Lynyi, the balance remained negative after K was applied (NPK) to a variable extent. They were only slightly negative at Xinji and Luancheng but considerably negative at Linzi and Linfen. This indicates that K application rates were not sufficient to balance the removal of K. On the other hand, all treatments receiving NPK plus wheat straw (NPKSt) revealed a positive K balance, with the exception of Linzi, where even both NPK and straw did not compensate for the K losses by removal.

Table 9. Annual potassium balances* in the wheat-maize and wheat cropping systems in the north of China (average of 5 years)

Location	Cropping system	Potassium balance (kg K_2O ha^{-1})			
		NP	NPK	NPSt	NPKSt
Linzi, Shandong	Wheat-maize	-155	-146	-108	-45
Linyi, Shandong	Wheat-maize	-134	74	-84	168
Xinji, Hebei	Wheat-maize	-212	-5	-134	89
Luancheng, Hebei	Wheat-maize	-258	-7	-171	68
Linfen, Shanxi	Wheat	-195	-55	-63	81

*negative balance indicate the net loss of K balances

In the maize based cropping systems in the northeast of China annual K losses from the soil-plant system were much reduced compared to the wheat-maize rotations of the north. Largest losses again occurred in the NP treatment with amounts reaching –101 kg K_2O ha^{-1} at Liufangzhi. Application of the smaller rate of K_1 could only compensate for the losses by removal at Shuangzheng whereas the other two locations still showed a deficit of more than 30 kg K_2O ha^{-1}. The larger rate of potassium (K_2) led to positive K balances at all the studied locations (Table 10).

Table 10. Apparent potassium balances in the maize cropping system in the northeast of China (kg ha^{-1}, average of 5 years)

Location	Potassium Balance (kg K_2O ha^{-1})		
	NP	NPK_1	NPK_2
Shuangcheng, Heilongjiang	-69	1	66
Liufangzi, Jilin	-101	-36	30
Taojia, Jilin	-88	-39	58

In the northwest the largest negative balances were found in the wheat-maize rotation at Yinchuan with more than -500 kg K_2O ha^{-1} in the CK whereas maize at Zepu with –120 kg ha^{-1} showed the smallest K losses (Table 11). K application led to a clear reduction in the negative K balances of all cropping systems whereas K_1 alone did not overcome the losses by crop K removal. Based on the results it is evident that only K_2 substantially improved the K balances of the cropping systems Three out of ten crops showed a positive K balance in that treatment. There was still a big gap in the supply and removal in wheat in the wheat–maize rotation of Yinchuan and in maize of the wheat maize-rotation in Chanji. The possible explanations are that either the amount of mineral K or the amount of wheat straw was insufficient to cover the demand by the succeeding crop.

Table 11. Apparent annual potassium balances in various cropping systems in the northwest of China (kg ha^{-1})

Location	Year	Crop	Potassium Balance (kg K_2O ha^{-1})			
			CK*	K_1	K_2 or St	KSt
Changji, Xinjiang	1994	Wheat	-168	-106	-33	
	1995	Maize	-272	-237	-202	
Zepu, Xinjiang	1994	Wheat	-142	-59	20	
		Maize	-120	-36	28	
		Total	-261	-95	48	
	1995	Cotton	-370	-386	-346	
Yinchuan, Ningxia	1994	Wheat	-516	-509	-293	-146
		Maize	-346	-349	-11	78
Shaanxi	1997	Wheat	-152	-5	-42	88
		Maize	-98	-42	-105	-74

* CK = Control with NP only

Yield-increasing effect of returning residues and potassium application

The results indicate that under the wheat-maize cropping system in the north, the potassium application, the returning of residues and the potassium application together with returning residues could significantly increase the yields of wheat and maize. The observed yield-increasing effects of these three management practices were greater in maize than in wheat. However, for each crop, response to potassium was greatest if K was applied together with recycled crop residues of particularly wheat. Wheat yield increased by 12.5% whereas that of maize by 19.1% on average. The effect of returning residues alone was poorest, with a yield increase in wheat of only 4.9% for wheat and 8.6% for maize. The effect of potassium application alone had a medium effect, increasing wheat and maize yields by 8.5% and 12.4% on average (Figure 3).

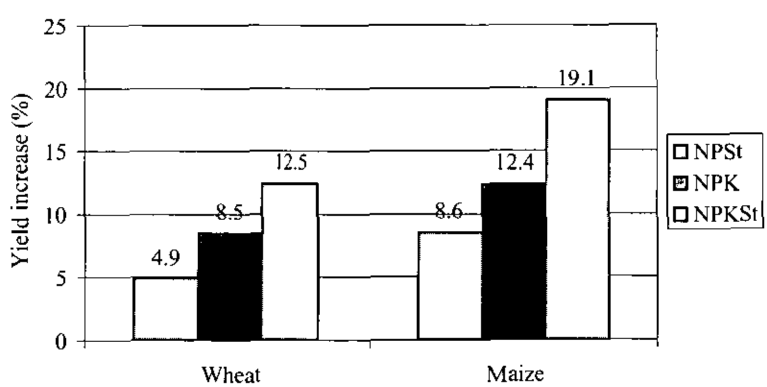


Figure 3. Average yield increase (%) caused by K application in Northern China

Yield increases differed between trial locations in different provinces of Northern China. Wheat yields on average over 5 years increased by more than 10% with potassium in Shuiping of Henan. In the treatment of returning residues together with potassium application (NPKSt), the yield increase of Shuiping, Linzi of Shangdong and Linfen of Shanxi was more than 10% each year. In Luancheng of Hebei and Luoyang of Henan in one out of 5 years yield increased by more than 10%. The probability of maize yield increase in Luoyang and Luohe of Henan was lowest.

In the one-season maize cropping system in Northeastern China, the potassium application increased yields significantly. Compared with the treatments without potassium application, larger rates also contributed to larger crop yields. However, in general, differences between yields of high and low potassium application at each trial location were small. On average, the smaller K application rates increased crop yield by 10.6% whereas only by 11.1% at the larger rate (K_2). Potassium applied to rice increased yields significantly by more than 10%.

In the wheat-soybean cropping system of the north and wheat-soybean cropping system in the northeast, K application, NPSt and NPKSt increased yields of wheat and soybean. Soybean yields benefited more from K application than those of wheat in this cropping system. In the Henan province, the yield-increasing effect of both potassium application plus returning of residues on a Shajiang black soil was better than that on the meadow soil in Helongjiang. The latter was also better than the average effect on wheat and maize in the north of China.

Compared with the significant yield effects in the north and northeast, there were also yield responses to K and to returning wheat straw in the various provinces of the northwest of China. In Shaanxi, the yield of wheat which received potassium without crop residues increased in 3 out of 5 years at a range of below 10%. The yield of plants which received potassium and residues (NPKSt) increased in all 4 years, and in 3 out of 4 years the yield increments observed exceeded 10%. The yield of maize receiving potassium increased by more than 5% only in one year whereas it increased by 10% in two years when both potassium and residues were applied. In Ningxia, both potassium application alone and potassium application together with residues caused a significant yield increase each year. Wheat applied with potassium or potassium plus residues showed yield increases of more than 5% in 3 out of 4 years and of more than 10% in only one year. A similar observation as for wheat was made for maize in Ningxia. Potassium application and returning of residues increased yield at many locations but within a narrow range. In 4 years, the fixed location trial of Qinghai showed a yield effect during drought whereas in the first year, when the wheat was irrigated, no yield response to K was observed. In Zepu of Xinjiang, potassium application to wheat increased the yields by more than 2-5% but more than 15% in wheat of Changji of Xinjiang. In this region, potassium application to maize increased yields by more than 8% and more than 10% with a larger rate of potassium application. Small application rates increased yields of cotton in Xinjiang by more than 8.8% whereas the larger K rates produced 16.2% more lint.

The calculation of the agronomic efficiency (1 kg grain per kg K_2O) shows that in the wheat-maize rotations of the north, each kg K_2O produced only 3.2 kg additional wheat grain (5.7% yield increase) on average. A slight additional wheat yield increase to 3.9 kg per kg K_2O was found when wheat straw was returned to the field. In maize, each kg K_2O produced 5.5 kg of grain on average. In maize of the northeast, each kg of K_2O produced additional 5.5 kg of grain at K_1 and 3.2 kg at the rate of K_2. Compared with that, the scope of increasing yield in the northwest with 0.4-0.8 kg kg^{-1} K_2O for wheat and 0.6-1.7 kg kg^{-1} K_2O for maize was much smaller than in the Northwest. In different trials of the same region, there was a big difference in the agronomic efficiency of potassium application.

Conclusion

In the winter wheat-maize, winter wheat-soybean, maize, rice, wheat-soybean, winter wheat-spring wheat and wheat-cotton cropping systems of Northern China, the potassium balance and the potassium cycle in the soil-plant system of fixed location trials over a period of 5 years showed:

1) There were distinct differences in the potassium absorption by plants between locations and between plants at the same location. The yearly potassium absorption by plants under different cropping systems was significantly different. There was a difference in crop potassium sink (potassium absorption) under different cropping systems in different locations. Without potassium, the yearly potassium absorption of a maize-wheat rotation in the north was greater than that of a one crop per season maize in the northeast. The potassium absorption increased significantly with potassium application and the practice of returning residues in a wheat rotation. The potassium distribution between grain and straw was affected by crop, trial location and fertilizer application.

2) Without potassium, the soil-plant system showed a K-deficit. The return of residues after harvest decreased significantly the apparent loss of potassium from the soil-plant system. In the wheat-maize cropping system, returning of wheat residues returned one third to one half of potassium absorbed by the crop. However, this amount was not sufficient to keep the balance between input and output. The apparent yearly loss of potassium in the wheat-maize cropping systems of the north was much greater than that of a one crop per season maize in the northeast of China.

3) In the wheat-maize rotation of the north of China, the potassium application, returning of residues and application of potassium together with residues significantly increased crop yield. Maize yields responded to these 3 treatments to a larger extent than wheat. Regarding the same crop, the application of potassium together with the return of residues was better. In the northeast of China with a one crop per season maize, the potassium application increased yields significantly. In the northwest, yield response to potassium alone and potassium with return of residues on wheat and maize was found to be within a narrow range. The probability of K promoting yields of cereals was limited with respect to certain locations and years.

Nutrient cycle and farmland nutrient balances of the Heilongjiang Province

Wu Ying, Wang Ying and Sun Bin

Soil and Fertilizers Institute, Heilongjiang Academy of Agricultural Science, Harbin, 150086

Abstract

In this paper, the input and output of N, P and K and their balance in the farmland ecosystem in the Heilongjiang Province during the period from 1977 to 1999 are discussed. Based on the analysis of the changes, taking place in the soil nutrient cycle and balance, fertilization measures are recommended for maintaining N, reducing P and supplementing K in the cropping systems of the Heilongjiang Province.
The nutrient cycle and balance is an important indicator of the potential farmland productivity. Therefore, a good understanding of the observed changes is of great significance in order to regulate the farmland nutrient cycle and balance as well as in establishing an ecosystem with a sustainable and large yield potential. The Heilongjiang Province with its favorable natural conditions and fertile soils, contributes greatly to the overall grain production of China. However, the production still has to overcome a number of limitations. For instance, the ever-deteriorating soil quality of the farmland and serious nutrient imbalances have started to affect ecological functions of the soil. The research was carried out by combining stationary investigations of cropping systems and soils of typical farmland around cities, towns and villages with an analysis of data from a survey and the provincial statistics.

Research method

Calculation of nutrient input into farmland

The calculation of nutrients in inorganic fertilizers was conducted on the basis of the rate of nutrient elements contained in the fertilizers applied.
Organic manure, including human and animal waste (night soil, pig dung, cow dung, sheep and poultry droppings), harvest residues (rice straw, wheat straw and corn stalks) and plant ash (only ash of burned rice, wheat, corn and bean plants) were analyzed for their nutrient content as well as seeds (including seedlings), irrigation water and precipitation.
For estimating the amount of symbiotically fixed N of soybean as main legume in Heilongjiang was calculated on the basis of 7 kg N mu^{-1} (105 kg N ha^{-1}).

Calculation of nutrient output from farmland

The nutrients taken up by crops were calculated on a basis of nutrient concentration in the biomass multiplied by the weight of the biomass.
The loss of nutrients from the soil, e.g. N by denitrification, volatilization, P through fixation and K through leaching and runoff and from organic manure through composting, was estimated.

Results and discussion

Nutrient input into farmland

In the past 20 years, the nutrient input into the farmland in the Heilongjiang Province has shown three main characteristics. The first is the ever-increasing application rate of inorganic N, P and K. N increased by 53.5% in the years from 1977 to 1987 and by 100% from 1977 to 1997; P (P_2O_5) by 42.8% and 92.8%, respectively, and K (K_2O) by 100% and 200%, respectively (Table 1). The input of large volumes of inorganic fertilizers has increased the material flow within the soil-plant system and plays also a key role in promoting material cycling within the whole ecosystem, maintaining soil fertility, and improving farmland productivity. The average grain yield in the Heilongjiang Province was 1,699.8 kg ha^{-1} in 1977 and has been raised up to 1961.4 kg ha^{-1} in 1987 and further to 2,638.9 kg ha^{-1} in 1997 (Table 2).

Table 1. Average application of mineral nutrients in the Heilongjiang Province during the past 20 years

Year	N	P_2O_5	K_2O	$N:P_2O_5:K_2O$
		kg ha^{-1}		
1977	22.5	21.0	1.5	1:0.93:0.06
1987	34.5	30.0	3.0	1:0.86:0.08
1997	45.0	40.5	4.5	1:0.90:0.10
2001	52.3	28.4	11.8	1:0.54:0.23

Table 2. Grain yield in the past 20 years in the Heilongjiang Province

Year	Acreage of farmland (1000 ha)	Total output of grains (M t)	Average yield (kg ha^{-1})
1977	8692	14.775	1699.8
1987	8859	17.376	1961.4
1997	11545	30.466	2638.9

The second characteristic is the serious imbalance of the NPK ratio of the supplied nutrients. The ratio was 1:0.93:0.06 in 1977, 1:0.86:0.08 in 1987 and 1:0.9:0.1 in 1997, though the input of inorganic fertilizers in 1997 was 4 times as much as that in 1977. The input of K is obviously inadequate. The Heilongjiang Province is an important grain producing region in China, where the practice of balanced fertilization is the key for achieving continuous high yields. K deficiency weakens the soil's self-regulating function, thus limits the farmland productivity. In the 1960's and 1970's, the N:P ratio of the supplied nutrients was 1:0.2-0.3. The correct ratio at the time should have been 1:0.4-0.5, showing that P deficiency was apparent in crop production. In the 1980's, the import of large quantities of diammonium orthphosphate and triple super phosphate rapidly raised the proportion of P, reducing the seriousness of P deficiency. Because of the strong ability of the soil to fix P and the steady expansion of the cultivated area of NK demanding crops and other cash crops, a surplus of P and a shortage in K developed in the soil in the late 1980's and early 1990's. The proper N:P:K ratio at that time was supposed to be 1:0.5:0.3 whereas the actual ratio in the nutrient input was 1:0.6-0.8:0.1.

The last characteristic is the downward trend of the organic manure input into the farmland ecosystem. Although the number of livestock in the year 1997 was much larger than that in 1977 and 1987, the farmers were reluctant to spend more efforts in using organic manure. They lacked faith in the policy of dividing land among farmers. In a few regions, only a small amount of farmyard manure was applied to the fields. Thus, the fertility of several major soil types in the province has decreased year by year. In some places the soil OM was reduced to only 1.2% - 1.5%. Investigations revealed that in recent years, of the major crops (maize, rice, soybean and wheat) grown in the province, all harvest residues (stalks, stems and straw of the crops, except stubs) were removed from the fields and almost never returned. About 90% of the maize stalks were used as fuel and 10% as silage; 70% of the rice straw was used as fuel, 20% as raw material for straw plaiting and 10% for livestock bedding; 60% of the soybean stems were used as fuel and 40% as fodder; and 95% of the wheat straw was used as fuel and 5% for bedding livestock or other purposes. Consequently, restoring soil fertility by increasing the input of organic manure has been classified as an important issue on the agenda for agricultural development in the province. The aim is to improve the yield and quality and therefore, the economic profit.

Nutrient output from farmland

The nutrient output from the farmland includes the nutrients taken up by the crops and nutrient losses from the soil. In the past 20 years, the nutrient output from the farmland ecosystem has been increasingly significant. The output of N, P and K increased by 248%, 163% and 157%, respectively, in the years from 1977-1979 to 1985-1989 and by 473%, 228% and 257% from 1977-1979 to 1995-1997 (Table 3).

Table 3. Nutrient input into and output from farmland in the Heilongjiang Province (1000t)

Year	Input			Output			Balance		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1977-1979	108	57	10	118.3	81	102.4	-10.3	-24	-92.4
1980-1984	206	147	12	193.5	134	124.5	12.5	13	-112.5
1985-1989	329	187	18	204	132	161	35	55	-143
1990-1994	515	304	36	463.5	154	211	51.5	150	-175
1995-1997	628	402	61	560.2	185	263.7	67.8	217	-202.7

Nutrient cycle of the farmland

The nutrient input (sum of mineral fertilizers applied, organic manure used and symbiotically fixed N) and the nutrient output (sum of nutrient removal with harvest, nutrient losses from mineral fertilizers and organic manure) were estimated for the whole province. Based on this, organic manure contributes about the same amount of N as the mineral fertilizers. For P the amount from organic manure was much less, contributing only 19% to the overall P consumption. For K the opposite was observed and from the total of 314,700 tons consumed only 16.5% came from mineral and 83.5% from organic sources. Under the assumption that for the nutrient N substantial losses from mineral fertilizers and organic manure, but no losses other than removals occur for P and K, the nutrient balance for Heilongjiang is clearly positive for N +67,900 tons, very positive for P (+415,800 t P_2O_5) and clearly negative at an amount of –231,600 t K_2O for potassium (Table 4).

Table 4. Nutrient balance of the farmland in the Heilongjiang Province (1997)

Nutrient flow	Item	N	P_2O_5	K_2O
		----------	10^3t	----------
Inflow	Mineral fertilizers	519.5	467.5	51.9
	Organic manure	523.4	92.8	262.0
	Symbiotically fixed N	206.7		
	Total	1249.6	540.3	314.7
Outflow	Removal with harvest	816.9	124.5	546.3
	Loss from mineral fertilizers	207.8	0	0
	Loss from organic manure	157.0	0	0
	Total	1181.7	124.5	546.3
Balance		67.9	415.8	-231.6

In the year 1997, an investigation was conducted to study the nutrient cycle of farmland covering 2 cities, 1 county, 6 towns and 48 farms. The survey of the two cities and one county revealed that the P surplus in farmland soils was remarkable. It reached

8,317 t in Shuangcheng City, 7,101 t in Suihua City and 6,292 t in Qingan County. The balance of N varied from place to place. Shuangcheng and Qingan had a deficit of about 9,798 t and 7,089 t, respectively, whereas Suihua had a surplus of 1,509 t. The shortage of K was also significant, reaching 12,171 t in Shuangcheng, 14,472 t in Suihua and 10,254 t in Qingan (Table 5).

Table 5. Nutrient balance in Shuangcheng, Suihua and Qingan (1997)

Place	Crop	Item	N	P_2O_5	K_2O
				t	
Shuang-cheng	Corn	Inflow	31,060	13,793	12,472
		Outflow	40,858	5,476	24,642
		Balance	-9,798	8,317	-12,171
Suihua	Corn, Rice Soybean	Inflow	23,749	11,150	3,886
		Outflow	22,240	4,048	18,358
		Balance	1,509	7,101	-14,472
Qingan	Corn, Rice Soybean	Inflow	17,758	9,654	4,936
		Outflow	24,846	3,362	15,190
		Balance	-7,089	6,292	-10,254

The nutrient balance of the fields of the 48 farm households investigated showed that for nitrogen the inflow was 157 kg N ha^{-1} and the outflow 164 kg N ha^{-1} with a deficit of nearly 8 kg N ha^{-1}; for, the inflow was 62 kg P_2O_5 ha^{-1}, the outflow 26 kg P_2O_5 ha^{-1} with a surplus of 37 kg P_2O_5 ha^{-1}. For potassium the survey revealed that the inflow was 18 kg K_2O ha^{-1} and the outflow 62 kg K_2O ha^{-1}, indicating a deficit of -44 kg K_2O ha^{-1} (Table 6).

Table 6. Nutrient balance in the fields of the 48 household farms investigated (1997)

Nutrient flow	Item	N	P_2O_5	K_2O
			kg ha^{-1}	
Inflow	Mineral fertilizers	87	35	10
	Organic manure	13	27	9
	Symbiotically fixed N	56		
	Total	157	62	18
Outflow	Mineral fertilizers	129	26	62
	Organic manure	26		
	Symbiotically fixed N	18		
	Total	164	26	62
Balance		-8	37	-44

Conclusions

1) The farmland in the Heilongjiang Province is very fertile, having a high production potential. However, in recent years, dramatic nutrient imbalances occurred with a clear surplus of P, N inputs, being almost in balance with the outputs whereas K outputs significantly exceed the inputs, creating a negative K balance. To fully utilize the natural production potentials of the soils as a foundation for high yield and good quality at reasonable cost, more attention has to be paid to balance the nutrient budgets of the farmland.
2) During the 20 years from 1977 to 1997, the input of large quantities of inorganic N and P nutrients improved soil fertility and promoted the crop yields. With increased biomass production the material flow and the biological circulation of nutrients in the farmland ecosystem of the province were stimulated. However, with increasing surplus application of P fertilizers in recent years, there was a continuous P accumulation in the soil. Consequently, measures need to be implemented to develop the agriculture in the province towards high yield and good quality and greater economic benefit. These include to use fully the potential of P accumulated in the soil and to increase the application rate of K.
3) Returning harvest residues to the field is another effective measure to improve soil fertility and to supply crops with nutrients. The soil fertility of the farmland in the Heilongjiang Province has been on the decline for years and consequently, one-third of the cultivated land has turned into medium- and low-yielding areas. Great efforts should be made to encourage the return of crop residues to the field, to reduce the waste of straw and to make full use of this resource. The effective use of barnyard manure should also be supported as well as the incorporation of organic management principles to improve soil fertility.

Analysis of the soil nutrient status of farmland and prediction of the mineral fertilizer demand in the Jilin Province

Huang Jian, Zhang Jiangtan and Liu Zhiwen

Jilin Province Soil and Fertilizers Head Station, 130012

Abstract

Based on the analysis of the farmland soil nutrient status and its evolution during the past decades, the soil nutrient supply and crop response to fertilization was studied. This paper suggests that priority should be given to an increase in K application rates and to a partial reduction of the P application rates. Calculated nutrient balances were used to determine the total demand for mineral fertilizers and to predict appropriate NPK ratios for the Jilin Province in the period from 2000 to 2010. The paper is providing a sound basis for an ecologically sound and sustainable utilization of the farmland.
Soil nutrient status has been assessed and evaluated as indicator soil fertility needed to support high and stable grain yields. Paying attention to farmland soil nutrient status and understanding its evolution will not only play a guiding role in current agricultural production, but also lay down a solid basis for developing sustainable agriculture.

Introduction

Lying in the hinterland of the Song-Liao Plain, the Jilin Province with a vast territory of fertile soil has long been enjoying the fame of "Black soil in Northeastern China and dark gold of the treasure land" which means that soils were regarded as very rich in nutrients. This was confirmed by two soil surveys conducted in 1958 and 1979. The province has a total of 5,351,000 ha of cultivated land comprising about 19 soil types, such as black earth, Chernozem, Baijiang soil, dark brown forest soil, meadow soil, paddy soil, young alluvial/colluvial soils, alkali-saline soil, aeolian sandy soil, etc. During the past 20 years, there was a distinct rise in the crop production and yields per unit area, especially after the reform in farming systems, intensifying the crop rotations and reducing the fallow periods. Furthermore, changes in mineral fertilizer use (both in rate and nutrient composition), the aggravation of soil erosion and some other factors have caused great changes in the farmland soil nutrient status. Based on several years of soil monitoring, including analysis of the farmland soil nutrient status, demonstration experiments, testing crop response to mineral fertilizers, this paper tries to predict with more precision the demand for and the structural changes in mineral fertilizer use. The interpretation of these data is aiming at providing a theoretical basis for developing beneficial agriculture and ecology-orientated, sustainable utilization of the farmland.

The nutrient status of farmland soil in the Jilin Province

The Jilin Province can roughly be divided into three parts. The eastern part is a mountainous and semi-mountainous region whereas the central part forms a hill plateau and the western part can be described as a plain. Differences between regions with regard to climate, landform, vegetation and some other soil forming factors like land use, multiple cropping indexes, cultivation history and management caused that the soil nutrient status of farmland today is distinctly regional.

Distribution of soil N content

The second soil survey of the province (1979) revealed that the total N content of the soil decreased from east to west. The average content of available N was 199 mg kg^{-1} in the eastern region, 104 mg kg^{-1} in the central and 97 mg kg^{-1} in the west (Table 1). According to soil types, N contents were larger in the mountainous soils and smaller in the meadow soils. Among the six soil types, i.e. dark brown forest soil, paddy soil, Baijiang soil, meadow soil, black earth, and chernozem, largest N contents were recorded in dark brown earth with an average of 207 mg kg^{-1} and the smallest in chernozem, averaging 98 mg kg^{-1}. The order of N availability in the six soil types was dark brown forest soil > paddy soil > Baijiang soil > meadow soil > black earth > chernozem.

Table 1. Soil N content in the plow layer of farmland in the 3 natural regions of the Jilin Province

Natural region	Total N (%)		Alcalytic N* (mg kg^{-1})	
	Range	Mean	Range	Mean
Eastern region	0.070-1.482	2.22	61-1014	199.0
Central region	0.020-0.361	1.17	14-268	104.4
Western region	0.021-0.395	1.08	10-238	97.0

*1.0 M NaOH incubation at 40 °C for 24 h, reflecting the available N pool

Distribution of soil P content

Similar to nitrogen, the distribution of soil P content also showed a general trend of gradual decline from east to west. The average content of readily available P in the plough layer was 10.3 mg kg^{-1} in the eastern region, 5.2 mg kg^{-1} in the central and 3.7 mg kg^{-1} in the west (Table 2). With regard to soil types, the largest P content was found in dark brown earth with an average of 11.4 mg kg^{-1} and the smallest in the aeolian soil with an average of 2.6 mg kg^{-1}. P availability in the soils followed the order dark brown forest soil > Baijiang soil > recent soil > meadow soil > black earth >paddy soil > chernozem > aeolian sandy soil.

Table 2. Soil P content in the plow layer of farmland in the 3 natural regions of the Jilin Province

Natural region	Total P (%)		Readily avail. P (mg kg^{-1})	
	Range	Mean	Range	Mean
Eastern region	0.009-1.18	0.56	0.9-36.6	10.3
Central region	0.07-0.137	0.38	0.1-22.8	5.2
Western region	0.014-0.11	0.29	0.2-69.3	3.7

Distribution of soil K content

Under the influence of their parent materials (mainly weathered feldspar and mica-type rocks in the eastern, loess-like sediments in the central and loess-like loamy sands in the western region), the soils of the province contain rather large amounts of total K. The average readily available K content was above 100 mg kg^{-1}. Within the province there is a decreasing trend in the K contents in the order: western region > eastern region > central region (Table 3). With regard to soil types the following order was observed: solonchak > solonetz > dark brown forest soil > black earth > chernozem > recent soil > Baijiang soil > paddy soil > meadow soil > aeolian sandy soil. The largest amounts of readily available K were found in alkali-saline soils, averaging 150 mg kg^{-1} and the smallest in the aeolian sandy soil, averaging 83 mg kg^{-1}.

Evolution of the soil nutrient status under farmland in the Jilin Province

In 1987, a long-term program of monitoring farmland soil fertility at fixed sites was started. Across 8 soil types (black earth, paddy soil, recent soil, Baijiang soil, chernozem, alkali-saline soil, meadow soil and peat soil) 40 monitoring posts were laid out, covering 1,705,300 ha, about 32% of the total acreage of cultivated land of the province.

Table 3. Soil K content in the plow layer of farmland in the 3 natural regions of the Jilin Province

Natural region	Readily available K (mg kg^{-1})	
	Range	Mean
Eastern region	28.1-239.6	116.8
Central region	25.7-324.6	103.3
Western region	33.2-412.5	129.4

The soil monitoring data of 1987 were taken as a basis and data collected from 1988 to 1995 were divided into two portions, one encompassing the data from 1988 to 1990 and the other batch from 1991 to 1995 for a comprehensive analysis on a period-by-period basis (Table 4).

Table 4. Nutrient status of farmland soils in the Jilin Province

Soil	Period	O.M. ($g\ kg^{-1}$)	Alcalytic N ($mg\ kg^{-1}$)	Readily av. P ($mg\ kg^{-1}$)	Readily av. K ($mg\ kg^{-1}$)	Yield ($kg\ ha^{-1}$)	Yield increment (%)
Black Soil	1987	24.4	128	10	184	6069	
	1988-90	23.7	135	12	171	6741	11.1
	1991-95	22.9	130	19	142	8050.5	32.6
Paddy Soil	1987	24.0	141	14	125	5250	
	1988-90	23.6	138	16	118	5445	3.7
	1991-95	23.3	127	23	102	6634.5	26.4
Chernozem	1987	24.1	119	8	146	6018	
	1988-90	23.8	116	9	139	6148.5	2.2
Baijiang soil	1987	24.7	143	7	115	2967	
	1988-90	26.9	142	9	126	4282.5	144.3
Alkali-saline soil	1987	21.6	144	7	188	4944	
	1988-90	21.2	141	6	177	5058	2.3
Recent soil*	1987	36.7	100	14	116	6226.5	
	1988-90	36.0	99	16	106	6997.5	7.6

* Newly reclaimed soil

Table 4 indicates that organic matter, alkalytic N in most soils, with the exception of Baijiang soil slightly decreased from 1987 to 1988-1990 and further to 1991-1995. Due to the short period of observation the decline in soil fertility was rather small, ranging between 0.7% and 9.9%. All soils showed a significant increase in readily available P levels of between 12.5% in the chernozem soil and 64.3% in the paddy soil from 1987 to 1991-1995. A decrease in readily available P of −14.3% was observed in the alkali-saline soil, where yield increase during the same period was also only marginal. Readily available K contents decreased in all soils, between -4.8% in the chernozem and -18.4% in the paddy soil (187 to 1991-95). An increase in K contents was found in Baijiang soil, where also the largest yield increase of 144% was recorded.

It can be inferred from the above described analysis that the farmland soil nutrient status varies in general, with N slightly declining, P significantly rising and K steadily declining. Further analysis showed that there are three major causes contributing to the variation. One is soil erosion that results in nutrient losses from farmland; another is consecutive years of cultivation of high-yielding crops that have removed large amounts of nutrients, particularly K from the farmland. On the other hand, there are also changes in the use of mineral fertilizers. In the 1970s, N was the main fertilizer used, combined with small amounts of P fertilizers whereas in the 1980's and 1990's, combined application of N and P prevailed with only little K added. Decades of application of diammonium phosphate resulted in an accumulation of P in the soil and rapid depletion of soil K and hence to a steady expansion of the area where K became deficient.

Crop response to mineral fertilizers in farmland

Crop response to reduced P application

In 1995, we carried out demonstration experiments on the effect of reduced P application in five typical soils of the province. The experiments had 5 treatments, i.e. treatment 1) control, 169.5 kg ha^{-1} of diammonium phosphate, which corresponds to the traditional application rate; treatment 2) reduced application rate by 15%; treatment 3) reduced application rate by 30%; treatment 4) reduced application rate by 45%; and treatment 5) reduced application rate by 60%. Results of the experiment are summarized in Table 5.

Table 5. Yield response of maize to reduced P application in 1995 (kg ha^{-1})

Treatment	Control (100%)*	T2 (-15%)	T3 (-30%)	T4 (-45%)	T5 (-60%)
Mean	8837.1	8885.4	8446.7	8473.9	8148.4
Variation		48.3	-390.4	-363.2	-688.7
Variation (%)		0.75	-66.0	-61.5	-115.5

*standard application rate of P = 100%

The analysis of variance and LSR test for multiple regression of the data in Table 5 showed that differences between the control and treatments 2, 3 and 4 were not significant. However, treatment 2 showed the best crop response and increased the utilization rate of fertilizer P from 14.5% in the control to 18.7%. On this basis, the following recommendations for P fertilizer application in the province were made: 1) For the current production level, application of P fertilizers at a rate of 15 – 45% less than the traditional application rate is economical and advisable; 2) In the central and eastern regions of the province, where P has been applied at a high rate for many years, it is recommended to reduce the P application by 45% whereas in the western region, where soil readily available P contents and P application rates were less during the past years, it is recommended to reduce the P application rate by only 15%; 3) In selected places, where the soil fertility is poor and fertilisation rate has also been low, it is not advisable to reduce the P application rate. 4) As P has a very low mobility in the soil, uptake may be restricted by low soil moisture contents, therefore, attention should be paid to the use of P fertilizers as basal dressing and more generously in areas, where dry-spells during the vegetation period are expected.

Crop response to K application

Benefiting from their parent materials, inherent K fertility of farmland soils in the Jilin Province is high. Crop response to K application therefore used to be insignificant in the past. In recent years, however, due to the causes discussed above, symptoms of K deficiency began to appear and response to K application became increasingly obvious.

Field experiments and surveys of farm households show that application of K produced varying yield responses. Crop response to potassium application in the six major soils in the province, generally follow this order: Recent soil > aeolian sandy soil > Baijiang soil > paddy soil > chernozem > black earth. Yield responses ranged between 5% and 10%. In soils, where readily available K was less than 100 mg kg^{-1}, yield response reached up to 10%. In soils with a readily available K ranging between 100 – 150 mg kg^{-1}, yield response was up to 5% whereas in soils with a readily available K content above 150 mg kg^{-1}, most crops did not respond to additional K, except some K-demanding cash crops, such as melons, fruits, tobacco, etc. Therefore, if K is applied in combination with NP at rates of 45 – 75 kg ha^{-1} K_2O a yield response of 4.5 kg maize, 3 kg rice or 2 kg soybean per every kilogram of K_2O applied can be expected.

Prediction of the province's demand for mineral fertilizers

Mineral fertilizer is an important factor for increasing grain output and to improve the farmland nutrient balance. Based on the general planning of the province for developing grain production, a prediction of the province's demand for mineral fertilizers in 2001 (actual use), 2005 and 2010 is made by using a nutrient accounting (input : output balance) system. The data in Table 6 are obtained through calculation, using the Stanford equation for the nutrient balance, that is $D = A - B/C$, where D stands for the predicted demand for mineral fertilizers, A for the total crop uptake of nutrients, which is worked out by multiplying the expected total output of five major crops in the target year by the nutrient demand per hundred kg economical yield. B signifies the available soil nutrients, which is determined by soil analysis and the calculation of soil nutrient supply, using the available nutrient multiplier method. The results are then weighted according to the acreage of each soil type. C stands for the fertilizer recovery rate by the crop within the respective period, which is the mean value of the results of years of experiments in the province.

Table 6. Prediction of the Jilin Province's demand for mineral fertilizer (10^3t)

Year		N	P_2O_5	K_2O	Total	$N:P_2O_5:K_2O$
2005	A	732.6	168.2	144.9		
	B	452.4	103.4	89.5		
	C	337.6	195.0	369.5		
	D	830	330	150	1,310	1:0.4:0.18
2010	A	750.3	178.6	193.2		
	B	463.3	110.3	119.3		
	C	337.6	195	369.5		
	D	850	350	200	1,400	1:0.41:0.24

Table 6 indicates that in the target years of 2005 and 2010, the Jilin Province needs a total of 1.31 and 1.4 million tons of mineral fertilizers (nutrient units). Following this predicted demand, the $N:P_2O_5:K_2O$ ratio will adjust to 1:0.4:0.18 and 1:0.41:0.24, respectively.

Nutrient status of farmland soils in the Hebei Province and approaches to its improvement

Lu Yinghua, Qin Shuangyue and Feng Hong'en

Hebei Province Soil and Fertilizers Head Station, 050021

Abstract

Data gathered from stationary monitoring and general investigations of nutrients in the plough layer of farmland soils show that the soil nutrient status varies depending on the studied parameters. However, it can be noted that over the years the organic matter level is maintained with a slight trend to larger nutrient contents, especially with regard to N. The readily available P in the soil is rising steadily whereas the contents of readily available K are continuously and drastically declining. The changes in nutrient status of the farmland soil are closely related to the cropping system, yield, application of organic manure, input of mineral fertilizers and other crop management practices. Based on research findings, approaches are promoted on how to improve the nutrient cycling in the farmland ecosystem.

Introduction

With the development of the agricultural production and the intensification of the crop management, great changes have taken place in terms of farming system, the agricultural production conditions and the soil nutrient status. In order to understand the changes happening to the soil nutrient status, a long-term stationary soil nutrient monitoring system was set up in 1984. It also aimed at studying the relationship between soil quality and yield to provide guidelines for the regulation of the nutrient management in the agricultural production systems. Monitoring sites were deployed all over the province, covering all major farmland soils, i.e. cinnamon soils, fluvio-aquic soils and paddy soils. Two treatments, no fertilization and conventional fertilization, were set up for the monitoring. For the purpose of verifying the findings of the monitored sites and remedying the shortcoming of the monitoring site, as they are representing a very large area, a province-wide investigation of soil nutrients in the plough layer of farmland was carried out in 1993. By comparing the findings with the data of the soil survey, a fairly sound knowledge was acquired concerning the trend in changes of the soil nutrient status of the farmlands all over the province.

Changes in farmland soil nutrient status and their causes

Organic matter maintained with a slight upward trend

According to the data from 12 monitoring sites, soil organic matter content increased from 9.8 g kg^{-1} in 1984 to 12.7 g kg^{-1} in 1996, which means an increase of 29.6% on average of all 12 sites. In the soil nutrient survey conducted in 1993, a total of 9,495 soil samples were collected for the determination of organic matter (SOM). With a mean value of 12.8 g kg^{-1}, SOM increased by 11.1% compared to the soil survey in 1984. About 69.5% of the soil samples had elevated whereas 29.2% showed decreased SOM and 1.3% of the samples remained unchanged. The rise in soil organic matter was attributed to larger quantity and quality of the applied organic manure. Especially, the areas to which harvest residues were applied showed also increased crop yields. Harvest residues that used to be fuel for cooking, are now used as manure and fodder, thus greatly raising the proportion of straw returned to the fields and therefore improving soil organic matter both in quantity and quality.

Accumulation of soil N

According to the data from the 12 monitoring sites, total soil N was 0.818 g kg^{-1} in 1996, about 31.7% larger than in 1984. Five out of 12 sites showed an accumulation of N. During the soil nutrient survey conducted in 1993, a total of 8,067 soil samples was collected for the determination of total N. The mean value of 0.87 g kg^{-1} was about 17.2% larger than during the soil survey in 1984. About 67.9% of the soil samples showed a trend towards larger, 31.2% towards smaller and 0.9% stagnating contents. The close relationship of total N with soil organic matter may explain the upward trend of nitrogen and is obviously a result of applying large quantities of N fertilizers in consecutive years as well as the supplementation of large amounts of quality organic manure.

To determine the easily available N fraction, the soil samples were analyzed for alkalytic N (incubating the soil with 1.0 M NaOH at 40 °C for 24 h). At the 12 monitoring sites, alkalytic N increased from 54.2 mg kg^{-1} in 1984 to 82.3 mg kg^{-1} in 1993 by more than 50%, about 28.1 mg kg^{-1} larger than in 1984. Of the 9,523 soil samples taken in the 1993 survey, the mean value was 68.5 mg kg^{-1}, about 11.7 mg kg^{-1} or 20.6% larger than that in 1984. About 68.4% of the soil samples showed an increase, 30.7% a decrease and 0.9% were unchanged, indicating a similar trend to that of total soil N. As a readily available nutrient, alkalytic N is subject to rapid changes in the soil and is mainly affected by N application.

Soil readily available P rises steadily

According to the statistics of the monitoring data from the 12 monitoring sites, in 1994 soil readily available P was 12.3 mg kg^{-1}, 6.0 mg kg^{-1} larger than that in 1984, showing an upward trend. The analysis of the 9,072 soil samples collected in 1993 all over the province revealed that the mean content of readily available P was 10 mg kg^{-1}, 4 mg kg^{-1} or 64.4% larger than in 1984. 69.7% of the soil samples taken showed an increase, 27.4% a decrease and 2.9% were unchanged. In the early 1980's, the second province-wide soil survey revealed that the mean content of readily available P in the soil was only 6.1 mg kg^{-1} and about 85% of the soil was deficient in P. To solve the problem of P deficiency, application of P fertilizers was promoted and introduced all over the province. Especially the extensive application of large amounts of P-based fertilizers, e.g. DAP, increased the soil P content year by year and eventually reversed the situation of P deficiency towards a P surplus. Although soil P increased to some extend, there is still a large proportion of farmland which is deficient in P with a soil P content of less than 10 mg kg^{-1}. Therefore, emphasis needs further to be laid on promoting adequate P application.

Soil readily available K dropping drastically

According to the 1996 statistics of the 12 monitoring sites, soil readily available K was reduced by 19.2 mg kg^{-1} or 18.3% compared to 1984. In the 7 monitoring sites with two crops per year, it decreased from 113.2 mg kg^{-1} in 1984 to 80.3 mg kg^{-1} in 1996, showing a drastic downward trend. The analysis of the 9,351 soil samples collected all over the province in 1993 indicated that the mean content of readily available K was 111 mg kg^{-1}, 20 mg kg^{-1} or 15.1% smaller than in 1984. 65.4% of the soil samples taken showed a reduction, 33.9% an increase and 0.7% remained unchanged. Before the second province-wide soil survey, it was believed that the soils in the Hebei Province were not deficient in K. Nevertheless, after the second soil survey, the long-term monitoring and the soil nutrient survey in recent years, it was discovered that soil readily available K in the farmland dropped drastically, causing widespread appearance of K deficiency symptoms. The yield response of cotton, wheat and rice to K application became significant. K deficient soils still deserve more attention. The main causes of the drastic decrease in soil readily available K are: Continued and increasing K removal with increasing crop yield, little K input in the form of mineral fertilizer. Furthermore, it was found that K in farmyard manure is inadequate to meet the crop needs. All this has resulted in the failure to stop decreasing K levels, hence, has led to the drastic drop of soil readily available K. That calls for readjustment of the NPK ratio in fertilization by supplementing K fertilizers, particularly in those high-yielding regions with two crops per year.

Changes in crop yields

Most of the monitoring sites in the province have been monitored for more than 10 years. The data show that the yield in the non-fertilized fields was relatively stable. According to the data of the monitoring sites, on the plain farmland with maize and wheat in rotation, it was found that unfertilised plots yielded only 44.1% of the fertilized fields. This figure was 4.1% less than in 1994. In paddy fields, the yield of unfertilized fields is only 35.8% of the fertilized fields, 6.5 % smaller than in 1994. This shows the dramatic yield increases by fertilization and the concomitant yield decline if no fertilizers are applied.

Usually more than 50% of the current yield is credited to mineral fertilization. It is obvious that the input of fertilizers is the dominant factor for high yields. Omission at fertilization for consecutive years will further reduce crop yield, but it was observed that after a certain number of years, the yield will maintain a certain level. The monitoring data of the past twelve years reveal that this yield without fertilization stabilizes at around 50% of the yields in fertilized fields.

Approaches to improve the nutrient cycle of the farmland

Increasing application rate of nutrients and improving nutrient recycling to farmland

Mineral nutrients applied to farmland not only increase the yield of crops but also the by-products, e.g. stalks, roots and leaves. A large part of these residues remain on the field at harvest or can be recycled in form of farmyard manure. This is often done if crop residues are used as fodder for the livestock. In addition, human and animal excretions (night soil, farmyard manure) can be recycled to the field. Still in the 1980's, the Hebei Province relied to a great extend on these organic nutrient sources. 52-54% of the N, 63-64% of the P and 95% of the K and most of the micronutrients applied to crops came from organic manure. This however, led to a dramatic depletion of the soil due to the fact that the nutrient cycle in the field is not closed and even under strictest control and recycling, nutrient losses are unavoidable.

It should be kept in mind that as long as there is no import of feed or food stuff to the country, to the province, county or farm, the organic manure and human wastes applied to the field contribute no net additions to the nutrient pools of the soil. They only return parts of what was removed for feed or food production during harvest. A combination of organic manure, recycling and demand adjusted mineral fertilizer application is therefore the only promising approach to sustainable crop production.

Readjusting N fertilizer application rate and improving N fertilizer recovery rate

Mineral fertilizer N has become the major source of nitrogen applied to farmland since it is the most important measure for achieving large yields. Recently, the Hebei Province consumes 1.5 million tons of N per year, with an average application rate of 231 kg ha^{-1}: Through its application both crop yields and soil N contents increased what is conducive to the N balance of the farmland but may also have side-effects which should not be ignored. For instance, poor N recovery rate, limited crop response, higher costs and pollution to the environment are problems which need to be tackled. Therefore, on the premise of maintaining the total N consumption constant, it is essential to readjust the allocation of N fertilizers according to the demand of the various regions. The N use efficiency in high-yielding regions should be improved by means of balanced fertilization whereas in the medium- to low-yielding regions N rates need to be increased. The same is required in regions with generally smaller, insufficient N application rates. N efficiency can be improved by means of balanced fertilization, split application techniques, etc. Poor N recovery rates of partly only 35% of the applied N or even below are a major problem in using N fertilizers. Consequently, the focus of scientific fertilization should be placed on improving the N recovery rate, rather than increasing N application rate alone.

Steadily increasing P application rate and crop response to P application

During the past twelve years, readily available P in soils has increased by more than 60% on average. The consumption of P fertilizers in the province has reached 450,000 tons averaging 69 kg P_2O_5 ha^{-1}. The current situation shows that, although soil P content rises rapidly, it is still at a low level and needs to be further supplemented by using larger P application rates. Region-specific or even site-specific P application strategies need to be adopted. In high-yielding regions where large rates of P fertilizers were applied in the past and led to a sufficient accumulation of available P in the soil, P fertilizers can be saved and can be used for only every second crop in the rotation. It is advised to apply the P to the most responsive crop.

Raising K application rate to reverse the trend of drastically falling K soil reserves

The drastic decline in soil K levels in farmland and the widespread crop response to K application has changed the traditional understanding that the soils in the Hebei Province are sufficient in K. Owing to limited K fertilizer resources and unpopular K application techniques, the Hebei Province only consumed 175,000 tons of K fertilizers (in 2001), leaving much of its farmland unsupplied. A large number of experiments needs to be carried out in order to determine area, distribution and extent of K deficiency in farmland. Furthermore, recommendations for proper K application rates need to be developed so that applied K can be used more efficiently. Priority in K supply should receive those crops with the largest response to K. Recycling of K with the aid of K containing organic manure such as straw, green manure crops, plant ash, etc., can reduce the decline of the K fertility of soils and to a certain extend can supplement mineral K application. It has to be born in mind that poor efficiency of nitrogen use is often caused by insufficient supply of P and especially of K.

Status quo and prospects for the use of mineral fertilizers in the Shandong Province

Liu Zhaohui, Jiang Lihua and Zhang Yulan

Soil and Fertilizers Institute of Shandong Province Academy of Agricultural Sciences, 250100

Abstract

Shandong is a big agriculture-based province, leading in output and yield per unit-area of grains among the provinces or regions in China. In recent years, Shandong's consumption of mineral fertilizers has been rising steadily. Within the 18 years from 1980 to 1997, its consumption increased by 1.86 times or at an average rate of 10.9% annually. K fertilizers and compound fertilizers increased at a faster rate than N fertilizers. In 1997, every hectare of farmland received on average 579 kg of fertilizers (on the basis of net nutrient), about 3.10 times as much as in 1980 (187 kg). Nevertheless, the grain output rose only at an average rate of 3.6% annually during the same period. This is an indication that certain problems exist with regard to the use of fertilizers in Shandong. For instance, in 1995, organic manure had only a share of 30% in nutrient supply; the system of fertilizer consumption was irrational with an NPK ratio (on the basis of $N:P_2O_5:K_2O$, the same below) being only 1:0.29:0.13; the distribution of fertilizers was unreasonable, showing abundance in the eastern region and shortage in the western part of the province. Especially in the eastern part, N fertilizers seriously pollute groundwater and agricultural products, bringing the nitrate levels in 30% of the shallow groundwater beyond the critical value of the water sanitation regulation. Based on the analysis of the use of fertilizers during those 18 years, it is predicted that the consumption of fertilizers will continue to rise in the coming years, with K fertilizers increasing at a faster rate than others, which should be taken care of when fertilizers are used in the future.

In 1996, Shandong's grain output reached 43.327 million tons and its yield 5,260 kg ha^{-1}. Such a large grain output is attributed to the input of fertilizers, which put Shandong in the lead among the provinces or regions in China. In 1997, it consumed 3.867 million tons (on the basis of net nutrient, the same below). On one hand the use of large amounts of mineral fertilizers has promoted the production of cereals and cotton in the province, but on the other hand it also caused a number of problems that need to be solved urgently.

Status quo of the use of fertilizers

During the study period of 18 years, the consumption of mineral fertilizers in Shandong has steadily increased (Table 1) from 1.3529 million tons in 1980 to 3.867 million tons in 1997 (Shandong Statistical Yearbook) by 1.86 times or at a rate of 10.9% annually. The proportion of K fertilizers and compound fertilizers expanded faster than that of N fertilizers. In 1997, every hectare of farmland received on average 579 kg of fertilizers, more than three times the amount as in 1980 (187 kg). The total grain output of the province rose from 23.84 million tons in 1980 to 38.522 million tons in 1997 at a rate of 3.6% annually. The relationship between the consumption of fertilizers and the output of grain is highly significant ($R^2 = 0.837$).

Table 1. The use of fertilizers in recent years in Shandong (1000 tons)

Year	N	P_2O_5	K_2O	Compound	Total	$N:P_2O_5:K_2O$ (N = 100)
1980	1,032	276	12	33	13,539	100:28.1:1.6
1985	1,274	249	36	299	1,858	100:29.7:5.9
1990	1,541	354	70	490	2,455	100:36.1:8.5
1992	1,589	450	142	638	2,819	100:43.9:13.3
1993	1,920	680	180	770	3,550	100:50.2:13.7
1994	1,714	499	212	841	3,266	100:47.6:17.1
1995	1,891	538	250	945	3,623	100:47.3:17.9
1996	1,923	554	258	997	3,733	100:48.2:18.2
1997	1,925	547	292	1,103	3,867	100:49.6:20.2
2001	1,970	575	389	1,373	4,286	100:54.0:24.8

Note: The data in the table are cited from "Shandong Agricultural Statistics Yearbook" and "Shandong Agricultural Statistics". The proportions of N, P_2O_5 and K_2O in the compound fertilizers were assessed based on the findings of the province-wide investigation, being 32.0%, 52.8% and 15.2%, respectively.

Investigations in different regions of the province show (Table 2) that among the three surveyed regions, Shouguang had the highest fertilizer application rates, while Wucheng had the lowest due to its less-developed economy; and Mouping had the most balanced NPK ratio in fertilization of wheat, while Shouguang had most unbalanced nutrient ratio. Studies on the use of fertilizers in vegetables cultivated in plastic-sheet greenhouses (poly-tunnels) in Shouguang revealed an over-dosage of nutrients and an improper nutrient ratio.

The survey of 242 farms in 1996 showed that less than 10% of the farmers used other macronutrients than NPK, e.g. calcium, magnesium and sulphur or micronutrients unless supplied by compound fertilizers. These nutrients were often not known to farmers.

Problems in the use of fertilizers

Smaller share of organic manure in nutrient supply

The share of organic manure in the nutrient supply to crops has continuously declined in recent years. It dropped from 66 – 99% of the total nutrient input in the period of the 1950's – mid 1970's down to less than 50% in the 1980's. The survey of 1997 showed that it accounted for 22.8% in N, 32.9% in P and 46.3% in K in Mouping. The situation was different in Shouguang, where organic manure occupied a very limited share in the case of grain production, but was abundantly used in the greenhouse vegetable production, where it accounted for 26.5% in N, 21.0% in P and 37.7% in K. In Wucheng, it accounted for 24.6% in N, 21.4% in P and 64.2% in K supply. Organic manure provided a larger proportion of K than N and P with the latter two occupying slightly more than 20% of the total nutrient application.

The inadequate input of organic manure may lead to a reduction of the soil organic matter content, reduced soil fertility and as a result poor ability to produce high and stable yields. Every year, the province has a huge amount of crop stalks or straw available for utilization. Except for only a small amount being used as manure, more than 12 million tons of the material are burned, not only polluting the environment but also wasting resources.

Table 2. Nutrient application rates of three surveyed regions in Shandong (kg ha^{-1})

Site	Crop	N		P_2O_5		K_2O		Ratio*	Sites
		MF	OM	MF	OM	MF	OM	N = 100	
Mouping	Wheat	168.9	51.0	115.1	35.4	80.9	42.8	100:68.1:47.9	n = 29
	Maize	122.6	3.6	17.1	4.3	20.9	5.8	100:13.9:17.0	n = 29
Shouguang	Wheat	300.2		203.7		21.1		100:67.9:7.0	n = 25
	Maize	186.5	30.2	61.1	12.4	16.5	100.9	100:32.8:8.8	n = 25*
	VG**	1828.8	659.0	2591.1	688.0	730.1	441.6	100:142:39.9	n = 31
Wucheng	Wheat	130.4	31.9	115.2	13.5	29.1	15.9	100:88.3:22.3	n = 30
	Maize	90.3	14.5	22.8	6.2	11.9	42.1	100:25.2:13.2	n = 22*
Mean	Wheat	199.8	27.6	144.7	16.3	34.0	19.6	100:72.4:17.0	
	Maize	133.1	16.1	33.7	7.6	16.4	49.6	1:0.253:0.123	

Note: MF stands for mineral fertilizers and OM for organic manure.

*: $N:P_2O_5:K_2O$ ratio, including OM in the form of crop residues returned to the field.

**: Vegetables in greenhouse.

Irrational structure of the mineral fertilizer consumption

Irrational NPK ratio, over-dosed N application, inadequate K fertilizers and negligence of the use of other macronutrients as well as micronutrient fertilizers are problems related to the use of mineral fertilizers. According to the statistics, the N:P:K ratio in the nutrient use was 100:28.1:1.6 in 1980 and 100:36.1:8.5 in 1990. Though it was readjusted to 100:49.6:20.2 in 1997, it is still far from the appropriate ratio of 100:45:35. Of the three surveyed regions, Mouping had a very narrow and balanced N:P:K ratio of the mineral fertilizers in wheat (100:68.1:47.9) and a rather wide ratio in maize (100:13.9:17.0). This practice led to K deficiency which is widespread in Mouping covering 13% of the farms. In Shouguang, the N:P:K ratio of 100:67.9:7.0 in wheat and 100:32.8:8.8 in maize resulted in a strong exploitation of the soil K resources due to inadequacy of K fertilizer application. This was the cause for K deficiency in about

84% of the grain-producing farmland. The N:P:K ratio of vegetables of 100:141.7:39.9 clearly shows that P was over-applied, resulting in an accumulation of a large P concentrations in the soils whereas the K supply was inadequate. In Wucheng, the N:P:K ratio applied was 100:88.3:22.3 to wheat and 100:25.2:13.2 to maize, which also showed significant K inadequacy, causing that 83.3% of the farmland became deficient in K.

An inadequate K input is the direct cause for a continuous expansion of the area being K-deficient, which has reached 65% of the farmland in Shandong in the meantime. About 35% of the area is seriously K deficient and our studies revealed that only 5.3% of the 432 wheat fields surveyed and only 3.8% of the 1,022 summer maize fields used micronutrient fertilizers. Owing to the neglect in the use of these nutrients, the area of soil deficient in certain macro (Ca, Mg, S) and micronutrients (B, Cu, Zn, etc.) expands, especially in the eastern, central and southern parts of Shandong. The area of Zn-deficient soils comprises 60%, of B-deficient soils 62% and of serious Mo-deficient soils 53% of the farmland.

Unreasonable fertilizer distribution

Unreasonable fertilizer distribution can be observed 1) between crops, 2) between fields and 3) between regions. Cereals generally receive much less fertilizers than vegetables and fruits. Especially, vegetables in poly-tunnel greenhouses were often over-fertilized, having only a very poor recovery rate of applied N and P fertilizers, resulting in a dramatic waste of resources and in environmental pollution. 2) Fields close to the village, though generally being more fertile compared to remote fields, generally receive larger fertilizer dressings than the latter. 3) Unreasonable distribution between regions manifests in the fact that the application rate is generally larger in economically well-developed regions, like the eastern and central part of Shandong. In Shouguang the application rate for wheat was about 1.92 times greater than in Wucheng. Obviously, too much was applied in Shouguang whereas it nutrients were inadequate in the economically underdeveloped regions like the western part of Shandong. In Wucheng, 40% of the studied 30 farms were deficient in N. The figure would have been larger if N losses had been taken into account.

Unreasonable use of fertilizers leading to environmental pollution

The analysis of a large number of research results revealed that the mean recovery rate of N fertilizers lingers around 30% and that the rest of the N applied was lost via various pathways into groundwater, surface water and the air. After N fertilizers entered the soil, a part is converted to nitrate-N, which is easily leached into the groundwater by rain or irrigation water. Nitrate- and nitrite-containing water is regarded as detrimental to consumer's health, because they may form carcinogenic nitrosamines. In 1997, 16 groundwater or surface water samples were collected from three different places (Table 3). The groundwater samples from Shouguang, though taken from deep layers, all contained considerable amounts of nitrates. The measured concentrations

Table 3. Element content in groundwater (mg l^{-1})

Location	K	P	NO_3^-	Use[1)]
Mouping				
Lijiatuan	1.50	N/D[2)]	100	Tap water
Dongxishan	7.70	N/D	50	Irrigation, drinking
Nangou Reservoir, Ninghai	2.20	N/D	10	Irrigation
Yuniao River	2.25	N/D	10	Irrigation
Gaoling Reservoir	2.25	N/D	0	Irrigation
Pohe River	2.70	N/D	25	Irrigation
Shouguang				
Liujia, Beiluo Town	1.05	N/D	200	Irrigation (18.5m)
Shangjia Village, Beiluo Town	0.40	N/D	100	Irrigation (19.0m)
Xichen Village, Wenjia Township	0.90	N/D	25	Irrigation, drinking (21m)
Zhaojia Village, Guzheng Township	0.90	N/D	50	Irrigation, drinking (17m)
Antou village, Gucheng Township	1.05	N/D	25	Irrigation (19m)
Wucheng				
Youfang, Caicun Township	2.40	0.002	0	Irrigation (17m)
Caixi Village, Caicun Township	0.90	N/D	0	Irrigation (13.2m)
Rongzhai, Caicun Township	1.85	N/D	0	Irrigation, drinking (6.9m)
Zhangwang Zhuang, Datun Township	0.60	N/D	0	Irrigation, drinking (11.5m)
Dingwang Zhuang, Datun Township	1.45	N/D	0	Irrigation, drinking (4.7m)

1) Depth from which sample was taken in brackets
2) N/D stands for not determined.

reached levels as high as 200 mg l^{-1}. The high nitrate concentrations in the groundwater are closely related to the large N application rates. Nitrates were also found in the ground and surface water samples taken in Mouping. No nitrates were detectable in the five groundwater samples from Wucheng. All 16 water samples contained K whereas large K concentrations of 3.1 mg l^{-1} on average appeared in the water samples from Mouping, Yantai, with the highest being 7.7 mg l^{-1}. There was seemingly no correlation between fertilization and K concentrations in the groundwater since in the water samples from Shouguang (largest amounts of K applied) only 0.86 mg K l^{-1} were found. On the other hand samples from Wucheng (smallest amounts of K applied) showed K concentrations in the groundwater of 1.44 mg K l^{-1}. Out of the 16 samples only one sample was analyzed for P, showing that in contrast to N and K the less mobile P is not found at substantial concentrations in the ground water but more often found in surface water, where it may lead to eutrophication of lakes and rivers.

Trends in fertilizer use and measures to be taken in the Shandong Province

Trends in fertilizer use in Shandong

The analysis of the fertilizer consumption in the period from 1980 to 1997 (Fig. 1) indicates that the consumption of fertilizers has increased linearly with time and that it can be expressed by the following equation: $y = 15.071x - 29723$ ($R^2 = 0.9372$), where y is the fertilizer consumption in t and x the time in years. Based on this equation, it can be predicted that the consumption of fertilizers (on the basis of net nutrients) reaches 4.944 million tons in 2005. Latest consumption figures for 2001 show that N, P, K consumption reached a total of 4.286 million tons ($N+P_2O_5+K_2O$). K_2O consumption has reached 389,000 tons, excluding the use of compound fertilizers which may contribute another 205,950 tons of K_2O based on a share of 15% of K in the compound formulas. It is predicted that in the years to come, the growth of K fertilizer consumption will surpass that of N and P fertilizers, especially due to expected further increase in compound fertilizer use by farmers.. The consumption of N and P fertilizers will also increase, but ought to be properly controlled.

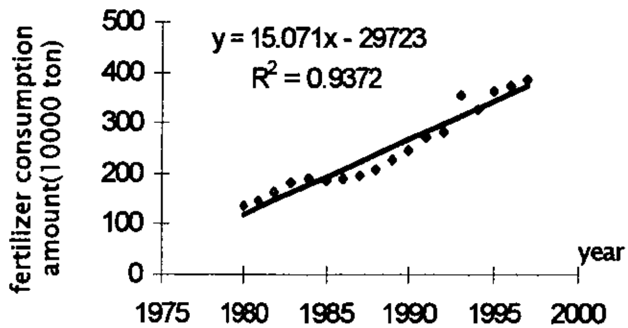


Figure 1. Increase in fertilizer consumption in Shandong during the past 20 years

Measures to be taken

Increasing the use of organic manure

Organic manure is an important source of organically bound carbon and nutrients. Application of organic manure can help to maintain soil fertility by recycling of carbon and nutrients to the soil. Organic C can help the soil to form granular structures, improve soil aeration and raise the soil's ability to retain water and nutrients. Furthermore, organic manure is feeding the soil flora and fauna and can stimulate rapid propagation of beneficial soil microbes. The latter may help to make unavailable macro and micronutrients available to the plants and to improve the quality of agricultural products. By improving the sorption capacity of soils, it can also increase the recovery rate of mineral fertilizers. It should therefore be emphasized that harvest residues and animal wastes are returned to the field in combination with the use of mineral nutrient sources.

Paying attention to the application of macro- and micronutrient fertilizers

The recent years, substitution of single super phosphate and calcium magnesia phosphate fertilizers by MAP and DAP has greatly reduced the amount of Ca, Mg and S, being applied to the field. With increasing crop yield, the removal of these nutrients also increased as it is confirmed by the expanding area of farmland deficient in these macronutrients in recent years. Field experiments also showed significant crop responses both in yield and quality to the application of Ca, Mg, S and to a variety of micronutrients (especially B, Zn and Mn). Besides the application of compound fertilizers containing all macro- and micronutrients, single micronutrient fertilizers are also recommended for the application to certain crops, especially vegetables.

Allocation of fertilizer nutrients to various crops in the Shandong Province

Ma Wenqi[1], Mao Daru[2] and Zhang Fusuo[2]

[1] College of Agronomy, Hebei Agricultural University 071001
[2] Plant Nutrition Department, Chinese Agricultural University 100094)

Abstract

Based on the available statistics and a survey with 1,000 farmers, the fertilization practice and the distribution of fertilizer nutrients among crops in the Shandong Province was studied. The results show that the largest area is cultivated with cereals which have the biggest share in both uptake and consumption of NPK nutrients from mineral fertilizers and organic manure followed by vegetables, melons and fruit trees. However, regarding the ratio between cultivated land and fertilizer consumption, a proportionally smaller amount of fertilizer is used in cereals than in vegetables, melons and fruit trees. Considering the nutrient demand, however, cereals would need a larger share in the proportional fertilizer allocation. In terms of nutrient recovery rate, cereals are more efficient than vegetables, melons and fruit trees. In the Shandong Province, about 49.8% of the N, 71.3% of the P and 58.6% of the K absorbed by crops are returned to the soil in the form of organic manure. Soil nutrients are also transferred from grain-producing fields to vegetable gardens and orchards in the form of organic manure. During the period from 1981 to 1996, the proportion of fertilizers applied to cereals decreased whereas fertilizer consumption in vegetables, melons and fruit trees increased. The total input of fertilizers, however, rose at about 50% in cereals, 25% in vegetables and melons and 20% in fruit trees. The province's macroscopic regulation of mineral fertilizer consumption aims at reducing N fertilizer application rates, especially in cereals, vegetables and melons, properly reducing P fertilizer application rates in vegetables, melons and fruit trees and maintaining the P application rate in cereals. Taking into account the return of K through organic manure, the use of mineral K fertilizers should be increased accordingly. The largest proportion should be used in cereals and fruit trees followed by vegetables and melons.

Introduction

Considering that the issues, such as population growth, food supply, resources and environment protection are increasingly becoming prominent, proper soil fertility management gains high priority. Sustainable agriculture that is based on comprehensive utilization of natural resources, protection of the agricultural environment and harmonized development of economical, social and ecological benefits has become the only way for countries throughout the world to develop their agriculture in the 21st

century. The management of mineral fertilizer and organic manure resources has evolved to be one of the world's most important problems in relation to the sustainable development of agriculture. In the past two decades, both China's production and consumption of mineral fertilizers have developed so rapidly that this country has become a major mineral fertilizer producer, importer and consumer. Ever since 1989, China has always ranked first among the mineral fertilizer consumers. In 2001, its mineral fertilizer consumption reached 42.540 Mt (on the basis of net nutrients, the same below), which exceeded its own production capacity by far. In 2001, it produced 29.527 Mt, amounting to only 70% of what was consumed. In 2001, 6.827 Mt were imported from other countries. For this, the country spent 1.849 billion USD, indicating the importance of fertilizer in the international trade relationships of China. At the same time, the mineral fertilizer recovery rate in China is very low, about 10 percentage points less than that in developed countries. That alone costs more than 9.00 Mt tons of nitrogen, equalling to over 38 billion Yuan RMB (4.6 billion USD). Consequently, how to use mineral fertilizers more efficiently, how to bring the yield-increasing effect of mineral fertilizers into full play, how to lower N loss and how to reduce pollution are now questions of utmost significance. The performance of macroscopic regulations for the production, distribution, importation and consumption of mineral fertilizers and the optimization of resource allocation are important approaches to raise the effectiveness of mineral fertilizers. Owing to the lack of needed information about the status quo of the distribution of crop nutrient resources within regions, a number of crucial issues remain not addressed, such as the relationship between the input of mineral fertilizers and the increase in crop yield, the rationality of the fertilization of cereals that enjoy a special position in the agricultural production of China. Furthermore, information is needed on the distribution of the large quantities of mineral fertilizers produced at home and imported from abroad and the allocation of mineral fertilizer resources on the basis of region, variety of mineral fertilizer product and crop and structure of mineral fertilizers allocated. For this reason, the following study was carried out looking at the distribution of fertilizer nutrients on the basis of crops by conducting a survey on fertilization systems.

Research method

Data collection and characterization of data

For the investigation, eight counties (or cities), i.e. Shouguang City, Qixia City, Pingdu City, Feixian County, Yuncheng County, Feicheng County, Qihe County, and Yangxin County, were chosen throughout the province. Then three or four townships out of every county (or city), three or four villages out of each township, and nine to fifteen farms out of each village were randomly selected. In total, 1,046 farmers were visited; each one had to fill out a questionnaire.

The survey covered basic conditions of the farms such as crops cultivated, fertilizers used, crop yields and output values and their knowledge about modern fertilization.

Before each visit, interviewers designed a questionnaire according to the outline of the investigation. The questionnaires were filled out during the farm visits.

Calculation of net nutrient content in organic manure

The net nutrient content in the different sources of organic manure was calculated on a type-by-type basis, referring to the "Manure Handbook", "Agro-chemistry", etc.

Distribution and fate of nutrients

Based on the findings of the investigation, mean nutrient inputs per unit area were calculated. If a large number of samples of a crop could be gathered, the calculation was conducted on the basis of the counties' average in combination with the cultivated area of that crop recorded in the statistics of the respective regions selected for the survey in each county. If only a few samples could be collected, the calculation was performed on the basis of a uniform average figure of the province.

Crop nutrient uptake

Crop nutrient uptake was calculated based on the crop production recorded in the statistics and the nutrient uptake parameters listed in relevant literature.

Macroscopic rational application rate

From relevant literature, data about the rational application rate of a crop was gathered, especially, the data concerning Shandong. Mostly the upper limits were used for the calculation of the province's mean suitable application rate, based on which the province's macroscopic rational application rate was worked out in combination with its cultivation structure.

Results and analysis

According to the 1997 statistics, in Shandong 63.5 % of the farmland was cultivated with cereals, 13.3% with vegetables and melons, 7.5% with fruit trees, 3.6% with cotton and 8.2 % with other crops, such as hemp, sugar crops and tobacco (Figure 1).

Crop nutrient uptake, application and balance of nutrients

Nitrogen

Table 1 shows that N comes in the form of either mineral fertilizer or organic manure. The total N input was 3.7807 Mt, of which 75% was in the form of mineral fertilizer.

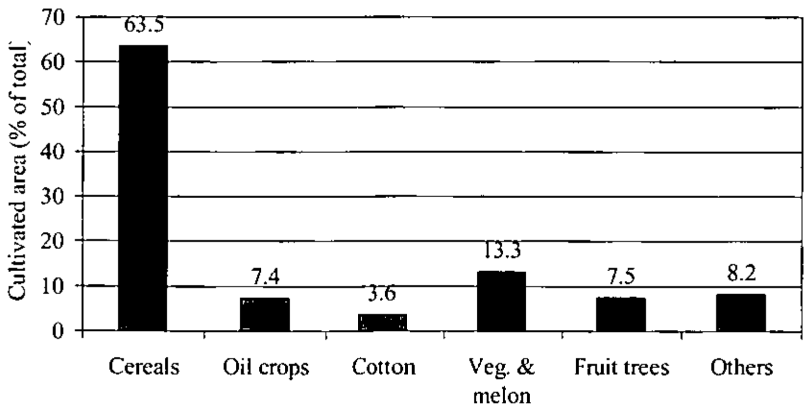


Figure 1. Proportional distribution (% of total cultivated land) of cultivated area in Shandong by the various crop types in 1997

The total crop N uptake was estimated at 1.8613 Mt, accounting for 49.2% of the total N input. The province's N equilibrium index (input : output ratio) was 2.04, indicating that the N input was twice as much as the N output. The investigation revealed that organic manure in Shandong, including mudash manure, barnyard manure, animal dung and crop stalks or straw, was returned to the field. All these types of manure mainly originate from harvest residues, returned to the field either directly or after processing or in the form of human and animal waste after digestion in their bodies. Therefore, the input of nutrients in the form of organic manure can be taken as the amount of nutrients recycled within the entire production system. Thus, the nitrogen recycling rate of the province was reckoned at 49.8%, that means that about half of the nutrients present in harvest residues was returned to the soil.

Among the crops, cereals are still the biggest consumer of N with approx. 64.7% of the total consumption. This is less than could be expected from the proportion cereals occupy in terms of cultivated area. Vegetables and melon crops were the second largest N users with 17.9% whereas fruit trees sharing 10.3% are ranked third. Both higher crop groups had much larger N consumption than could be expected from their share in area. Cereals used 49.8% of the total organic N (from manure), which is less than their respective share in the mineral fertilizer N input. Vegetables and melons consumed 25.2% of the organic N which is larger whereas fruit trees consumed 13.0%, which is slightly larger than their respective share in the mineral fertilizer N input. N outputs by cereals accounted for 72.4% of the total N output, a share which clearly exceeds that observed in the inputs. This is different for vegetables and melons sharing 13.7% of the total outputs by crops and being less than their respective share in the total N input and cultivated area. N output by fruit trees was only 6.0% of the inputs allocated to these crops. Cereals with 0.58 had a higher input : output ratio than vegetables and melons. This shows that the problem of irrational fertilization with vegetables, melons and fruit trees is more serious than in cereals. The percentage of total N input, deriving from organic manure, was the lowest in cereals, only 20% lower than the province's average, around 30% in oil crops, cotton, vegetables, melons and fruit trees and 55.6% in other crops. The N input : output ratios show that in the mean over all crops more than twice the amount of N removed by the crops was returned to the fields by both organic manure and fertilizer application. Looking at the individual crops reveals that in fruit trees more than 16 times, in cotton more than 6 times and in vegetables almost 3 times the amount of N removed is applied. An apparent under-supply of N in oils crops is due to the fact that leguminous crops are in these group where less N is applied and the amount of N2 fixed from the atmosphere has not been assessed.

Table 1. Input and output of nutrients by mineral fertilizer and organic manure in major crops in the Shandong Province (Unit:1,000 t)

Nutrients		Cereals	Oil crops	Cotton	Vege-table & melons	Fruit trees	Other crops	Total
N	Input							
	Min. fertilizer	1,846	96	84	510	294	23	2,853
	Org. manure	462	46	38	234	120	28	928
	Output	1,347	210	18	254	25	6	1,861
	Balance	961	-68	104	490	389	44	1,919
	Input : output	1.72	0.68	6.67	2.94	16.67	8.33	2.04
P_2O_5	Input							
	Min. fertilizer	678	64	46	280	200	14	1,282
	Org. manure	209	21	17	148	66	13	473
	Output	508	40	6	98	9	1	663
	Balance	379	44	57	330	257	25	1,092
	Input : output	1.75	2.08	10.00	4.35	25.00	25.00	2.63
K_2O	Input							
	Min. fertilizer	170	30	2	92	91	0	386
	Org. manure	524	55	44	210	123	31	987
	Output	1,188	118	16	326	34	2	1,683
	Balance	-495	-32	30	-24	181	29	-311
	Input : output	0.58	0.72	2.86	0.93	6.25	16.67	0.81

Phosphorus

Table 1 shows that the total P input in the province was 1,755,100 t, of which the major part with 1,282,200 t P_2O_5 entered the systems in form of mineral fertilizer P. Organic manure with 472,900 t P_2O_5 accounted only for 26.9% of the total input. The total crop P uptake was 0.663 Mt, resulting in a balance index (input : output) of 2.63, which means that the total P input was 2.6 times the amount of P removed by all crops. Similar to N there is a large difference in this ratio between the individual crops, showing that fruit trees and other crops received the most excessive rates, followed by cotton and vegetables. Cereals and oil crops received about double the amount of P that is removed from the soil. Cereals are the largest P consumer with 51.9% of the total mineral P fertilizer, which is less than could be expected from their share in the cultivated area of the province. Vegetables, melons and fruit trees consume about 21.9% and 15.6% of the total P supplied to agriculture. Both crop types consumed larger amounts than could be expected from the cultivated area under these crops. Most of the organic manure P, 44.3%, were recycled to cereals whereas 31.3% were entering the vegetable and melon sector. Fruit trees received 14.0% of the organic manure, similar to their share in the mineral fertilizer P input. Putting the manure consumption into perspective with the area occupied by both crop types (13% under vegetables, 7.5% under fruit trees), it is evident that there is a large transfer of nutrients from other crops, especially cereals, to vegetables and fruit trees.

Potassium

Table 1 indicates that the province had a total K input of 1,372,600 t, of which 385,900 t were from mineral fertilizer and 986,700 t from organic manure. The latter accounted for 71.9%, which implies that organic manure is the major source of K. The crop K uptake reached 1,683,300 t, much larger than the total K input, forming a balance index of 0.81. Therefore, most of the cropping systems in the province revealed a deficit in K, though the soil K values were not extremely low. With 42.9% of the total mineral fertilizer K input, cereals consume the largest proportion of K consumed in the province, followed by vegetables and melons, consuming about 23.8%, and fruit trees with 23.7%. Regarding the K inputs from organic manure, cereals shared 53.1%, which is larger than their share in the mineral fertilizer K input. Vegetables/melons and fruit trees received 21.2% and 12.5% of the organic manure K, respectively, both indicating smaller values than their share in the mineral fertilizer K input. In terms of total crop K removal (output), cereals accounted for 70.6%, which is larger than their share in the total K input. Vegetables and melons reached 19.3%, which is less than their share in the total K input, and fruit trees only 2.0%, which is also much less than their share in the total K input. Unlike N and P, the percentage of the total K, deriving from organic manure exceeded 50% in all crops. Cereals occupied 75.5%, vegetables and melons 69.4% and fruit trees 57.4%. Input : output ratios indicate that in cereal 58%, in oil crops 72% and vegetables 93% of the amount of K removed is only returned to the fields by mineral and organically recycled K. In cotton and fruit trees almost 3 and more than 6 times the removed amount of K is returned to the field. This shows that a dramatic under-supply of K in cereals and oil crops on one hand, contrasts a K over-supply in cotton and fruit trees. Among all these crops, cereals showed poorest return of removed K, indicating that a net transfer of K nutrient exists between different cropping systems, dominantly from cereal fields to orchards and cotton fields in the form of organic manure.

Yearly variations in nutrient supply

The distribution of mineral fertilizers among crops in different years was assessed based on the proportions the crops under investigation share in the total input of mineral fertilizer nutrients (on the basis of $N + P_2O_5 + K_2O$), the cultivation structure and the total consumption of mineral fertilizers of each year. The results show that in 1981 cereals consumed 73% of the total input, vegetables and melons 5.5%, fruit trees 4.0%, cotton 10.1%, oil crops 5.1% and other crops 2.3%. By 1988, the share of cereals in the consumption of mineral fertilizers had dropped to 62.5%, that of oil crops with 5.1% remained the same, that of cotton increased to 13.2%, that of vegetables and melons increased to 7.0% and that of fruit trees increased to 9.6%. By 1996, the share in fertilizer consumption of cereals, oil crops and cotton further declined to 59.6%, 4.8% and 4.2% whereas the share in fertilizer consumption of vegetables and melons rose to 17.5% and that of fruit trees to 12.5%. From 1981 to 1988 and to 1996, though the relations fluctuated, total consumption of mineral fertilizers increased in all the crops, except for cotton in 1996 (Figure 2). In the case of cotton, the consumption of mineral fertilizers increased significantly from 1981 to 1988, but dropped from 1988 to 1996 to more or less the same level as in 1981, which is closely related to recent reduction in the area under cotton fields. The incremental increase in mineral fertilizer consumption from 1981 to 1996 can be to 50% attributed to cereals, 25% to vegetables and melons, 20% to fruit trees and 4.5% to oil crops, which shows clearly that cereals remain to be the major consumer, calling for more mineral fertilizers.

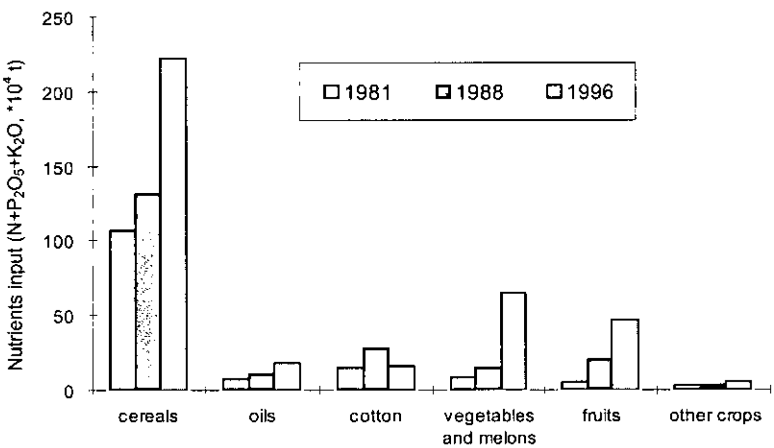


Figure 2. Input of mineral fertilizer nutrients to various crops in different years in Shandong

Strategy for the regulation and rational distribution of mineral fertilizers among different crops

Based on the fertilizer application rates recommended in the literature for various crops and the cultivation areas of various crops in the province's agricultural yearbook, rational consumption of mineral fertilizers for every type of crop in the province was assessed. The comparison of the actual consumption and the rational consumption

(Table 2) shows that in general N was seriously oversupplied, P slightly oversupplied and K clearly undersupplied.

Table 2. Comparison of the actual with the recommended fertilizer consumption to different crops in the Shandong Province (Unit:1000t)

Item	Total	Cereals	Oils	Cotton	Vegetables & melons	Fruits	Others
Fertilizer N							
Actual	2853.1	1846.3	96.0	84.3	510.2	293.8	22.5
Recommended	2037.5	1356.1	59.4	81.7	275.6	241.4	23.3
Balance	815.6	490.2	36.6	2.6	234.6	52.4	-0.8
Fertilizer P							
Actual	1282.2	677.8	63.7	46.4	280.2	200.3	13.9
Recommended	1107.7	671.8	72.8	45.5	188.5	118.0	11.0
Balance	174.5	6.0	-9.1	0.9	91.7	82.3	2.9
Fertilizer K							
Actual	385.9	169.6	30.2	2.3	92.0	91.4	0.4
Recommended	660.0	261.5	25.1	14.5	151.8	185.1	22.0
Balance	-274.1	-91.9	5.1	-12.2	-59.8	-93.7	-21.6

The whole province consumed 815,600 t of mineral fertilizer N in excess to the recommended rates. All the major crops or cropping systems were treated with excessive N fertilizer, e.g. cereals, particularly vegetables and melons, receiving an excess of 490,200 t and 234,600 t N, respectively, whereas oil seeds (36,000 t), cotton (2,600 t) and fruit trees received only 52,400 t in excess to the recommended N supply to the respective crop type. The difference in the order of magnitude between crop types is mainly explained by the larger area (cereals) or it is a clear expression of the excessive use in case of vegetables. Therefore, the aim of the macroscopic regulation is to reduce the application rate of N fertilizer, especially for cereals, vegetables and melons. The actual consumption of mineral P fertilizer exceeded the recommendation by 174,500 t, which was mainly due to the large amounts of P used in vegetables & melons and fruit trees. In cereals, P inputs matched well the recommended amounts. As a result, reducing the P application rate in vegetables, melons and fruit trees is also a target in the years to come. The actual consumption of mineral K fertilizer was inadequate with a shortage of 274,000 t K_2O yr^{-1}, particularly in cereals and fruit trees, which lacked 91,900 t and 93,700 t K_2O, respectively. Vegetables and melons were also short of 59,800 t K_2O.

NPK balance in farmland soils and future strategy for fertilization in the Shandong Province

Yan Peng and Mi Yunlu

Shandong Province Soil and Fertilizers Head Station, 250100

Abstract

At present, the farmland of Shandong has a deficit of 311,800 t K. Field experiments demonstrate that each kilogram of K can increase the yield by 8.34 kg. In a first step, it is recommended to increase the K input by 311,800 t which could lead to an additional grain output of 2.60 Mt. To further increase the cereal production to 7.40 Mt, vegetable & melon production to 10 Mt and fruit production by another 2 Mt, additional 304,200 t N, 60,400 t P and 589,800 t K (equal to 138,300 t P_2O_5 and 707,800 t K_2O) will be required. If in the increment of fertilizer input the current ratio between nutrients from mineral fertilizers and those from organic manure will be sustained, in 2010 the province will have an additional demand for 228,200 t N fertilizers, 107,700 t P fertilizers and 336,200 t K fertilizers. It is predicted that in 2010 Shandong will consume 4.43 million t of mineral fertilizer nutrients, accounting for 8.7% of the country's planned total of 50.0 million t. The $N:P_2O_5:K_2O$ ratio in Shandong will then be 1:0.41:0.32. Calculation on such a basis indicates that in the next 10 years the fertilizer input will increase by 0.05–0.06 million t every year, about 0.1 million t less than the annual increment in the past 10 years.

Introduction

Shandong is a major agriculture-based province in China. With a total land area of 156,700 km^2, it has about 8.001 million hectares of cultivated land and produces various agricultural products, all accounting for a fairly large proportion of the total agricultural output of the country. The province, on the other hand has a total population of 87 million, which means only 0.092 ha of cultivated land per capita. Constraints to agricultural production are particularly inadequate fresh water resources, which are on average 4,560m^3 ha^{-1}, only one-sixth of the country's average. As a result, there is a high pressure on the resources due to high population and fast economic development which leads to concerns regarding the ecological balance. Consequently, in order to develop agriculture in future, the Shandong Province has to continue to raising the per unit land productivity by developing sustainable agriculture. Soil fertility is the base for sustainable development of agriculture, in which the balance of soil nutrients plays an essential role. Scientifically based fertilization, using the knowledge of the law of nutrient recycling and monitoring the status of nutrient balance in the soil-plant system, is a crucial approach to raising soil fertility, protecting and improving the farmland ecosystem. In this paper, the NPK balance in farmland of the Shandong Province is studied, which is used as a basis for recommendations for future nutrient management practices.

Changes in soil NPK content of the farmland in Shandong

The four major soil types, fluvio-aquic soil, cinnamon soil, brown earth and Shajiang black soil, account for 84% of all soils of Shandong's cultivated area. Comparison of the results of a long-term stationary soil fertility monitoring program (Table 1) and the results of soil nutrient surveys over several years (Table 2) show that the changes in the soil nutrient contents of farmland since the early 1980's can be described as follows:

1) The organic matter and total N contents have increased significantly in fluvio-aquic soils, cinnamon and brown earths but decreased in Shajiang black soils. This may be due to the large proportion of organic matter in Shajiang black soil, which has been mobilized through the higher intensity of the cultivation by mineralization.
2) The alkalytic N (easily available N) and available P contents have increased significantly in all four soil types. Available P has increased by over 50%. That is because more N and P fertilizers have been applied to farmland since the second soil survey in the 1980's.
3) The readily available K content has decreased in all four soil types. In relative terms, soils which originally had a high readily available K have lost more K than those with low readily available K at the beginning of the study. For instance, Shajiang black soil, originally with 113 mg kg^{-1} of readily available K, has been losing 2.4 mg kg^{-1} every year whereas brown earth with originally 68 mg kg^{-1} lost only 0.92 mg kg^{-1} every year. Brown earths are the soils which are the most deficient in K in Shandong and hence, the first receiving K fertilizers. The relatively large input of K causes that the readily available K in brown earth soils is not too rapidly decreasing.

Table 1. Results of long-term monitoring of nutrients in topsoils (0-20cm) under farmland in the Shandong Province

Soil	Year	O.M. (g kg^{-1})	Total N (g kg^{-1})	Alkalytic N (mg kg^{-1})	Available P (mg kg^{-1})	R. available K (mg kg^{-1})
Fluvio-aquic	1985	9.0	0.63	63	5.9	97
soil (n=11)	1996	11.3	1.23	69	19.0	78
Cinnamon	1985	10.5	0.70	70	6.1	90
(n=6)	1996	11.6	1.12	111	10.1	84
Shajiang black	1985	13.4	0.8	68	4.7	122
soil (n=7)	1996	11.8	1.14	74	18.0	101
Brown earth	1985	8.0	0.59	63	5.9	75
(n=9)	1996	12.3	1.20	113	21.4	67

Note: O.M. = organic matter, Alkalytic N = determined by 1.0 M NaOH incubation at 40 °C for 24 h, representing the available N pool, R. available K = readily available or exchangeable potassium

Table 2. Results of surveys on soil nutrient contents in topsoils (0-20cm) of the major soil types in Shandong

Soil	Year	O. M. ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Alkalytic N ($mg\ kg^{-1}$)	Available P ($mg\ kg^{-1}$)	R. available K ($mg\ kg^{-1}$)
Fluvio-aquic	1980-85	9.1	0.62	55	5.9	110
soil	1992-97	10.4	0.68	63	12.8	91
Cinnamon	1980-85	10.8	0.72	56	5.9	97
	1992-97	12.4	0.85	86	12.7	89
Shajiang black	1980-85	14.0	0.94	59	4.3	133
soil	1992-97	12.5	0.78	78	10.4	104
Brown earth	1980-85	8.1	0.54	56	5.5	68
	1992-97	9.5	0.64	76	14.4	57
Mean	1980-85	10.5	0.71	57	5.4	102
	1992-97	11.2	0.74	76	12.6	85

Note: The data in the table are mean values.

NPK balance in farmland soils

According to historical material, during the period from 1950's to mid-1970's, the farmland always suffered from a nutrient deficit, and inputs were almost exclusively supplied in the form of organic manure. Since the 1970's, the consumption of mineral fertilizers increased rapidly. In 1976, the supply of N by mineral fertilizer exceeded that of organic manure. In 1982, fertilizer P had surpassed the amount applied by organic manure. During this time, supply of both nutrients began to turn from deficit to surplus. Since the 1990's, the input of K fertilizer has been rising rapidly and by the year 2001, the province's total consumption of mineral fertilizers reached 4.286 Mt, accounting for 10.1 % of the country's total and averaging 380 kg ha^{-1} (based on a sown area of 11 M ha in 2001). This figure was far beyond the country's average and close to four times as much as the world's average. The nutrients were applied at a ratio of 1:0.45:0.21 N : P_2O_5 : K_2O and accounted for 75%, 77.9% and 47.5% of the respective nutrient in the total input (mineral fertilizer plus and organic manure).

Our survey conducted in 1996 shows that the total N input reached 3,024,300t, of which 1,987,200t, about 65.8%, was in the form of mineral fertilizer, 21.7% in the form of organic manure and anticipated 8.4% from the biological N_2 fixation. The total N output was 2,538,949 t, of which 60.3% were removed with crop harvest and 30.4% lost by various pathways. The total N input was 1.19 times as much as the total N output, thus leading to an N surplus of 455,081 t (Table 3).

For the past twenty four years, N input always exceeded the N output, which is reflected by the rising trends in soil N levels. In 1997, the province's total consumption of N fertilizer reached 2.24 million t or 9.3% of the country's total. Average application at this time was 248.0 kg N ha^{-1} whereas for the whole country it was 188 kg N ha^{-1}. According to local research results, a surplus of 10% in soil N may affect both quality of agricultural products and that of the environment. To secure large yields at the current nitrogen uses efficiency, which varies from crop to crop and cropping system, the high-yielding regions in Northern China, such as Shandong, require relatively large inputs of N. Nevertheless, it is recommended for especially environmental reasons to limit the N application to 400 kg N ha^{-1} in a two cereal crops per year rotation and to 500 kg N ha^{-1} to vegetables. Whether these limits are feasible under practical conditions, however, needs more research.

Table 3. Nutrient balance (1000 t) in the farmland of the Shandong Province (1996) (Mt)

Balance	Item	N	P	K
Input	Mineral fertilizers	1,987	378	428
	Organic manure	600	97	322
	Stalks	56	7	102
	Biological N fixation	254		
	Rain & irrigation	76	0.4	50
	Seeds	50	9.6	16
	Subtotal	3,024	492	918
Output	Harvest	1,561	280	1,230
	N loss from fertilizer	751		
	N loss from manure	180		
	Leaching & runoff	47		
	Subtotal	2,539	280	1,230
Balance		485	213	-312

Table 4 shows that crop yield response to N fertilizers was most expressed in fluvio-aquic soil and similar for the other three soils. This was consistent with the observation that the fluvio-aquic soil contained less nitrogen. The farmland which records an N surplus has reached 19.1%.

Table 4. Balance of soil nutrients and permissible surplus or deficit rate in the major soils in Shandong (kg ha^{-1})

Soil	N	P	K
Fluvio-aquic soil			
Actual balance	+26	+79	-37
Permissible balance range	-5	+4	-73
Cinnamon			
Actual balance	+19	+74	-21
Permissible balance range	-21	-9	-69
Brown earth			
Actual balance	+17	+67	-12
Permissible balance range	-13	-23	-51
Shajiang black soil			
Actual balance	+25	+78	-34
Permissible balance range	-19	+13	-81

The surplus, however, varies drastically from place to place and from crop to crop. Investigations showed that N input to cereals and to cash crops was close to the demand oriented amount so that farmland under these crops generally had only a little surplus of N. This did not lead to a substantial increase in nitrate contents in either the ground water or the harvested crop. On the other hand, there exists a distinct N surplus in vegetable gardens. As a result, in some vegetable-producing regions, nitrate content in the well water reached 170 – 250 mg l^{-1}, which is regarded as detrimental to the groundwater quality. This situation aggravated to a serious problem in the meantime, calling for urgent solutions.

Farmers in the Shandong Province began to use P fertilizers only in the 1960's. Until this time and for another 20 years after introduction, P input into farmland has been inadequate. P deficiency as a major yield limiting factor was the consequence. However, large scale extension of P use began only after the second soil survey in the 1980's. The introduction of P fertilizer application caused significant yield responses of crops grown in all soils, especially in soils like fluvio-aquic soil and Shajiang black soil, which were seriously deficient in P. In 1984, certain farmlands already started to show a surplus in application. By 1996, the surplus had reached 240,100 t and the I/O ratio of P reached 1.76. Table 4 shows that the current P balances for the four main soils in Shandong were similar. Field experiments indicate that currently the yield response to P fertilizers ranges between 18% and 27%, which is about 10 – 15% less compared to the 1980's. It could be shown that if the yield response to P fertilizers should be in a range of 10% - 25%, a surplus of < 20% in P application is required. In case of yield response should exceed 25%, a balance of 20% or slightly above is tolerated, depending on the soil P reserves. Though crops may benefit from the generally long lasting residual effects of P application, strong P accumulation in the soils can have negative effects on uptake of other nutrients, e.g. micronutrients like Zn. Furthermore, the economic and ecological aspects of continued application of large amounts of P fertilizers need to be taken into consideration.

The soil K balance in the farmland depended mainly on the K supply through organic manure and therefore showed a clear undersupply in this nutrient. In 1990, the province consumed a total of 2.455 Mt mineral fertilizers with an NPK ratio of 1:0.35:0.09 which means that only 152,000 tons of K_2O were consumed. Since the early 1990's, great efforts have therefore been made to promote the use of K fertilizers in the province. K consumption took off, especially in the brown earth regions with good K response. As a result, the K deficient area declined and by 1996 the area of K deficient soils had declined to 25%. Today, the extent of K deficiency varies from soil to soil and is smaller in brown earths and larger in fluvio-aquic soils and Shajiang black soils. A large proportion of the K consumption is used in vegetables & melons and fruit trees in recent years. This means that cereals usually do not receive adequate amounts so that the K deficit in soils of cereal fields persists. The results of the current field experiments with cereals show yield responses of 8 – 15% to K application in fluvio-aquic soils, cinnamon and Shajiang black soils. These soils were formerly categorized as adequate in soil K. There is evidence that these soils are in the process of changing from K adequacy to K deficiency. In brown earths, cereal yield responses to K application have generally reached more than 20%. Based on the principle of conserving soil fertility and under the present production conditions, the province need to increase the K consumption by another 311,800 t to keep the soil K supply in balance with the demand.

Forecast of Shandong's demand for fertilizers for agricultural production in the future

In the next 10 years with the current growth of population and development of the economy, the demand for agricultural products will increase and so will the requirements for product quality. According to the province's development plan for agriculture, on the premise of maintaining the current dynamic balance of the farmland, by 2010, the cereal output will have to be increased from the present 43.20 Mt up to 53.20 Mt. The vegetable & melon output need to be raised from 62 Mt to over 70 Mt, the fruit output from 8.0 Mt to 10.0 Mt and the output of other cash crops by a fairly large degree. To meet the targets of the plan, it is essential to readjust farmland input and to raise the level of scientifically based fertilization.

The course of reaching the planned target of increasing the cereal output by 10.0 Mt can be divided into two phases. Phase I is to increase grain yield by readjusting the ratio of soil nutrient input and correcting the soil K deficit. At present, the farmland of the whole province has a deficit of 311,800 t K. Field experiments showed that each kilogram of K can increase the yield by 8.34 kg. Thus increasing the K input by 311,800 t can lead to an additional grain output of 2.60 Mt.

Phase II is to achieve the remaining part of the increment in grain output by increasing the NPK input. To produce 7.40 Mt of cereals, the crops need to absorb 181,300 t of N, 34,400 t of P and 142,700 t of K. To produce an additional 10.0 Mt of vegetables and melons, the crops need additional 0.06 Mt of N, 8,800 t of P and 66,600 t of K. And to raise the fruit output by 2.0 Mt, the fruit trees need additional 662,900 t of N, 13,700 t of P and 68,700 t of K. The increment in the NPK consumption needed to raise the output of other crops will come from the cut of NPK use in those crops of which the area under cultivation decreases as a result of readjustment of the crop cultivation structure. At the same time, it is also under consideration that within the next 10 years, the savings in fertilizers due to improved fertilization technology can be used to balance the incremental fertilizer needs. To sum up, the additional amounts will be 304,200 t N, 60,400 t P and 589,800 t K (equal to 138,300 t P_2O_5 and 707,800 t K_2O).

If the current ratio between nutrients from mineral fertilizers and those from organic manure will be sustained, in 2010 the province will have an additional demand for 228,200 t N fertilizers, 107,700 t P fertilizers and 336,200 t K fertilizers or 672,100 t altogether. Considering the current surplus of soil P, it is not advised to further increase P input. The needed incremental production by crops due to P can be obtained by readjusting the ratio of fertilization and by raising the fertilizer recovery rate. In this case, in 2010, the province will consume 4.43 million t of mineral fertilizers, accounting for 8.7% of the country's planned total of 50.0 million t. Its $N:P_2O_5:K_2O$ ratio should be

1:0.41:0.32. This means that in the next 10 years, the fertilizer consumption will increase by 0.05– 0.06 million t every year, which is about 0.1 million t less than the observed annual increment during the past 10 years.

Strategy for fertilizers management in the future

The increase of nutrient recovery rate from fertilizers and the increase in economic benefit from fertilization by applying fertilizers in a scientific way is an important part of a sustainable agriculture. Based on the current situation of Shandong, the work in the following aspects should be accomplished for future fertilization management:

1) Readjust the ratio of mineral fertilizer nutrients input. Currently the ratio of fertilizer input is 1:0.45:0.21 ($N:P_2O_5:K_2O$). According to the prediction, the total fertilizer consumption in 2010 will range between 4.40 – 4.50 million t with a proper ratio of 1:0.41:0.32. Therefore, in the coming years, the input of mineral fertilizers ought to follow the principle of slightly increasing N, maintaining P and increasing K inputs. The fertilizer application rate to vegetables has to be reasonably reduced while the rate in low-yielding cereal fields has to be increased.
2) Establish a consumer-demand-oriented production system and a service-oriented distribution system. For that purpose, it is essential to set up consumer markets, produce adequate quantity of demanded products and make stocking plans. Sales of mineral fertilizers should also be based on providing farmers with technical service and supplying mineral fertilizers combined with guiding farmers to scientifically based fertilization. The production of blended fertilizers should be standardized and the scope of their application expanded. Now the province has more than 300 fertilizer blending plants with a total designed capacity of over 6.0 million t. But their actual output is less than 3.0 million t, far from the actual demand of 6.0-7.0 million t. The extension of fertilizer blending techniques should be promoted and the plants reasonably designed and located so as to reduce unnecessary transport. The producers of fertilizers must comply to strict quality criteria, optimize formulas and improve technology. Each plant should build up its own consistent service unit, not only supplying farmers with blended fertilizers, but also helping farmers to analyze soil samples and to set up fertilization records and files. Furthermore, providing technical consultation service and even apply fertilizers for farmers could be part of the agro-technical service centers.
3) Increase and improve types of mineral fertilizer. For long, the province used only a few, mainly single nutrient, straight fertilizers with often low nutrient contents. Their average nutrient content was only 29.1%. Urea and ammonium bicarbonate were the dominant N fertilizers, among which the latter accounted for 49% of the N supply. Calcium phosphate and calcium magnesium phosphate amounted to approx. 50% of the P fertilizers. From now on, it is a priority to raise the proportion of highly concentrated compound fertilizers. Then, while efforts are made to change ammonium bicarbonate production lines into urea plants, the production of improved ammonium bicarbonate should be promoted to increase the use efficiency of this N source

in the meantime. Moreover, it is necessary to develop a series of granular N and P fertilizers and stimulate the development of BB manure. In addition, research and production of controlled-release fertilizers, instantly soluble fertilizers, liquid fertilizers, microbial additives and commodity organic manure should be promoted.

4) Make full use of crop residues (straw and stalk) as a source of nutrients. Every year, the province produces 63.0 million t of crop residues of which about 20% (13.0 million t) are not utilized. The technology of returning crop residues to the field through machines during harvesting, through digestion by animal and through fast-composting processes ought to be widely extended. At the same time, efforts have to be made to tap other sources of organic manure. Investigations revealed that in the province, one hectare of farmland could have 52.5t of fresh organic manure, of which only 75% is utilized at the moment.

5) Intensify research and extension of scientific fertilization techniques. This is a strategic measure to raise the economic benefit of fertilization. For that purpose, a complete and sound extension system has to be set up and through the system the technology of balanced fertilization has to be widely popularized by means of training, publicizing, conducting demonstration experiments, etc. Currently, emphasis should be laid on intensifying the use of K fertilizers, micronutrient fertilizers, blended and compound fertilizers, fertilization in protected cultivation, deep placement of mineral fertilizers and returning crop residues to the field. Then a fertilizer testing network and an information system should be established or restored to intensify the study on fertilization techniques and enhance the practical implementation. The focus of the study should be on cumulative recovery rate of fertilizers in high-yielding rotation systems and scientific fertilizer application methods, relationship between fertilization and the environment, preparation of new types of fertilizers and breeding of new crop varieties with improved or genetically modified nutrient features.

Farmland nutrient balances and prediction of the mineral fertilizer requirement for the 21st century in Henan

Jiao You Li Guibao[1], Duan Guangyin[2], Qiao Wenxue[3]

[1] Soil & Fertilizers Institute, Henan Academy of Agricultural Sciences 450002
[2] Soil & Fertilizer Station, Lankao Agricultural Bureau
[3] Agricultural Station, Shuitun Township, Runan County

Abstract

Nutrient balance studies of 65 households in 3 counties of the Henan Province were carried out. The investigation revealed that there is a surplus application of the nutrients N and P whereas K is under-supplied. The rate at which K farmers of the studied counties returned K to replace removals was in the order of Runan > Lankao > Mengzhou. Of the total nitrogen fertilizer input, straight nitrogen fertilizer accounts for about 50%, mainly in form of ammonium bicarbonate. Among the phosphate fertilizers, SSP is the major type used with only a little calcium magnesium phosphate included in compound fertilizers. K from straight potassium fertilizer accounts for less than 50% of total K input and makes up only 20.3% in Lankao. In this county N inputs were almost in balance with the output. The same was observed for P in Mengzhou and for K in Runan. There was a dramatic K deficit in Lankao and Mengzhou. At the provincial level, all the nutrients, including N, P and K were not compensating for the losses from the soil by harvest. The current use of mineral nutrients (2001) is 1.977 Mt of N, 547,000 t of P_2O_5 and 403,000 t of K_2O. For sustained productivity of its farmland, by 2020, Henan farmland requires N at the amount of 2.07 million tons, P at 510,000 tons of P_2O_5 and K at 680,000 tons of K_2O from mineral sources to cover the demand for an increased food production. The amounts were calculated based on the observation that 30% of the N requirement will be supplied by organic sources (residues, farmyard manure, etc.) and the application ratio in this material is 1 : 0.6 : 1.5 and the efficiency including residual effects of the mineral fertilizers is 60%, 70% and 100% for N, P and K, respectively.

Introduction

Henan is located in the central part of China. The total area is 16.7 M ha, equal to 1.74% of the national area. By the end of 2001, the population was 96.03 million, ranking first and comprising 7.71% of the national population. Being situated in north subtropical and temperate zones, Henan agricultural production benefits greatly from sufficient radiation, temperature and water resources. With the increase of yield per ha and the multiple crop index, the nutrient input to farmland became insufficient, thus nutrient input/output are not balanced. Therefore, it is necessary to investigate the nutrient balance status and to predict the future mineral fertilizer requirement in Henan.

Materials and methods

Three counties, each representing a typical agricultural production area, were chosen in Henan. Mengzhou in the North-West (low hill), Lankao in the eastern plain and Runan in southern depression. Two representative townships from each county, two production groups from each township and four to five rural households from each production group were chosen. A representative soil sample, weighing about 500g, was collected from the farmland of each household. Three to five irrigation water samples from each county were collected and were tested for NO_3-N at the site with an indictor paper. The nutrient balance for the households were calculated with the obtained results. The nutrient balances for the county and provincial levels were gained from statistics. The results shown in the tables were calculated on area sown per crop and on average weight. Animal excrements were considered in the manure application.

Lankao is located in North-East Henan. The mean annual precipitation is 678 mm and the mean temperature is 14° C. Three former branches of the Yellow River crossed the territory, thus fluvio-aquic soil is the major soil type derived from alluvial deposit. Agricultural development has always been severely limited by wind, sand, salinity and alkalinity. It is one of the poorest counties in Henan. Total population in 1997 was 734 thousand, including the agricultural population of 615 thousand. The cultivated area is 60.3 thousand hectares. Major rotations are wheat-maize and wheat-oilseeds. The most commonly used fertilizers are urea, ammonium bicarbonate and single super-phosphate. In recent years potassium chloride has also been used in small quantities.

Mengzhou is located in northwest Henan with a mean annual precipitation of 550 mm and a mean annual temperature of 15° C. Total population in 1997 was 330 thousand, including the agricultural population of 235 thousand. Its cultivated area is 23.3 thousand hectares. Wheat-maize/cotton is the major rotation. The main soil types used for cultivation are cinnamon soil derived from loess and fluvio-aquic soil derived from alluvial deposit. Ammonium bicarbonate and single super-phosphate are popular fertilizers in Mengzhou. A small amount of potash is used in the fields since the end of the 1980's.

Runan is located in southern Henan. The mean annual precipitation is 876mm and the mean temperature is 14.9° C. Total population in 1997 was 808 thousand, including the agricultural population of 734 thousand. The cultivated area is 100 thousand hectares. Wheat-maize/oilseeds is the major rotation. This area is dominated by Shajiang black soil derived from sediments of old rivers or lakes. Owing to extensive cultivation, drought problem over the recent 10 years and rainfall not synchronized with crop growth, crop yield is low and unstable.

Result and discussion

Nutrient input : output for household fields

In total, 21 households were surveyed in Lankao. Of them, 10 were from Mengzai Township with an cultivated area of 4.19 ha, mainly situated on light loam or loamy soils. 11 households were from Yifeng with a cultivated area of 9.35 ha mainly located on loamy or clayey soil. Soil analysis revealed 1) N and P inputs largely exceed their output, especially P, whereas K was insufficiently supplied with a return rate of only 59.8% of the removed amount (Table 1). 3) Urea and ammonium bicarbonate are common nitrogen fertilizers and the rest in form of compound fertilizer which greatly increased recently (data of 2001) to 887,000 t of nutrients. The calculated nutrient input ratio (excluding compounds) of N: P_2O_5: K_2O was 1:0.48:0.19, whilst the ratio of removal by crops was 1:0.30:0.52. It is clear that the amount of K input cannot guarantee an adequate replacement.

20 households were surveyed for the nutrient balance in Mengzhou. Of them, 10 were from Zhaohuo township with a cultivated area of 9.68 ha, consisting mainly of cinnamon soils. The other 10 households were from Xiguo with a cultivated area of 5.65 ha on mainly fluvio-aquic soils. As shown in Table 1, there was a certain surplus of N whereas P inputs nearly met the crop requirement based on a 70% recovery efficiency (including its after-effect).

Table 1. Nutrient input-output balance in the fields of households studied in 1997 (Unit: kg)

	Item	Lankao (21 households)			Mengzhou (20 households)			Runan (24 households)		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Input	Mineral single fertilizers	2729	1405	240	5025	907	708	2655	502	445
	Compound fertilizers		197	214	95	792	692	80	477	538
	Manure	1340	413	820	1034	347	559	1207	211	717
	Straw returned	22	11	29	111	58	149	27	5	37
Total		4288	2044	1184	6962	2004	1496	4366	1257	1199
	Nutrient ratio	1	: 0.48 :	0.28	1	: 0.29 :	0.21	1	: 0.29	: 0.27
Output	Grain	1389	462	1395	2710	1171	2697	974	418	974
	Cotton	409	612	421	89	33	68	43	14	34
	Oil crop	516	65	161	359	94	240	434	112	288
	Vegetables	-	-	-	90	43	112	43	21	53
	Mineral N lost[a)]	1092			2010			1062		
	Manure N lost[b)]	402			310			362		
Total		3807	1139	1977	5568	1341	3117	2917	565	1349
Nutrient ratio		1	: 0.30 :	0.52	1	: 0.24 :	0.56	1	: 0.19 :	0.46
Balance (+/-)[c)]		+480	+905	-793	+1394	+663	-1621	+1448	+691	-150
Return rate(%)[d)]		113	179	60	125	150	48	150	222	89

Note: a) calculated on 40% of mineral fertilizer, b) calculated on 30% manure, c) input – output, d) (input : output)×100

On the other hand, K input : output ratio is extremely unbalanced with the K supplied, covering only less than 50% of the crop requirement. Taking into account that ammonium bicarbonate with 58% is the major nitrogen source, N losses may be large so that the balance for nitrogen is less positive than calculated above.

24 households were chosen for the nutrient investigation in Runan. Of them, 15 are from Shuitun township with a cultivated area of 6.02 ha. The other 9 households were from Hanzhuang with a cultivated area of 4.76 ha. Shajiang black soil is the major soil type in this county plus some yellow cinnamon soil. In this county, N and P show an obvious surplus compared with the other two counties mentioned above, due to nitrophosphate as common fertilizer used by these households (Table 1). About double of the removed amount was returned by mineral fertilizer, leading to a P return rate of 222%.. K inputs were smaller than the outputs, however, to a lesser extent than in the two counties. It is therefore recommended that the use of N and P ferilizer should be decreased and that the K input should be increased accordingly. For such an adjustment, compound fertilizer with low P and high K could be introduced for the future. In order to save costs, indigenous soil nutrients should be activated through appropriate tillage and cultural practices, considering the high nutrient supply potential of the Shajiang black soil.

County-wide nutrient balance for Lankao, Mengzhou and Runan.

The county-wide nutrient balances were calculated based on the cropping pattern, respective yields and nutrient uptake by the crops and compared with the input by mineral fertilizer and organic manure. The total figures were then divided by the area that each crop occupies in the county to calculate the average figures per hectare (Table 2).

Table 2. Average nutrient balance on farmland of the three surveyed counties based on statistical data in 1997

County	Lankao			Mengzhou			Runan		
	N	P_2O_5 (kg ha^{-1})	K_2O	N	P_2O_5 (kg ha^{-1})	K_2O	N	P_2O_5 (kg ha^{-1})	K_2O
Input M.F [a)]	118	81	22	207	65	42	158	76	37
O.M. [b)]	45	29	57	35	24	42	52	33	72
Total	163	110	79	242	89	84	210	109	110
Output									
Cereals	93	31	93	161	69	160	82	35	82
Cotton	27	41	27	5	2	4	4	1	3
Oilseeds	35	4	11	21	5	14	37	9	24
Vegetables	-	-	-	5	3	7	4	2	4
Total	155	76	131	192	79	185	127	47	113
Balance	8	34	-52	50	10	-101	83	62	-3

Note: a) M.F. = Mineral fertilizer N utilization rate of 60% (including after-effect); P utilization rate of 70% (Including after-effect); b) O.M. = Organic manure: N utilization rate 60% (including after-effect).

Lankao: The comparison between inputs and outputs reveal that supply and removal are in balance for N with a slight surplus of N and P. However, these amounts can only be regarded as surplus under the assumption of the respective nutrient utilization rates. Based on the calculations outputs exceed the inputs of K by 52 kg ha^{-1} of K_2O which means that on average of the county this amount is lost from the soil K reserves every year.

Mengzhou: Mengzhou is one of the counties in Henan characterized by high crop yield due to intensive cultivation. The calculated nutrient balance shows a positive balance for N and P and a negative balance at an annual rate of -101 kg K_2O ha^{-1} for potassium. With this kind of insufficient replacement of removed K, soils in the medium to long-term will be depleted of potassium.

Runan: Crops production due to less favourable conditions in Runan is difficult and related production problems receive high priority by the provincial government. At the time of the survey, the county had a positive balance for N and P whereas K with application rates of 110 kg was rather balanced. The surplus application of N and P is related to the widespread fertilisation practice of using nitro-phosphate as common mineral fertilizer in this county.

Changes in nutrient balances for the whole Henan Province

To monitor the trends in soil fertility and as a decision tool for the fertilizer supply application in order to enhance their economic efficiency, nutrient balances should be periodically assessed. Using available statistical data, nutrient inputs and outputs for the whole Henan Province were calculated for three different periods (Table 3).

From 1980 to 1997, with the increase in yields and the raise in the multiple crop index, the demand for N, P and K increased accordingly. Although the nutrient input was also increased, no nutrient balance was achieved due to an inefficient fertilizer input system. Assuming a nutrient utilization efficiency for N of 60% in 1980, only 80% of the N removed by the crops was replaced by nutrients from organic and mineral sources. In the two periods of the 1990's though N inputs were increased, there was no substantial oversupply (7% in 1992 and 11% in 1997) of nitrogen. This is different for P which was insufficiently supplied in 1980 and covered only approx. 74% of the amount removed. In the 1990's, this P deficit in the balance has changed to a surplus supply of 60% in 1992 and about 50% in 1997. These amounts of P were badly needed to compensate for the P depletion of the soils that took place in the 1980's. In the meantime soils have, however, been charged with P and application rates can be reduced. This is different for K, where until today removals greatly exceed the inputs, showing that only between 51% in 1992 and approx. 60% in 1997 of the removed amounts are returned to the fields. With annual K undersupply of 584,000 tons, Henan soils would loose more than 10 Mt of K_2O until 2020. Since this cannot sustain the needed high crop production, the province has implemented a "K supplementation project". With regard to the requirement of the crops, the $N:P_2O_5:K_2O$ with 1: 0.41-0.42: 0.94-0.98 is almost constant. The small deviation is due to the annual changes of sown areas allocated to various crops. Field experiments carried out over several years showed that N fertilizer had the strongest effect on crop yields.

Estimation to the requirement of mineral fertilizers in Henan

Population growth is the key, driving force for the nutrient consumption in the 21st century to supply the growing food demand. It is estimated that the population of Henan will reach its peak of 108.73 million in 2020, from 96.03 million in 2001. In order to maintain the level of food supply from the main crops grown in Henan, food agricultural production has to match the rate of population growth (Table 4). By means of extrapolation from the current yield levels and the respective nutrients needed to supply the requirements to produce these yields, the future nutrient has been anticipated. In 1997, 80%, 78% and 42% of the total N, P_2O_5 and K_2O input to farmland was supplied by mineral fertilizers, respectively. By including nutrients from recycled crop residues and farmyard manure, etc., it is estimated that the nitrogen coming from mineral fertilizer will around 70% of the total demand in the future. The rest needs

Table 3. Nutrient balance for Henan farmland in 1980,1992,1997 (Unit: 1000 tons)

Crops	1980				1992				1997			
	Yield	N	P_2O_5	K_2O	Yield	N	P_2O_5	K_2O	Yield	N	P_2O_5	K_2O
					Removal by crops							
Cereals	21486.8	601.6	260.0	599.5	31096.0	871.6	377.1	869.0	38946.6	1090.5	471.2	1086.6
Cotton	406.2	60.9	21.9	48.7	658.5	98.8	35.6	79.0	790.0	118.5	42.7	94.8
Oilseeds	462.0	20.0	8.2	18.7	1336.3	89.3	21.0	52.1	2766.6	16.60	43.7	110.7
Fibres	84.9	6.8	2.0	4.2	136.8	10.9	3.1	6.8	137.3	11.0	3.3	6.7
Tobacco	188.9	7.7	1.3	2.1	45.0	18.8	3.2	5.0	416.0	17.0	2.9	4.6
Fruits	435.5	2.2	0.8	2.6	877.9	4.4	1.8	5.3	2692.6	13.5	5.4	16.2
Vegetables	5755.0	23.0	11.5	28.8	9789.0	39.2	19.6	48.9	24936.8	99.7	49.9	124.7
Total		722.2	305.7	704.6		1133.0	461.4	1066.1		1508.7	619.1	1444.3
Nutrient ratio		1 :	0.42 :	0.98		1 :	0.41 :	0.94		1 :	0.41 :	0.95
					Input (after considering the nutrient utilization rate)							
Mineral fertilizer[a)]		350.8	79.0	27.3		941.3	569.7	129.0		1344.1	722.0	360.6
Organic manure[b)]		235.1	146.5	379.6		272.1	169.5	412.4		328.2	204.9	499.5
Total		585.9	225.5	406.9		1213.4	739.2	541.4		1672.3	926.9	860.1
Balance(+/-)		-136.3	-80.2	-297.7		+80.4	+277.8	-524.7		+163.6	+307.8	-584.2
Return rate[c)] (%)		81.1	73.7	57.5		107.1	160.2	50.7		110.8	149.7	59.6

Note a) Mineral fert.: N utilization rate 60% (including after-effect), P utilization rate 70% (including after-effect), b) Organic fert.: N utilization rate 70% (including after-effect), c) returned nutrients to the field in percent of the total amount removed.

to be balanced by mineral sources and it is estimated that the amount of mineral N fertilizer required by crops will hence be 1.24 million tons N in 2020. Based on the assumption that the

N : P_2O_5 : K_2O ratios from the applied manure will remain at the observed ratio of 1 : 0.6 : 1.5 (see Table 3) also substantial amounts of the other two nutrients will originate from this source. In contrast to N and K, except for sloping areas where soil erosion is a problem or on very light soils, P losses are much reduced and once charged with P, application of mineral P needs just to balance the difference between removals and the crop residues returned to the field. Therefore, it is estimated that there is only a very limited potential for further growth in P consumption in the future. Therefore, in the year 2020, the amount of phosphate needed in the form of mineral fertilizers is estimated as 842,000 tons P_2O_5. Based on the above observation (see Table 3) that there is a relatively fixed ratio of about 1 : 1.5 between the N and K in the organic manure and 30% of the N uptake is from this source, approximately 762,000 t of K_2O will be from organic manure. The rest of 932,000 t of K_2O to balance the crop removals has to come from mineral fertilizer. Given the utilization rate of mineral fertilizers of N, P and K with 60%, 70% and 100% (including after-effect) as of 2020, mineral fertilizer requirement will be: 2.07 million tons of N, 842,000 tons of P_2O_5 and 932,000 tons of K_2O. This will result in an N : P_2O_5 : K_2O consumption ratio of 1 : 0.41 : 0.45. With a wider ratio of N : K_2O of 1 : 0.25 as it is currently recommended, the demand for K will be around 520,000 tons of K_2O, which however would lead to a further K depletion of the soil.

Table 4. Nutrient demand from mineral fertilizer for Henan in 2020

Crops	Yield (1997)	Yield (2020)	Nutrient uptake by crops (1000 tons) N	P_2O_5	K_2O
Cereals	38,950	45,820	1,280	550	1,280
Cotton	790	930	140	50	110
Oilseeds	2,770	3,260	200	50	130
Tobacco	420	490	20	3	5
Fruits	2,690	3,160	16	6	19
Vegetables	24,940	29,340	120	60	150
Total uptake			1,776	719	1,694
- NPK supplied by organic manure*			533	129	762
Theoretical requirement by mineral fertilizers			1,243	590	932
Effective requirement by mineral fertilizers**			2,072	842	932

*based on the assumption that 30% of the N is from organic manure and the N : P_2O_5 : K_2O application ratio through organic manure will be the same as in Table 3, namely 1 : 0.6 : 1.5.

**determined based on 60%, 70% and 100% efficiency of the applied N, P and K fertilizer.

Conclusions

The nutrient balance study in cropping systems of 65 households in 3 counties, application of mineral N exceeded the removal through the crops by between 13% and 50% in the order of Runan > Lankao>Mengzhou. At the time of the study most of the N (>50%) was applied in the straight form, mainly as ammonium bicarbonate. In case of phosphorus, the amount applied on average exceeded the removal through the crops by 50% and 120% in the order Mengzhou < Lankao < Runan. Among the phosphate fertilizers, single super-phosphate is the major type with only a little calcium magnesium phosphate included in compound fertilizers. The K balances of the studied households revealed that between 48% (in Mengzhou) and 89% (in Runan) of the amounts of K removed were returned to the field by mineral and organic sources. This indicates a continued depletion of the soil K pools.

The nutrient balance of farmland at the provincial level reveals that in 1980 all the considered nutrients were insufficiently supplied, causing negative balances of N, P and K. This changed in 1992 and 1997 when slight surplus application of N and a stronger surplus of P occurred. This latter was probably due to the strong P depletion of the soils in the years until 1990 and to the requirement of recharging the soils with P. With a continued undersupply of K, Henan soils are facing a strong depletion of their K pools. For a sustained productivity of the soils, the removals must be balanced and the recommendation for the future nutrient consumption in Henan has to be adjusted accordingly. It will mean that N and P fertilizers should only have a moderate growth whereas for K a strong growth in consumption is recommended to reach crop production goals and to meet the future food demands of the province.

Nutrient cycle and nutrient balances in farmland ecosystems of the Shaanxi Province

Yang Xueyun, Zhang Shulan, Wang Xifang, Tong Yan'an, Sun Benhua and Zhao Hubing

Shaanxi Province Soil and Fertilizers Institute 712100

Abstract

Results of studies on nutrient cycles and balances in farmland of the Shaanxi Province indicate that in 1977 all three nutrients, N, P, K, were deficient but N and P developed to a slight surplus at the end of the 1980's. The surplus of these two nutrients further increased until 1997, while K remained deficient. In 1997, the $N:P_2O_5:K_2O$ ratio of fertilizer consumption with 1:0.26:0.08 was significantly wider compared to that in the developed countries of 1:0.42:0.42. It is estimated that the province's demand for fertilizers for its farmland in 2007 – 2012 will be 0.87 Mt N, 0.365 Mt P_2O_5 and 0.174 Mt K_2O with a ratio of 1:0.40 - 0.42: 0.15 - 0.20.

Introduction

A farmland ecosystem is very susceptible to the influence of anthropogenic factors, affecting the nutrient cycle and its balance. Therefore, a study of the current nutrient cycle of various farmland ecosystems can serve as a basis for issuing new regulations to improve the nutrient supply to crops towards a more sustainable agriculture.
So far, nothing has been reported about the nutrient cycle and balance of the farmland ecosystem of the Shaanxi Province. Based on field studies of typical cropping systems selected at representative sites in the province and the agricultural statistics of different time periods, the nutrient cycle and balance of the farmland at different scales of the province were assessed.

Natural conditions

Placed in the middle reaches of the Huanghe River, the Shaanxi Province strides over three climatic zones, i.e. the northern subtropics, the warm temperate and the temperate climate. Furthermore, Shaanxi has three distinct moisture zones, i.e. a humid, a semi-humid and a semi-arid zone. The Beishan Mountain and the Qinling Mountain ranges split the province into three natural regions, i.e. the Loess Plateau in the north, the Guanzhong Basin in the center and the Qinba mountain region, each having its own distinct features. For this research project, three counties (cities), Yan'an, Fufeng and Hanzhong were selected to represent the three typical agro-ecological zones of the province. Yan'an in the north of the province is characterized by the lowest mean temperature and the smallest amount of annual rainfall (Table 1). Only one crop per year can be cultivated in this region. Towards the center of Shaanxi, in Fufeng the annual temperatures and rainfall are sufficient for 2 crops-per-year rotation systems mainly based on either wheat-maize or oilseed rape-maize. In Hangzhong in the south, rainfall and temperature are adequate to grow rice based cropping systems of wheat–rice or oilseed rape–rice.

Table 1. Natural conditions in the typical agro-ecological regions of Shaanxi

Region	Yan'an, north	Fufeng, central	Hanzhong, south
Climatic zone	Mid-temperate, semi-arid	Warm temperate, semi-humid	North subtropics, humid
Cropping system	Maize, upland cereals (one crop a year)	Wheat (rape)-maize (two crops a year)	Rice-wheat (rape) (two crops a year)
Annual mean temp.	9.0	13.0-15.0	14.3
≥0°C cumulative temp.	3000-3500	>4000	>4500
Annual precipitation	400-450 mm	545-700 mm	800-1200 mm
Landform	Hills-gully residual plateau	Fluvial terraces, loess plateau	Basin
Soil type	Huangmiantu	Loutu	Yellow cinnamon
Parent material	Loess	Loess	Alluvium

Basic status of soil nutrients

The soil analysis of the plough layer (0-20 cm) in the surveyed farmland indicates significant differences between the three counties in respect to their soil nutrient status. The soil properties show distinct regional difference, with most parameters increasing from north to south (Table 2).

Table 2. Soil nutrients in the investigated regions

Item	Yan'an, north	Fufeng, central	Hanzhong, south
Organic matter (g kg^{-1})	7.10	11.40	17.50
Total N (g kg^{-1})	0.61	0.80	1.38
Total P (g kg^{-1})	0.62	0.79	1.42
Total K (g kg^{-1})	23.00	23.00	22.40
Available N (mg kg^{-1})	43.00	57.00	96.00
Available P (mg kg^{-1})	4.70	8.80	9.80
Available K (mg kg^{-1})	118.00	179.00	106.90
pH	8.50	8.20	6.50

An exception of this is the K supply of the soils which is largest in the center and declines towards the south again. Also the soil pH which is high in the north declines to the south, caused by the higher rainfall and greater losses of basic cations through leaching.

Methods and parameters for calculation of nutrient cycling and balance

The selection and the estimation of parameters used for the analysis of the farmland nutrient cycle are crucial for the results. Therefore, the basic assumptions and figures are shown in the Tables 3-5. These data were used as inputs, the amounts removed by the harvested crops were used as outputs to calculate the farmland nutrient balances.
Based on the "Outline of the Chinese Fertilizer Science", "Fertilizers handbook" and "Teaching materials of Agro-chemistry" the nutrient input through applied night soil (human excretes), livestock wastes and chicken droppings was calculated. It was estimated that from only 50% of the population night soil was collected with a utilization rate of 50%. The animal excretes were estimated based on the number of the livestock at the end of the year and a collection and utilization rate of 50% (20% only for goat) was taken anticipated (Table 3).

Table 3. Nutrients in human and animal excretes (kg head^{-1} yr^{-1})

Item	N	P	K
Pig	4.90	1.30	5.01
Cow	40.00	5.30	25.71
Horse	33.80	5.60	21.71
Goat	2.30	0.40	1.10
Man	5.40	0.57	0.91
Chicken	0.11	0.05	0.05

The amount of nutrients applied through the irrigation water was determined by estimating the amount of water applied and the concentration of nutrients in the water which was collected at various stages during the vegetation period. A mean value was calculated and multiplied by the amount (Table 4). No data existed for the earlier periods so that in 1977 and 1987 this contribution to the nutrient cycle was not considered (see Table 6).

Table 4. Nutrients measured in irrigation water in 1997 (mg l^{-1})

Location	NO_3-N	P	K
Yan'an	0.83	0.06	2.93
Fufeng	5.42	0.04	1.97
Hanzhong	1.96	0.05	3.70

Nutrient removal by the crop was calculated using the nutrient concentrations of the various plant parts at harvest and the weight of the biomass produced at this stage (Table 5).

Table 5. Nutrient removal at harvest (kg t^{-1} harvested crop)

Crop	N	P_2O_5	K_2O	Crop	N	P_2O_5	K_2O
Wheat	25.0	5.0	17.0	Hemp	79.6	10.0	40.8
Maize	22.0	4.0	18.0	Sweet potato	4.8	0.8	7.1
Soybean	28.0*	6.0	28.0	Tomato	2.8	0.6	3.2
Millet	17.0	5.0	38.0	Cabbage	5.3	0.5	5.7
Rice	20.0	4.0	18.0	Carrot	4.2	0.8	5.6
Oilseed rape	60.0	9.0	38.0	Cucumber	1.8	0.5	2.5
Peanut	24.0*	5.0	26.0	Vegetables (mean)	3.9	0.7	5.1

*The amount of symbiotically fixed N_2 deducted.

The amount of nutrients recycled to the field in form of crop stalks and straw was not taken into account since based on the current practice by farmers only a very small proportion of this material is returned to the field. The amount of symbiotically fixed nitrogen by leguminous crops was deducted from the amount of N removed in the harvested crop and hence not added as additional input. Non-symbiotically fixed N_2 and N in irrigation water was neglected. The N loss from mineral fertilizers was set as 40% whereas it was assumed that losses of P and K are negligible in the studied areas. The nutrient input by mineral fertilizer was taken from the statistical yearbooks. The nutrients deriving from compound fertilizers were calculated on the basis of an $N:P_2O_5:K_2O$ ratio of 2:3:1 in the formula and then added to the N, P and K consumption figures.

Results and discussion

Farmland nutrient balance in the province

The farmland nutrient balance for the whole province of the years 1977, 1987 and 1997, using data from the statistical yearbooks, have been calculated. It is evident that from the 1970's to the 1990's, the Shaanxi Province experienced three completely different phases in N, P and K balance (Table 6). The three major nutrients were all deficient at the end of the 1970's. During the next phase, at the end of the 1980's, the nutrients were balanced with a slight surplus in N and P and a deficit of K of approximately 30 kg K_2O ha^{-1}. The surplus in N and P further increased to reach 90 kg N ha^{-1} and 15 kg P_2O_5 ha^{-1} in 1997. At this time, the input of nitrogen by organic manure accounted for 17.4% of the total input, which was much less than in 1977 and 1987, due to the larger amounts of mineral N supplied. The absolute amount of N applied through organic manure even slightly increased from 1977 to 1997. In the case of phosphorus, the proportion of P from organic manure declined to 22.5% in 1997 which is also due to the increased use of mineral P fertilizer. With regard to K, there was also a decline in the proportion of organic manure contributing to the K supply due to increased mineral K application. However, in 1997 still 63% of the K applied to farmland was coming from organic manure.

Table 6. Farmland nutrient balance in the Shaanxi Province (1000 t yr^{-1})

Item	1977			1987			1997		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Input									
Mineral fertilizers	127.6	6.1	5.2	345.0	33.3	12.3	703.2	79.6	47.8
Organic manure	107.6	16.9	58.8	117.9	17.8	61.7	148.2	23.1	80.3
Seeds	5.6	0.9	1.5	5.9	1.0	1.6	5.8	0.9	1.6
Irrigation water	--	--	--	--	--	--	18.4	0.3	19.3
Subtotal	240.8	23.9	65.5	468.8	52.1	75.6	875.6	103.9	149.0
Output									
Cereals	189.5	35.1	146.3	236.8	45.1	179.6	247.1	48.4	184.6
Oil crops	16.0	2.5	9.8	25.6	3.5	15.0	24.5	3.4	14.7
Loss from fertilizers	51.0	-	-	138.0	-	-	281.3	-	-
subtotal	256.5	7.6	156.1	400.4	48.6	194.6	552.9	51.8	199.2
Balance (1000 t)	-15.7	16.3	-90.6	68.4	3.5	-119	322.7	52.1	-50.2
Balance (kg ha^{-1})	-4.1	-3.56	-23.5	19.2	0.9	-30.9	90.6	14.6	-14.1

The fertilizer input quadrupled during these 20 years, signifying the great changes that took place in the agricultural development of the province. Nevertheless, the increment in grain yield credited to the input per unit of fertilizer decreased by a large extent, whilst the input of one kg fertilizer nutrients (NPK) led to a yield increase of 8.4 kg of grain in 1977, this ratio declined to 3.9 kg kg^{-1} fertilizer in 1997. In 1997, however, the province consumed on average 211.5 kg ha^{-1} N, 54.9 kg ha^{-1} P_2O_5 and 17.3 kg ha^{-1} K_2O with an $N:P_2O_5:K_2O$ ratio of 1:0.26:0.082 (see Table 11 and 12). This rate of N was comparable to the amounts used in one cereal cropping season in developed countries whereas the rates of P and K were much less. It is quite obvious that the potential in using fertilizers is great, but inappropriate application may also result in certain risks.

Farmland nutrient balance in typical counties (city)

Based on the statistical yearbooks, the farmland nutrient balances were estimated for the typical counties (Table 7, 8 and 9), resulting in a more or less similar trend to that of the province. However, the absolute variations in input and output varied greatly between counties or districts.

In the three years, shown in Table 7, mineral fertilizer application in Yan'an increased dramatically by more than 5 times for N and by almost four times for P whereas no mineral K was applied. This created a fairly large surplus in both N and P in 1997 and a K deficit, ranging between 17 and 44 %.

Table 7. Farmland nutrient balance in Baota District, Yan'an (t yr^{-1})

	1977			1987			1997		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Input									
Mineral fertilizers	-	-	-	771.5	129.3	-	4241.0	466.9	-
Organic manure	1020.0	144.0	523.0	1190.0	170.2	614.3	1820.0	279.3	1021.0
With seeds	79.9	8.4	24.2	73.2	7.7	22.2	72.3	7.6	22.1
Irrigation water	-	-	-	-	-	-	5.7	0.4	20.3
Subtotal	1099.0	152.4	547.3	2035.0	307.2	636.5	6139.0	754.2	1063.0
Output									
Cereals	940.0	183.3	963.0	1340.	218.2	1096.	1390.	240.0	1262.
Oil crops	20.0	4.4	16.6	40.0	4.4	16.6	40.0	4.4	24.9
Fertilizer losses	-	-	-	308.6	-	-	1697.	-	-
Subtotal	960.0	187.7	979.6	1689.0	222.6	1113.0	3127.0	244.4	1287.0
Balance rate(%)	14.5	-18.8	-44.1	20.5	38.0	-42.8	96.3	208.6	-17.4
Balance (kg ha^{-1})	3.77	-0.96	-11.7	10.2	2.5	-14.1	90.5	15.3	-6.73

In Fufeng fertilizer consumption more than doubled during the period 1987-1997 for N and tripled in case of P (Table 8). The consumption of mineral K increased by even more than 11 times. This caused that nutrient balance became more positive for all the nutrients and there is a surplus of 160 kg N ha^{-1} and 58 kg P_2O_5 ha^{-1} whereas there is a deficit of –54 kg K_2O ha^{-1} in 1997.

Table 8. Farmland nutrient balance in Fufeng (t yr^{-1})

Item	1977			1987			1997		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Input									
Mineral fertilizers	1879.0	-	6.2	7763.0	1055.0	74.7	17363.0	3345.0	850.1
Organic manure	1310.0	200.7	714.0	1330.0	200.7	705.7	1110.0	174.6	531.3
With seeds	97.1	18.9	28.6	92.9	18.1	27.4	82.2	16.0	24.2
Irrigation water	-	-	-	-	-	-	867.7	6.3	315.0
Subtotal	3286.0	219.7	748.8	9186.0	1274.0	807.8	19423.0	3541.0	1720.0
Output									
Cereals	2797.0	533.3	2051.0	5276.0	1023.0	3869.0	5230.0	1012.0	3761.0
Oil crops	515.0	80.3	322.9	651.0	96.9	410.1	437.0	64.2	271.5
Fertilizer losses	751.4	-	-	3105.0	-	-	6945.0	-	-
Subtotal	4063.0	613.6	2374.0	9032.0	1120.0	4279.0	12612.0	1076.0	4033.0
Balance rate (%)	-19.1	-64.2	-68.5	1.7	13.8	-81.1	54.0	229.1	-57.4
Balance (kg ha^{-1})	-15.5	-7.9	-32.4	3.2	3.2	-72.3	160.5	58.1	-54.5

In Hanzhong mineral fertilization started earlier with already substantial use in 1977 (Table 9). However, the nutrient consumption was not adequate to replace the removed and lost nutrients by the various pathways so that until 1987 all nutrients had a negative balance. This drastically changed in 1997, when the increase input of especially N caused an oversupply of this nutrient at an amount of almost 172 kg ha^{-1}. Similar observations were made for P, where increased inputs by mineral fertilizers caused that the balance became slightly positive with 19 kg P_2O_5 ha^{-1} in 1997. Increased application of mineral K also caused that the balance for this nutrient improved from –146 kg K_2O ha^{-1} to –74 K_2O ha^{-1} in 1997. The major part of the K applied, however, still came from the organic manure. This proportion significantly declined for the other two nutrients.

Table 9. Farmland nutrient balance in Hantai District, Hanzhong (t yr^{-1})

Item	1977			1987			1997		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Input									
Mineral fertilizers	968.4	144.0	71.9	3953.0	396.0	107.8	8032.0	790.8	362.5
Organic manure	1030.0	161.5	506.4	1080.0	170.2	514.7	1320.0	222.6	655.9
With seeds	60.7	11.0	12.6	56.9	10.3	11.9	58.8	10.6	12.2
Irrigation water	-	-	-	-	-	-	370.4	9.1	699.8
Subtotal	2059.0	316.5	590.9	5090.0	576.5	634.4	9781.0	1033.0	1730.0
Output									
Cereals	2150.0	427.7	1810.0	3220.0	645.9	2698.0	3167.0	632.8	2632.0
Oil crops	170.0	26.2	107.9	480.0	74.2	307.2	520.0	78.6	332.1
Fertilizer losses	387.4	-	-	1581.0	-	-	3213.0	-	-
Subtotal	2707.0	453.9	1918.0	5281.0	720.1	3005.0	6900.0	711.3	2964.0
Balance rate (%)	-23.9	-30.3	-69.2	-3.6	-19.9	-78.9	41.8	45.2	-41.6
Balance (kg ha^{-1})	-37.4	-7.9	-76.7	-11.7	-8.8	-146.	171.7	19.2	-73.5

A closer look at this reveals that the input of N, P and K with organic manure in Yan'an accounted for a very large proportion, still over 30% in 1997 which is explained by its rapid development of the animal production (Table 10). In Yan'an, organic manure in 1997 was the only resource for K since no mineral K was used. This is exceptional for the three regions studied and can't be continued in the long run without any detrimental effect on the productivity, despite the intensive animal husbandry, unless feed staff is imported. This is different in Fufeng, where only 6%, 5% and 38% of the N, P and K were applied through organic manure. Mineral fertilizers there are the main nutrient suppliers to farmland. In Hanzhong this is different and organic manure still contributes significantly to the nutrient supply of the farmland with 14%, 22% and 64% for N, P and K.

Table 10. Contribution of organic manure to the total input of nutrients (%) from 1977 to 1997

Region	1977			1987			1997		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Shaanxi	45.7	73.5	91.9	25.5	34.8	83.4	17.4	22.5	62.7
Yan'an	100.0	100.0	100.0	60.7	56.8	100.0	30.0	37.4	100.0
Fufeng	41.1	?	99.1	14.6	16.0	90.4	6.01	5.0	38.5
Hanzhong	51.5	52.9	87.6	21.5	30.1	82.7	14.1	21.9	64.4

Using the N : P_2O_5 : K_2O ratios of mineral fertilizer use (Table 11) as an indicator for balanced fertilization it is evident that throughout the periods studied the ratios divert very much from ratios found in the removal of nutrients which on average are 1 : 0.4 : 1 (N : P_2O_5 : K_2O). The application ratios were extremely wide for N : K, showing that there is a strong reliance by the farmers to supply the crops nearly from indigenous K sources (soil and organic manure): This is particularly evident from the fact that the surveyed farmers in Yan'an and Fufeng were not using any mineral K at all (Table 11).

Table 11. N:P_2O_5:K_2O ratios of mineral fertilizer consumption in Shaanxi in comparison to the surveyed regions

Region	1977	1987	1997	Farmer*
Shaanxi	1:0.11:0.05	1:0.22:0.04	1:0.26:0.08	
Yan'an	-	1:0.38: -	1:0.25: -	1:0.29:0
Fufeng	1:?:0.004	1:0.31:0.01	1:0.44:0.06	1:0.468:0
Hanzhong	1:0.34:0.089	1:0.23:0.03	1:0.23:0.054	1:0.38:0.075

* Based on a survey of farm households

The nutrient application rates confirm the described situation, but indicate a clear increase, showing a doubling of the N and P rates and a tripling of the K rates on average of the studied regions (Table 12). Very large rates of N and P in Fufeng and Hanzhong are in contrast to the relative moderate application rates in Yan'an. In the latter region, no K is applied which may be due to the overall smaller yield potential in this region.

Table 12. Nutrient application rates in Shaanxi and the typical regions investigated (kg ha^{-1})

Region	1977			1987			1997		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Shaanxi	33.1	3.63	1.6	96.8	21.5	4.2	211.5	54.9	17.3
Yan'an	-	-	-	22.9	8.8	-	127.4	32.1	0
Fufeng	37.5	-	0.2	161.8	50.4	1.9	409.1	180.6	24.1
Hanzhong	55.9	19.0	5.0	243.0	55.8	8.0	478.7	108.0	26.0

Nutrient balance in farmers' field

The nutrient balances in farmers' fields in the three typical regions in 1997 are shown in Table 13. The comparison of Table 13 with Table 7, 8 and 9 shows in farmers' fields in Fufeng and Yan'an, there was more serious K deficit than the average of the respective region. In Hanzhong, crop yield response to K was significant, while in Fufeng and Yan'an, the soils contained relatively large amounts of available K, so farmers seldom get response to K, hence omit application. The N and P surpluses in the farmers' fields in Yan'an were much smaller than the county's average whereas in Fufeng, they were quite close to the county's average. In Hanzhong, the N surplus in the farmers' fields was smaller than the county's average and the P surplus slightly bigger, which could be attributed to the local farmers' preference for diammonium phosphate.

Table 13. Farmland nutrient balance in farmers' fields (mean value) [kg ha^{-1} yr^{-1}]

Item	Yan'an			Fufeng			Hanzhong		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Input									
Mineral fertilizers	136.7	17.7	0	356.6	72.8	0	358.2	59.5	22.3
Organic manure	17.6	2.5	6.6	30.3	4.4	9.6	44.1	6.4	15.4
With seeds	2.2	0.2	0.7	1.9	0.4	0.6	3.5	0.6	0.7
With irrigation water	1.8	0.1	6.3	20.4	0.1	0.5	22.1	0.5	41.7
Subtotal	158.3	20.5	13.6	409.1	77.7	10.7	427.9	67.0	80.1
Output									
Removal with harvest	75.2	13.1	68.7	114.5	22.0	85.9	235.8	44.5	189.0
Loss from fertilizers	54.6	-	-	142.6	-	-	143.3	-	-
Subtotal	129.8	13.1	68.7	257.1	22.0	85.9	379.1	44.5	189.0
Balance rate (%)	22.0	56.5	-80.2	59.1	253.2	-87.5	12.9	50.6	-57.6

Farmland nutrient status

Based on the research method of Lu Rukun *et al.*, permissible balance rates were elaborated for nutrients in the Guanzhong region (Table 14). Based on this in Yan'an, the soil nutrient balance was reasonable both on the scale of the region and on farmers' fields. It is quite interesting to note that the N, P and K surpluses in the farmers' fields were apparently smaller than indicated by the statistical yearbooks. Investigations revealed that in that region, the actual area of farmland under cultivation was much larger than the area of farmland under contract[1].

[1] (Here, 'farmland under contract' means the farmland lent to the farmers by the government under a contract. For all the farmland belongs to the Country, the official report includes only the farmland area

Table 14. Permissible balance rates for farmland nutrients in Yan'an and Fufeng

Location	Item	Scope	N	P	K
Yan'an	Actual balance rate (%)	County	96.3	208.6	-17.4
		Farmers	22.0	56.5	-80.2
	Permissible balance rate (B%)		132.0	250.0	-100.0
Fufeng	Actual balance rate (%)	County	61.4	229.1	-57.4
		Farmers	67.8	253.2	-87.5
	Permissible balance rate (B%)		98.6	160.0	-100.0

It was quite common that farmers reclaimed wasteland on slopes of more than 20 degrees. Cultivation of land that according to the land use regulations should have been forestland or grassland also received fertilization, which resulted in a reduced application rate to land classified as farmland. This important aspect should receive more attention in future agricultural production. In Fufeng, the nutrient balance in the farmers' fields was close to the county's average, with N surplus and K deficit being within the permissible range. Only the application rate of P fertilizers was too high, which was also reflected in the N : P ratio (see Table 11), because the local farmers are used to apply one bag of white fertilizer and one bag of black, i.e. ammonium bicarbonate and high-effective P fertilizer (18% P_2O_5). P fertilizers were usually applied to wheat, rather than to maize. The method is worth, being extended to general practice, but at a smaller application rate. At present, there are no data of any long-term stationary field experiment available that could be used to evaluate the nutrient balance in the southern part of the Shaanxi Province. But enough field experiments have been carried out to confirm a significant crop response to K application in the region. In 1997, the K application rate for farmland was only 26 kg hectare. The project of "K supplementation" has shown its effectiveness. Efforts should be continued in related aspects.

Prediction of the fertilizer consumption for the next 10 years in the Shaanxi Province

The major concerns in the use of mineral fertilizer application are related to the dramatic increase in nitrogen consumption which in certain regions reached levels which are far beyond the requirements and it seems that certain accumulation in the ecosystems could be the result of this practice. To address this issue, it was suggested to regulate the N fertilizer supply to crops by setting the recommendation to 150-180 kg N ha^{-1}, independent of the crop, e.g. rice, wheat or maize. This was based on observations that yield response was usually insignificant when the rate was raised to 250-270 kg ha^{-1}. The field experiments conducted in the past two years have shown similar results. When the application rate of N reached 210-270 kg ha^{-1}, the crop yield did not further increase by additional N. Concerns are particularly related to the ground water pollution with nitrate, which should not exceed 11 mg N l^{-1}. Investigations revealed that in some wells the nitrate content of the water reached 9.3 mg N l^{-1} and in Guanzhong, about 29.7% of the well water was already contaminated with nitrate at levels above

under contract. However, the authors' investigation revealed that there is a considerable area of farmland owned by the farmers.)

the critical 11 N mg l^{-1}. In Shaanbei (the northern part of the Shaanxi Province), 21.5% of the sampled wells exceeded this value. Consequently, 375 kg ha^{-1} N for two crops and 195 kg ha^{-1} N for one crop have now been established as acceptable norms for controlling N application and reducing its side effects. Inefficient use of N, hence larger nitrate residues in the soil, may also be caused by insufficient supply of other nutrients, especially of K. In recognition of this fact, large emphasis is placed on adjusting adequate nutrient ratios which for the whole China are proposed as $N:P_2O_5:K_2O$ of 1:0.40-0.45:0.25. The current $N:P_2O_5:K_2O$ ratio of the province is only 1:0.26:0.08, and it has been found, due to the relative well supplied soils and the prevailing cropping systems, the ideal ratio for the Shaanxi is in the region of 1:0.42:0.20. Based on such a ratio and the multiple-cropping index of 137% (mean of 1986–1997) Shaanxi will need 0.870 Mt N, 0.365 Mt P_2O_5 and 0.174 Mt K_2O during the next 10 years. It is not likely that the N consumption will reach 1.00 Mt, although the province's fertilizer consumption will possibly increase to a great extent due to expansion of the acreage of high-yielding fields. Furthermore, expansion of cash crops, a reduction of the area of cultivated land, strong development of animal husbandry and related feed requirements will have a positive effect on the future mineral fertilizer consumption. The proposed improved utilization of crop stalks and straw, the technical advancement in raising the fertilizer recovery rate and heightened awareness of environment protection will certainly have their impacts so that a rather moderate increase in fertilizer consumption may be expected. Since in most regions, soil K supply is regarded as high and crop yield response to K application in long-term experiments is only 2-6% at the moment, it is predicted that organic manure and crop straw recycling will continue to remain the main sources of K. Therefore, during the next decade, no exceptional growth in the consumption of mineral K in Shaanxi can be predicted despite the irrational N : K ratios and the negative K balances in the various regions.

Problems in farmland nutrient cycling and suggestions for a better balance

1) Farmland ecosystems of Shaanxi reveal an inadequate $N:P_2O_5:K_2O$ application ratio which is currently 1:0.26:0.08. In addition to increasing N input, P and K input should be increased too, to bring the ratio up to 1:0.40-0.45:0.15-0.20. It is not advised to reach an $N:P_2O_5$ ratio closer than 1:0.50.
2) There is a widespread practice of burning of crop stalks and straw in the province's fields. It is suggested that more efforts should be made in research and management on the re-use of straw and stalks. Regulations should be formulated that encourage the composting of organic manure and to prevent straw burning.
3) Improved regulations for the farmland nutrient cycling should increase farmers' awareness of cultivating in a scientific way and to prevent irrational fertilization, causing environmental problems, which deserve high attention by the agricultural administration.

Chapter III

Farmland nutrient balance and fertilizer requirement of Southern China

Spatial and temporal variation in the nutrient cycle of rice fields in Jiangsu

Dong Yuanhua, Wang Xia and Xu Qi
Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008

Abstract

Rice cultivation has been practiced for almost 6,000 years in Jiangsu. With the utilization of improved seeds and mineral fertilizers, rice yield has been increased gradually year by year since 1949. Meanwhile, the cropping system and the fertilizer application practice have also been changed. Studies on nutrient cycling in rice field ecosystems began at the end of the 1970's and became a hot topic in the 1980's in China, of which a substantial amount of research was conducted in Taihu areas. This paper highlights the spatial and temporal variation of nutrient cycling in the rice field ecosystem in the Jiangsu Province, based on the results of field experiments carried out by the Institute of Soil Science in the 1960's and 1980's and the investigation of fertilization in high yielding rice fields by the Jiangsu Station of Soil and Fertilizer, in the late 1990's.

Temporal variation in the output of the rice ecosystem

The output of rice has changed during the different periods and can be largely attributed to the cropping system, improved seeds and increased fertilization. In the Taihu area, for example, at the beginning of the 1960's, the output of rice and wheat were 5,340 kg ha^{-1} and 3,810 kg ha^{-1}, respectively, and 6,510 kg ha^{-1} and 3,360 kg ha^{-1} in the early 1980's. The decrease of wheat output at that time may be caused by the triple cropping system. In the early years of the 1990's, rice yields reached 8,040 kg ha^{-1}, which is an increase of approximately 50% in comparison to the 1960's and by 22% in comparison to the 1980's (Fig.1).

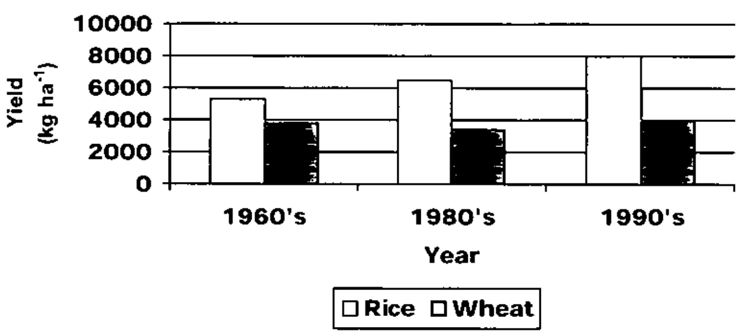


Figure 1. Rice and wheat yields in Taihu area

Temporal change of fertilization system in the rice ecosystem

The amount of nutrients removed from the ecosystem has undoubtedly increased with the growth in rice yield. To obtain the expected higher yield, the mineral fertilizer use increased from year to year. Therefore, the fertilizer application system has been changed greatly. For instance in the Taihu area, in the early years of the 1960's, the applied nitrogen came mainly from organic manure, such as animal manure, compost and pond sludge. The input of nitrogen from organic manure reached up to 1,011 kg ha^{-1}, while that from mineral fertilizer was usually less than 30 kg ha^{-1}. However, nitrogen from organic manure was nearly reduced to zero in the 1990's, while that from mineral fertilizer increased to 525 kg ha^{-1} on average.

Organic manure as a source of phosphorus has lost importance whereas that of mineral fertilizer has gained year by year. For example, in the 1960's, phosphorus came mainly from organic sources and reached 903 kg ha^{-1}, but there was almost no phosphorus applied from mineral fertilizer. At the beginning of the 1980's, the input of phosphorus from organic manure decreased to 88 kg ha^{-1}, meanwhile, mineral phosphorus fertilizer was used more commonly, reaching 18.6 kg ha^{-1}. In the 1990's, the phosphorus applied by organic manure decreased to almost zero, but P inputs from mineral fertilizer reached 84 kg ha^{-1}.

The change of K applied is similar to that of P. Potassium from organic sources was 106 kg ha^{-1} and no mineral potash was used in the early 1960's. In the early 1980's, K from organic manure decreased to 156 kg ha^{-1} while that from mineral fertilizer reached about 21.8 kg ha^{-1}. From the early 1990's, K applied by mineral fertilizer increased to 150 kg ha^{-1}, while the supply from organic manure was negligible even if some straw was returned to the fields. Although the mineral K fertilizer applied was much higher compared to the 1980's, the deficiency of potassium has become increasingly serious, worsening the nutrient imbalance (Table 1).

Table 1. Input of nitrogen, phosphorus and potassium to rice fields of Taihu area (kg ha^{-1})

Year	Nutrient source	N	P_2O_5	K_2O	$N:P_2O_5:K_2O$
1960's	Organic manure	1,011	903	1,006	1:0.87:0.97
	Mineral fertilizer	30	0	0	
1980's	Organic manure	41.7	88	156	1:0.32:0.54
	Mineral fertilizer	286.2	18.6	21.8	
1990's	Organic manure	0	0	0	1:0.16:0.28
	Mineral fertilizer	525	84	150	

Nutrient balance in the rice ecosystem of different periods

The nutrient imbalance was more pronounced in the 1990's than in the 1980's (Table 2). In the past decades, nutrients supplied by organic manure alone were not meeting crops' demand. However, in recent years, with the increasing surplus of N and the deficit in P and K, environmental pollution has become a more important issue in regard to farmland and water bodies (such as rivers, lakes, etc). To a great extent, this may be attributed to the change of the fertilization practice. The surplus of nitrogen as indicated in Table 2, however, does not pose serious problems to the soil quality. It is merely the imbalance of $N:K_2O$ input that may negatively affect the sustainability of production.

Table 2. Change of nutrient balance and input/output ratio in different periods in the Taihu area

Period	Nutrient balance (kg ha^{-1})			Input/output		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1980's	7.0	-4.1	-14.6	1.47	0.63	0.45
1990's	16.1	-7.7	-33.4	1.85	0.42	0.23

Cropping systems and nutrient removals

The cropping system has a distinct influence on the nutrient cycling and balance. Triple cropping systems of rice-rice-winter crops have been practiced in Jiangsu since the 1970's, and in the Taihu area for the last 10 years. Generally speaking, yields of triple cropping are larger than in double cropping systems of rice-winter crops grown in fertile soils. For example, annual yield of rice-wheat cropping was 9,870 kg ha^{-1}, while that of rice-rice-wheat could reach up to 12,400 kg ha^{-1}. Studies showed that nitrogen removed from soil amounted to 236 kg ha^{-1} in the double cropping system and 281 kg ha^{-1} in the triple cropping system. The removals of phosphorus and potassium showed a similar trend (Table 3).

Table 3. Nutrients removed from soil in different cropping systems (kg ha^{-1})

Cropping system	N	P_2O_5	K_2O
Double cropping	236	166	542
Triple cropping	281	202	641

Spatial variation in the nutrient cycling of rice fields in the Taihu area

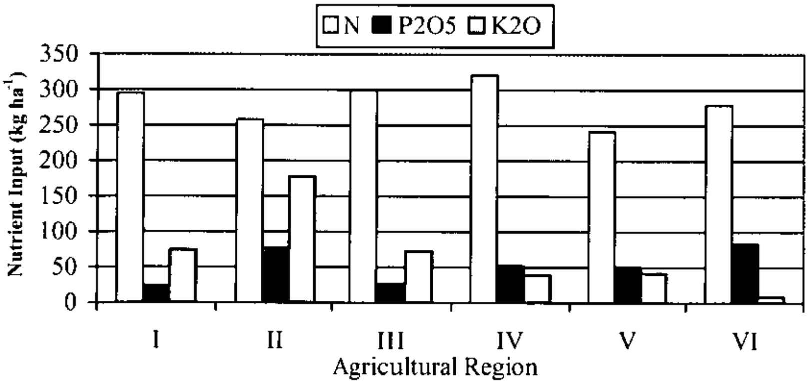
The Taihu area can be split into five geographic zones, namely Taihu plain, higher elevation plain, plain along the Yangtze river, polder and hill. The nutrient cycles and balances are different in each of the various zones. In the double cropping system of rice-wheat for example, the annual output was 10,500 kg ha^{-1} in Taihu plain, 9,600 kg ha^{-1} and 9,700 kg ha^{-1} in the higher elevation plain and plain alone and 9,300 kg ha^{-1} along the Yangtze River whereas in the polder and hill areas average yields reached only 7,600 kg ha $^{-1}$. Fertilizer input varied also according to the zones. Input of nitrogen, phosphorus and potassium depended on crops and soil fertility, which significantly influenced the annual yield and nutrient balance (Table 4).

Table 4. Spatial variation of nutrient balance in the Taihu area (kg ha^{-1})

Zone	Nutrient input			Balance		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Taihu plain	417	88	56	38	44	131
Plain along Yangtze river	436	101	71	41	59	-124
Higher elevation plain	398	80	60	35	41	-104
Polder	398	70	50	64	35	-88
Hill	363	70	44	18	32	-135

Spatial variation of nutrient cycling in rice fields of Jiangsu

The rice growing area in Jiangsu can be divided into 6 zones, based on geographical and geomorphologic factors, namely Ningzhen hill region, Taihu plain region, the valley of the Yangtze, the coastal area of the East China Sea, Lixiahe region and Xuhuai region. With diverse economical and soil conditions in the various zones, the fertilization level, yield levels and nutrient cycling also differed greatly (Fig. 2). As a consequence, there is a good relation between fertilization level and the productivity of rice fields. The removal of nutrients was greatly influenced by the output (Table 5). In 6 agricultural areas, input to output ratios of nutrients showed that in each area there was a surplus of nitrogen, while phosphorus and potassium were both insufficiently supplied (Table 6).



I: Taihu plain, II: Ningzhen hilly region, III: Yangtze river valley
IV: East China Sea coast, V: Lixiahe region, VI: Xuhuai region.

Figure 2. Spatial variation of nutrient input during the whole rice growing season (2-3 crops) in Jiangsu

Table 5. Spatial variations of rice yields (kg ha^{-1}) and nutrient removals in 6 agricultural regions of Jiangsu (kg ha^{-1})

Zone		Taihu plain	Ningzhen hill	Yangtze river valley	Region along East Sea	Lixiahe	Xuhuai
Total yield		8,040	8,520	8,085	8,175	8,025	8,010
Nutrient removal	N	170	181	171	173	170	170
	P_2O_5	120	128	121	122	120	120
	K_2O	420	445	422	427	419	418

Table 6. Spatial variation of nutrient input/output ratio in rice field in Jiangsu

Zone	N	P_2O_5	K_2O
Taihu plain	1.73	0.20	0.18
Ningzhen hill	1.43	0.60	0.40
Yangtze River valley	1.74	0.22	0.17
East China Sea coast	1.85	0.42	0.09
Lixiahe	1.42	0.42	0.10
Xuhuai	1.64	0.69	0.02

Conclusions

Before the 1960's, the fertilization systems in the Jiangsu Province were dominated by application of organic manure. Inputs and outputs of nitrogen, phosphorus and potassium were in balance but in low supply. Hence the productivity of the rice fields was low. Obvious changes took place in the early 1980's. Nitrogen input mainly originated from mineral fertilizer, while phosphorus and potassium were largely applied in form of organic sources. An imbalance of nitrogen, phosphorus and potassium was the result. In the early 1990's, the fertilization system completely changed. Nitrogen, phosphorus and potassium originated mainly from mineral fertilizer. The imbalance between nitrogen, phosphorus and potassium worsened.

Farmland nutrient balances in Jiangsu Province

Du Chenglin and Zhang Zhongyi

Institute of Soil Science, Chinese Academy of Sciences 210008

Abstract

Representative case studies and the analysis of the statistics for the whole province reveal that Jiangsu has a surplus in the N and P supply and a deficit in the supply of K to its farmland. All the soils of the province, except warp soil and Lianghetu soil derived from the Huanghe River flood sediments as well as the coastal saline soils of central Jiangsu, have a poor K-supplying potential. In general, nutrient imbalances through the management practices of farmers developed to such an extent that they adversely affect crop production. As a result, it is a crucial link in farmland nutrient management to continue implementing the project of "K supplementation" by increasing K application rates.

Introduction

The total area of cultivated land in the Jiangsu Province declined from 4,672,790 ha in 1977 to 4,435,450 ha in 1997, at a mean rate of 11,870 ha per year during these 20 years. The area of cultivated land per hundred persons also declined from 8.1 ha to 6.2 ha during the same period. It is anticipated that the gap between the increasing population and the shrinking cultivated land will widen. Since the province's land reserves are limited and it is very difficult to further raise its multiple cropping index, the increase in yield per unit area by improving and maintaining soil fertility has to become general practice. In the following paper a farmland nutrient balance was calculated for the counties/cities of Siyang, Qidong and Changshu, which differ widely with regard to ecotype and production level. In the study, the fertilization levels and yields of the different cropping systems were investigated. Furthermore, with related statistical data the nutrient balance for the whole Jiangsu province was analyzed, in order to recommend measures for improving and maintaining the soil fertility.

Material and methods

For the investigation the counties/cities of Siyang, Qidong and Changshu were selected to represent three major agricultural zones, Xuhuai, Binhai and Taihu in Jiangsu. Out of the three counties, six townships (or towns) were selected, being different in production levels and soil types. In each township, two villager teams were chosen and in each villager team, 4 - 5 farmers were nominated for the investigation. 61 farms were studied in total. At the same time, soil samples were taken in autumn before sowing.

During the investigation, in addition to related materials collected from the province and city statistic bureaus, information was gathered about each farm, including number of family members, area of farmland they cultivate, the area covered by cereals, cotton or oil crops. Furthermore, yield, type and quantity of fertilizers used, size of livestock herd, source of feed, use of crop straw and stalks in 1997 were assessed. This information was used for the analysis and computation of the farmland nutrient balance.
The major farming system of the province is a two-crops-per-year rotation system of wheat (or oilseed rape, broad bean, pea) and rice (or maize, soybean, cotton). Farmland NPK nutrient balance was assessed on the basis of a rotation cycle (one year) by deducting nutrient output from input of the field. The data were used to calculate nutrient gains or losses in the respective system.

Results and discussion

Nutrient inputs and balances in farmers' fields in Siyang, Qidong and Changshu

As mineral fertilizers have an instant and distinct effect and are easy to handle, farmers are willing to invest in them, pushing the dosage higher and higher up, especially N fertilizers (Table 1). The comparison between the three counties/cities reveal large differences in nutrient application rates. Largest amounts of all nutrients were applied in Changshu. It is assumed that this is associated with its better economic conditions compared to the other two regions. On the other hand, Qidong had the smallest application rates in all nutrients, but particularly the K application rate was small, leading to the widest N : K ratio.

Table 1. Rate and ratio of mineral nutrient inputs in the three regions (1997)

Region	Number of farms*	Rate (kg ha^{-1}) N	P_2O_5	K_2O	N : P_2O_5 : K_2O
Siyang	18	299	79	78	1 : 0.27 : 0.25
Qidong	20	253	78	23	1 : 0.31 : 0.09
Changshu	23	521	94	100	1 : 0.18 : 0.19

*: Number of farms investigated

Although farmyard manure is rich in organic matter and contains a variety of nutrients, its relative contribution to the total quantity of nutrients applied is declining. One of the possible reasons for this is the inconvenient and labor-consuming handling of the manure.
Traditional organic manure mainly consists of animal wastes. However, because of rising animal feed costs, strongly fluctuating meat prices, decreasing profits and increasing environmental sanitation requirements the size of livestock herds is apparently shrinking in the studied areas. For instance, in Changshu City, out of 23 farmers under investigation, only 21.7% kept pigs. Even on pig-rearing farms the average number was only 9.6 pigs per farm. In Qidong City, of the 20 farms under investigation, 33 goats and 1 buffalo were kept, but no pigs. In Siyang, where for years much

attention had been given to pig rearing, 18 farms kept 42 pork pigs, 2 sows, 42 piglets, 4 buffaloes and goats. The decrease in the size of livestock herds and the popularization of farming machines directly affect the input of nutrients from animal wastes.

As buffaloes and goats often graze in the field, the utilization rate of their wastes is estimated at 75% only. There is also a certain proportion of pigs that is herded outside, so that about 10% of their excretion is lost. By deducting that portion which is used on cash crops, about 50% of cattle and sheep droppings are recycled to cereal and cotton fields. The proportion of pig dung returned to the field with 70% of the total is slightly larger.

The investigations in these regions revealed that the practice of returning crop stalks and straw to the field is gradually popularized. It is done roughly by three techniques.1) harvesting rice or wheat, leaving high stubs in the field, usually 10-15 cm taller than before, equaling to 15-20% of the total amount of straw; 2) returning stems and straw directly, for instance, in Qidong, farmers often bury wheat straw, horsebean and pea stems and leaves directly in the soil between cotton rows, using about 30% of the total residues. In Changshu, small-sized combine harvesters are used to harvest cereals which leave the straw in the field at harvest. But the farmers usually burn the straw so that the amount of straw returned to the field reaches only about 30% of the total and 3) returning straw to the field after it was used for livestock bedding. This accounts for 5-10% of the total.

In this paper, the nutrient input of the farmland covers only nutrients supplied by mineral fertilizers, organic manure, seeds, seedlings and also the amount of symbiotically fixed N whereas the farmland nutrient output includes nutrients removed in the harvested crop and nutrient losses from fertilizers. Statistical analyses were carried out with the results gained from 61 farms, looking separately at each source of the nutrients N, P and K. The results show that N and P were mainly supplied by mineral fertilizers (fertilizer N : manure N = 1 : 0.03-0.27, and fertilizer P : manure P = 1 : 0.11-0.40) whereas K was mainly supplied through organic manure (fertilizer K : manure K = 1 : 0.68-2.43). The quantity and quality of organic manure used is the key factor to determine whether there is a gain or loss in farmland K.

The farmland nutrient balances of the 61 farms are shown in Table 2, which indicate that N and P balances are positive to a varying extent due to differences in the production level. On the other hand, the K balance was negative with the exception on farms where pigs were kept.

Table 2. Farmland nutrient balance of typical farms (1997)

Region	Number of farms*	Balance (kg ha^{-1}) N	P_2O_5	K_2O
Siyang	18	3.8	8.8	-14.5
Qidong	20	28.8	25.5	-58.4
Changshu	18**	61.4	-15.6	-104.9
	5***	203.7	40.2	103.6

*: Number of farms investigated. ** farms without pigs. *** farms with pigs.

Data from 50 fertilizer monitoring posts in Changshu (Table 3) also indicate that within a period of seven years, the total N content increased from 1.10 g kg^{-1} to 1.12 g kg^{-1} and alkalytic N (see Table 3) increased by 11.45%, but K decreased by 10% or 40.8% as compared to the figure of 179.0 mg kg^{-1} found in 1980. This observation is consistent with the negative K balance.

In Changshu, the 14 years continuous rice-wheat rotation system on a yellow earth (waterlogged paddy soil) received a total of 5,773 kg N, 857 kg P_2O_5 and 705 kg K_2O per hectare. During the same period (1984-1997), a total of 173,262 kg crops were produced that removed 3,764 kg N, 749 kg P_2O_5 and 3,048 kg K_2O. By balancing the input with the removal, it was found that the soil gained 2,008 kg N and 109 kg P_2O_5, which was basically in balance with the removals, but lost 1,112 kg K_2O. It has to be mentioned that the farmers who were assigned as monitoring posts were local farming headmasters with a relatively good knowledge of science based cultivation techniques. Even under such circumstances, K deficit seemed to be inevitable.

Table 3. Variation of major soil nutrients in Changshu

Year	Total N (g kg^{-1})	Alkalytic N*	Readily available P	Readily available K
		......................mg kg^{-1}	....	
1990	1.10	82.1	6.7	116.0
1993	1.09	110.3	5.9	107.4
1996	1.12	91.5	6.6	106.3

* 1.0 M NaOH incubation at 40° C for 24 h

Farmland nutrient balance in Jiangsu Province

Since 1978, with implementation of the family output-based contract system farmland nutrient input gradually increased, thus ensuring a continuous increase in the yield of cereals, cotton and oil crops (Table 4).

From there, it is evident that yields of all the major crops increased, except cotton, yields which fluctuated sharply due to pests, adverse weather conditions and changes in marketing. In 1997, the output of grains, lint and oils were 96%, 34% and 737%, respectively, larger than 20 years ago. If furthermore the substantial reduction in area available for farming is taken into account which coincided during this period, the real yield increments per unit area were even larger.

Table 4. Development in major crops in Jiangsu Province during the past 20 years

Year	Grains		Lint		Oils		Total	
	10^3 t	%	10^3 t	%	10^3 t	%	10^3 t	%
1977	18,197	100	380	100	169	100	18,746	100
1982	28,555	157	576	152	917	541	30,048	160
1987	32,577	179	444	117	1,208	713	34,229	183
1992	32,913	181	527	139	1,273	752	34,714	185
1997	35,638	196	508	134	1,419	837	37,564	200

Sources: Jiangsu Province Statistics Bureau

Table 5 shows that the input of mineral fertilizers rose significantly over the years, while the input of organic manure remained stagnated at the same level, which implies that in the meantime, mineral fertilizers dominate the nutrient input today. Readjustment of the N: P_2O_5: K_2O nutrient application to an acceptable ratio is a key measure for a sustainable development of the agriculture in Jiangsu Province.

Table 5. Nutrient input by mineral and organic sources in different years in Jiangsu Province (1,000 t)

Year	N		P_2O_5		K_2O	
	Mineral fertilizers	Organic manure	Mineral fertilizers	Organic manure	Mineral fertilizers	Organic manure
1982	1,038.1	96.6	325.0	26.8	30.0	87.2
1987	1,201.9	93.8	368.0	21.9	82.5	85.2
1992	1,530.1	107.9	483.0	25.0	215.6	114.2
1997	1,906.4	105.0	624.3	24.1	328.8	94.4

Based on the data provided by the provincial Statistical Bureau and related departments on outputs of crops and nutrient contents in the crops, nutrient balances of the province in different years were estimated (Table 6). These show that the inputs of N, P_2O_5 and K_2O in 1997 have significantly increased in comparison to 1977. Though K_2O in particular increased by 261.9%, the province still suffers an annual K_2O deficit of 314,900 t. On the contrary, in 1997 N showed a surplus supply of 1,047,100 t and P_2O_5 of 510,900 t. If the status of nutrient imbalance is not remedied, it is expected that besides yields and quality of the crops, the profits and also the environment will be negatively affected.

Table 6. Nutrient balances of Jiangsu Province in different years (1,000 t)

Year	Input			Removal			Balance		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1982	1,135	352	117	786	168	583	349	184	- 466
1987	1,296	390	168	891	180	669	404	210	- 501
1992	1,636	508	330	910	190	687	726	318	- 359
1997	2,011	648	423	964	178	738	1047	471	- 315

Note: Calculation based on data supplied by the Jiangsu Province Statistics Bureau

Soil K supply in Jiangsu

Since the 1970's, systematic studies have been carried out on soil K supply and crop response to K application in different soils and in different regions. Results indicate that only the warp soil in Xuhuai and the saline soil along the coast are fairly rich in K. On these soils, crop response to K application is generally insignificant.. All the other soils in the province have a K supply potential basically below medium level. In the 1990's, studies in different regions concentrated on determining the trend of soil K variation. In summary, the findings revealed that readily available K dropped rapidly due to inadequate K application. For instance, in Xuhuai with fairly good inherent soil K supply, long-term monitoring showed that the mean readily available K in soils of the farmland was 116.3±57.7 mg kg^{-1} (n = 111) in 1988 and 106.3±21.5 mg kg^{-1} (n = 534) in 1995. This clearly shows a decline of 10.1%, decreasing at a rate of 1.7 mg kg^{-1} yr^{-1}. The Xuzhou Agricultural Research Institute conducted crop response experiments for 15 years in a row. The results revealed that from 1981 – 1983, yields could be increased from 12,639 kg ha^{-1} in NP to 14,053.5 kg ha^{-1} in NPK, showing a incremental increase through K of 11.2%. From 1993–1995, the respective yield increased from 11,098 kg ha^{-1} to 12,832 kg ha^{-1}, equivalent to 15.6%. In Yixing, where soil K supply is medium to low, from 1983 to 1994 soil readily available K dropped by 13.8 mg kg^{-1} and even by 28.1 mg kg^{-1} in the whitish soil. The slowly available K decreased by 77.4 mg kg^{-1}. This trend can be attributed to the successive under-supply of K to the farmland in Jiangsu.

The current determination of soil K in the three counties/cities revealed that the mean readily available K content ranges between 68 and 132 mg kg^{-1} and the slowly available K between 384 and 618 mg kg^{-1} (Table 7). The soil supply potential expressed by the slowly available K contents was in the medium or slightly above medium range whereas all the soils were rather poor in readily available K, except the warp soil in Siyang and coastal saline soil in Qidong.

Table 7. Soil K contents and K supply potentials in different regions (1997)

Location	Soil	No. of samples	Mean K content (mg kg^{-1})		K supply class
			Readily avail. K	Slowly avail. K	
Changshu	Whitish soil, yellow earth, Wushantu	23	76 (52-132)	384 (244-603)	Medium
Qidong	Saline soil, Jiashatu, yellow earth	24	132 (57-295)	732 (589-855)	Upper medium
Siyang	Warp soil, sandy soil, Lianghetu, Gangbaitu	23	68 (24-197)	618 (381-1180)	Upper medium

Note: Figures in parentheses stand for ranges found

Strategy for farmland nutrient management in Jiangsu Province

As discussed in the previous sections of this paper, in the past 15 years, soil nutrient balances of the farmland in Jiangsu Province showed a surplus in N and P and a deficit in the K supply. This resulted in a universal decrease in soil K fertility. Therefore, "saving N, controlling P and adding K" will play an important role in the farmland nutrient management in the years to come.

First of all, endeavors will be concentrated on readjusting the nutrient composition in the fertilizer supply by increasing K application rate. In the mid 1990's, in view of the widespread appearance of K deficiency and the fact of decreasing soil K fertility, Jiangsu took the lead in the country in proposing and implementing a large scale project of "K supplementation", which led to significant changes in the nutrient management techniques by farmers.

Secondly, the practice of returning straw to the field should be extended more vigorously. The data in Table 5 indicate that in the past 15 years, Jiangsu depended mainly on mineral fertilizers to increase its nutrient input, with the input of organic manure remaining stable at around 0.1 Mt N, 0.025 Mt P_2O_5 and 0.09 Mt K_2O. Whether the input of organic manure can be increased, will largely depend on the success of expanding the practice of returning straw to the field. Currently, average rice yields in Jiangsu are 6,000 kg ha^{-1} which means at the same time approximately 6,000 kg ha^{-1} of straw are produced (grain : straw = 1:1). If 30% of the straw were returned, each hectare of farmland would save 45 kg of K_2O which is an important means to maintain K fertility. But the current situation shows that only 10% of the rice or wheat straw are returned by means of leaving longer stubs during harvest. In the cotton fields along the coast, cotton stalks are left standing in the field until the frost causes the leaves to fall and thus returning the nutrients to the field. Rainfall during this period helps the K in the cotton stalks to be washed into the soil for recycling. In general, returning straw may pose some difficulties to the farmers due to slow mineralization and immobilization of N by soil bacteria. Furthermore, the shortage of fuel in certain rural areas causes that straw is used as fuel for cooking and heating. Another factor limiting the popularization of returning crop residues is the lack of suitable machines to chop straw and to incorporate it into the soil.

Where crop stalks are used as fuel, effective measures have to be implemented to return the ash and prevent its loss through runoff or leaching.

Changes in soil fertility and prediction of fertilizer demand in Jiangsu

Yin Guangde, Liu Linwang, Xu Xuehong, Gao Qin and Liang Yonghong

Jiangsu Province Soil and Fertilizers Technique Guiding Station 210013

Abstract

In this paper the changing pattern of the physical and chemical properties of the major soil types in the Jiangsu Province in the late 1990's are studied by monitoring the change in soil fertility, the yield in relation to soil fertility and the basic land contribution rate. Soil organic matter, total N, readily available P and readily available K, all showed an upward trend. The indigenous soil productivity and its proportional contribution to rice and wheat production rose steadily. This can be mainly attributed to the dissemination of multi-pattern practice of returning straw to the field, the "K-supplementing project" and balanced fertilization techniques through the research and advisory system in the province during this period. Nevertheless, it is important to note a trend towards poor soil physical and chemical properties. Though soil readily available K was recovering, levels still ranged below those found in the second soil survey during the 1980's . It is a long-term challenge to halt the decline of soil K. According to the requirements of the agricultural development plan of the Jiangsu Province for the early 2000's and based on cultivation experience and the nutrient balance method, Jiangsu's demand for fertilizers in 2005 and its nutrient composition are predicted. Based on this, the demand for N is 1.5862 Mt, for P_2O_5 0.6473 Mt and for K_2O 0.7044 Mt, forming an $N:P_2O_5:K_2O$ ratio of 1:0.41:0.44. In order to ensure the supply of agricultural products and to promote sustainable development of agriculture with high yields, quality and benefit, it is important to readjust the total quantity of mineral fertilizer input. An optimization of the fertilization system means to improve fertilization efficiency by making rational plans, applying fertilizers in a scientific way and by intensifying the fertilizer management. Through the extension of reducing N and supplementing K for balanced fertilization, more efforts should be made to improve techniques and mechanisms as well as to promote the extension of improved soil management and fertilization techniques.

Introduction

Located at the lower reaches of the Changjiang River, the Jiangsu Province has a total area of 0.1026 M km^2, accounting for only 1.05% of the country's total area, and has a population of 70 M people which means less than 0.067 ha of cultivated land per capita are available for crop production. It is a typical province that has a large population, small land resources. The province has six major agricultural regions, Taihu (the Taihu Lake region), Yanjiang (areas alongside the Changjiang River), Yanhai (coastal region), Ning-Zhen-Yang Hills (Nanjing-Zhenjiang-Yangzhou region), Lixiahe and Xuhuai, producing mainly cereals (rice, wheat, barley, rye and maize), cotton and vegetable oils (oilseed rape and peanut). Having only 4.7% of the country's farmland, Jiangsu produces 7% of the China's cereals, approx. 10% of the country's cotton and 7% of the country's oil. During the late 1990's, the agriculture and rural economy showed a trend towards the following:

1) The agricultural production conditions were improved and the ability to produce major agricultural and sideline products was further strengthened. For four consecutive years, excellent yields were achieved. For the first time, the highest historical production of 35 Mt grain was recorded in Jiangsu in 1997. In 1999, the production could be further improved up to 35.59 Mt, achieving the best annual average yield ha^{-1} during the period from1995 to 1999. In 1999, the output of vegetable oil reached 1.84 Mt, about 15.7% larger than that in 1995, being the highest historical record in acreage, yield and total output in oil production. The output of cotton was 0.246 Mt, about 56.2% lower than in 1995 as a result of the macroscopic-factor-induced reduction in cultivated cotton area. A synchronized development of forest ecology and forestry industry was achieved. In 1999, the total rural social output value of the province reached 1,308,771 M Yuan, 23.8% higher than in 1995. The gross output value of agriculture, forestry, animal husbandry and fisheries was 183,740 M Yuan, a 7.2% increase compared to 1995 on the basis of comparable prices. The farmers' net income per capita was 3,495.2 Yuan, 42.2% higher than in 1995. Obviously, the rural integrated economic strength was further strengthened.
2) The process of readjusting the industrial structure was sped up by continuous rationalization. In 1999, the ratio of the primary, secondary and tertiary industries was 14:77:9 and increased by about 2 percentage points in the secondary and tertiary industries compared to 1995. The proportion of high quality farm products increased so that in 1999, the area of quality japonica rice rose to 77% and the area of quality oilseed rape to 11%.
3) The results of invigorating agriculture by developing science and education were significant, and the contribution of science and technology to agricultural development was also increased. Three fields of innovations are envisaged, including seeds, techniques and knowledge. The "seed breeding project", the "K-supplementation project" and the "balance fertilization project" were launched and implemented in this course. The contribution of science and technology to the growth of agriculture rose from 45% in 1995 to 51.4% in 1998, 10 percentage points higher than the country's average.
4) A big headway was made in agricultural industrialization. Advantages of regional scale for 3 highly-efficient animal husbandry belts in Jiangnan, Huainan and Huaibei and 10 horticulture bases were taking shape.

Results and analysis of the changes in soil fertility in Jiangsu

Changes in fertility of major soil types in different agricultural regions

Based on the findings of 8 national and 72 provincial long-term stationary soil fertility monitoring posts all over the province and some local soil monitoring sites, the dynamics of the changes in fertility of the major soil types of the province are summarized in the following.

Yield in relation to soil fertility and contribution of indigenous soil fertility

Indigenous soil fertility, though the result of a number of factors, is still an important index for evaluating soil fertility and integrated productivity of the soil. Generally, it is expressed by the yield of a crop grown in soil without fertilization. To facilitate its comparison with the yield of crops grown in fertilized soil, indigenous soil fertility as proportional contribution to yield is used. With the other conditions being the same, the yield of a crop grown in soil without fertilization (omitting nutrient application in the measured crop) is set against the yield of the crop grown in soil fertilized at a conventional rate expressed as percentages. For example, looking at the two major cereals rice and wheat in Jiangsu in the 1990's, for both the yields of unfertilized and conventionally fertilized crops were rising (Table 1).

Table 1. Variation of the proportional contribution of indigenous soil fertility to the production of rice and wheat in Jiangsu in the 1990's

Year	Wheat				Rice			
	Sample (*n*.)	Yield (kg ha^{-1}) CK	Fertilized	CISF * (%)	Sample (*n*.)	Yield (kg ha^{-1}) CK	Fertilized	CISF* (%)
1990	76	1695	4155	40.8	64	4575	7080	64.6
1995	42	2235	4545	49.2	41	5100	8130	62.7
1999	59	2820	5010	56.3	48	5535	8295	66.7

*: Contribution of indigenous soil fertility.

The contribution of indigenous soil fertility to wheat yield rose from 40.8% in 1990 to 49.2% in 1995 and to 56.3% in 1999. In the case of rice, it decreased from 64.6% in 1990 to 62.7% in 1995 and increased again to 66.7% in 1999. The contribution of indigenous soil fertility in the latter case is on average 10 percentage points higher than in the former case, indicating that rice depends more heavily on soil fertility than wheat. The built-up of soil fertility helps to lower fertilization costs and to increase returns from fertilization. Indigenous soil fertility of the regional soils in rice and wheat production areas of the province varied unevenly and sharply during the period from 1990 to 1999. For example, in 1997 the contribution of indigenous soil fertility of Huanggangtu soil in the Zhenjiang Hilly regions was 45% ~ 50% in rice and 20% ~ 30% in wheat, while that of a whitish soil in Yixing was 73.1% and 48.2%. Recently, with the improvement of irrigation facilities and the increased fertilizer application rates, the indigenous soil fertility has increased in medium- and low-yielding fields in Ning-Yang-Zhen Hills, Xuhuai, Yanhai and the Yanjiang agricultural regions. On the other hand, it decreased to a certain extent in some high-yielding fields in Taihu and the Lixiahe agricultural regions due to long-term depletion by large nutrient removals with inadequate replacement, especially through organic manure.

Soil physical properties

Results of the soil fertility monitoring all over the province indicate that in the past twelve years soil physical and chemical properties in parts of the province have been deteriorating, which is mainly reflected in shallower plough layer, greater bulk density and lower porosity. For example, in Xuzhou city the plough layer decreased in thickness, on average, from 18.6 cm in 1984 to 14.4 cm in 1999 and from 16.2 cm to 14.0 cm in farmland under a rotation system of paddy and upland and from 19.8 to 14.9 in upland. Results of an investigation at 110 sites in Siyang county in 1995 revealed that the thickness of soil plough layer dropped from 18 cm in 1982 to 14.8 cm. The bulk density of this layer rose from 1.26 g cm^{-3} to 1.32 g cm^{-3}. Data of monitoring posts installed by the M.O.A. in Xinghua city showed that the bulk density of the plough layer increased from 1.33 g cm^{-3} in 1984 to 1.36 g cm^{-3} in 1999 whereas the total porosity decreased from 49.95% to 48.64%.

Soil chemical properties

In comparison to the nutrient status in the second soil survey (late 1980's and early 1990's), in the late 1990's an upward trend could generally be noted of all major soil nutrient indexes, soil organic matter, total N, readily available P and readily available K (Table 2).

Table 2. Comparison of major soil nutrient indexes between different years

Year	Organic matter (g kg^{-1})	Total N (g kg^{-1})	Readily available P (mg kg^{-1})	Readily available K (mg kg^{-1})
1982	16.30	1.08	5.50	118.0
1990	19.35	1.18	6.83	92.6
1995	19.57	1.29	8.65	90.4
1999	19.89	1.43	10.45	109.0

Soil organic matter

Mean soil organic matter content of the province in 1999 increased by about 15.37% compared to 1995 (Table 2). However, the studies in the six major agricultural regions could not confirm this trend and there was rather a stagnation in the O.M. with the exception of Yanjiang and Yanhai. Between the regions, there was a distinct pattern in the soil organic matter contents in the following order of Taihu > Lixiahe > Yanjiang > Hills > Xuhuai > Yanhai. It needs to be noted that 4 years is not a period which can be regarded as very representative and indicative for the dynamics in O.M. which usually takes longer unless very dramatic measures have been taken, e.g. application of huge amounts of organic manure, etc.

Table 3. Change in soil organic matter in Jiangsu during the late 1990's (g kg^{-1})

Region	1995	1996	1997	1998	1999
Taihu	28.48	28.71	28.93	28.55	28.45
Lixiahe	21.33	21.57	21.99	21.94	21.95
Yanjiang	19.74	20.08	19.98	19.89	19.92
Hills	18.64	18.63	18.51	18.33	18.61
Xuhuai	15.44	15.29	15.73	15.81	15.88
Yanhai	13.78	13.55	13.98	14.62	14.53
Mean	17.24	19.63	19.85	19.73	19.89

Total N

The mean total soil N of the province increased from 1.29 g kg^{-1} in 1995 to 1.44 g kg^{-1} in 1999, by 12% or at an annual rate of 0.0375 g kg^{-1} (Table 4). The increment was the largest in the agricultural regions Xuhuai and Lixiahe and then in the regions Hills, Yanhai and Yanjiang and at last in the region Taihu, where the total soil N leveled off. The mean value of total soil N in the six regions were in the order of Taihu > Lixiahe > Hills > Yanjiang , Xuhuai > Yanhai.

Table 4. Changes in total N in soils of Jiangsu during the late 1990's (g kg^{-1})

Region	1995	1996	1997	1998	1999	1995-1999 (in %)
Taihu	1.80	1.92	1.86	1.66	1.79	0
Lixiahe	1.26	1.49	1.26	1.48	1.52	21
Yanjiang	1.32	1.42	1.36	1.38	1.38	4
Hills	1.37	1.39	1.44	1.49	1.47	7
Xuhuai	1.06	1.19	1.37	1.36	1.38	30
Yanhai	0.95	1.06	1.05	1.17	1.08	14
Mean	1.29	1.41	1.39	1.42	1.44	12

Readily available P

The mean readily available P in the soils of the province rose faster in the late 1990's, which is associated with the vigorous extension of the application of P, including compound (blended) fertilizers during this period (Table 5). It was raised by 21% over that in 1995 and by 90.18% over 5.5 mg kg^{-1} in 1982. But readily available P varied strongly between agricultural regions. The largest increase was recorded in Lixiahe, reaching 1.55 mg kg^{-1} per year, while it dropped signficantly in Yanjiang and Hills by –20% and –11% compared to 1995. The agricultural regions could be arranged according to their available P contents in the soil in the order of Xuhuai > Hills > Lixiahe >Yanhai > Taihu > Yanjiang in 1999.

Table 5. Changes in readily available P in soils of Jiangsu during the late 1990's (mg kg^{-1})

Region	1995	1996	1997	1998	1999	1995-1999 (%)
Taihu	6.27	7.58	8.1	7.4	8.03	28
Lixiahe	6.33	10.58	8.3	12.34	12.55	98
Yanjiang	7.68	6.09	6.63	5.34	6.18	-20
Hills	15.02	15.16	15.14	12.5	13.4	-11
Xuhuai	10.75	12.87	12.79	13.49	13.57	26
Yanhai	5.87	7.26	6.5	10.17	9.07	54
Mean	8.65	9.9	9.58	10.21	10.47	21

Readily available K

After 1995, when Jiangsu was the first province to propose and implement the "K supplementation project", the downward trend of soil readily available K was effectively halted and turned into a rising trend (Table 6). The mean content of readily available K of the province's soils increased by about 20 % from 1995 to 1999. It rose at a rate of 4.7 mg kg^{-1} per year. But it was still lower than during the second soil survey in the 1980's. Based on K levels, the six agricultural regions were in the order of Yanhai > Lixiahe > Hills . Xuhuai > Yanjiang > Taihu, with the latter three regions revealing still low K availability in their soils.

Table 6. Changes in readily available K in soils of Jiangsu during the late 1990's (mg kg^{-1})

Region	1995	1996	1997	1998	1999	1995-1999 (%)
Taihu	79.38	74.47	80.63	75.7	86.56	9
Lixiahe	98.02	103.89	105.56	135.57	127.89	30
Yanjiang	74.73	75.57	74.15	85.24	88.13	18
Hills	77.42	78.04	79.51	115.5	107.41	39
Xuhuai	83.8	86.72	87.67	109.76	98.76	18
Yanhai	128.76	131.74	131.88	145.32	144.78	12
Mean	90.35	91.74	93.23	111.18	108.92	20

Available micronutrients

The soil samples from 80 soil monitoring posts all over the province were also analyzed for available micronutrients in 1997 (Table 7). Available Cu was commonly high, except for a few soil types. Available Zn was higher in South Jiangsu than in North Jiangsu. Though it was lower in Xuhuai and Yanhai, it was still above the critical value of 0.5 mg kg^{-1}. Available Mn varied strongly and was higher in Hills, Lixiahe and Taihu and lower in Xuhuai. The regions varied in the supply of these different micronutrients, depending on the element. For available Cu, the order was Taihu > Hills > Lixiahe > Yanjiang > Xuhuai > Yanhai, for available Zn Lixiahe > Yanjiang > Taihu > Hills > Yanhai > Xuhuai, for available Mn Hills > Lixiahe > Taihu > Yanjiang > Yanhai > Xuhuai.

Table 7. Status of available micronutrient contents in soils of Jiangsu in 1997

Region	Cu	Zn	Mn
	....	(mg kg^{-1})	....
Taihu	5.98	2.32	86.8
Lixiahe	4.56	2.60	92.9
Yanjiang	4.18	2.51	68.8
Hills	5.00	2.26	101.5
Xuhuai	2.83	1.72	39.9
Yanhai	2.71	1.76	52.7
Mean	4.01	2.12	64.9

Causes of changes in the indigenous soil nutrient supply in Jiangsu during the late 1990's

Multi-pattern practice of returning crop residues to the field

In the 1990's, the traditional practice of preparing and applying organic manure could not keep soil fertility at a satisfying level. In particular, green manure crops are only grown in small patches, totaling less than 0.1333 M ha. Multi-patterned practice of returning crop residues to the field has shown to be an effective measure to increase input of organic material into the farmland. During the late 1990's, the province produced approx. 50 Mt of crop residues annually. In addition to the movement of "the year of raising farmland quality" and other activities such as the enforcement of the ban of burning of straw and the popularization of the technique of "comprehensive utilization of straw", increased the amount of straw returned to the field up to one-third of the total amount produced. According to statistics, the area of farmland where the practice was adopted rose from 2.33 M ha in 1985 to 4.0 M ha in 1995 and 4.67 M ha in 1999, and the rate also increased from 1,650 kg ha^{-1} in 1985 to 3,570 kg ha^{-1} in 1999. The recycling of straw in the farmland ecosystem has laid down a basis for maintaining and raising soil organic matter and soil fertility, and partially makes up for the shortage of mineral K fertilizers in China. At the same time, wastes from livestock and some other organic wastes are processed into refined organic manure through special fermentation, which is also a new approach to raise soil organic matter for production of quality products.

Balanced fertilization

During the late 1990's, the extension of the "technique of balanced fertilization" was intensified, by setting up 13 balanced fertilization demonstration counties (cities) in Jiangsu. Launching a movement of "extending balanced fertilization by conducting integrated soil testing, designing formulas and supplying fertilizer to one thousand villages" aimed at improving the fertilization practices. The establishment of an integrated service of soil testing, designing of fertilizer formula, production, supplying and application, the system of fertilizer input and the fertilizer recovery rate were improved. In 1995, the total input of NPK (in blended fertilizers) was 1.50 Mt N, 0.2153 Mt P_2O_5 and 0.2052 Mt K_2O, forming a ratio of 1:0.14:0.14. In 1999, though the acreage of farmland shrank to some extend, the output of cereals, cotton and vegetable oil was increased and the input of NPK fertilizers was 1.6162 Mt N, 0.4066 Mt P_2O_5 and 0.2856 Mt K_2O, forming a ratio of 1:0.25:0.18. The increment in NPK application was big and their ratio improved. Over 40% of the farmlands used formulated blended fertilizers at that time.

Prediction of Jiangsu's demand for fertilizers in the period until 2005

Basis for prediction

For this prediction the agricultural development plan of the Jiangsu Province 2001-2005 and the following analysis were used.

Demand for assurance of supply of agricultural products

According to the agricultural development plan of the province for the next five years, the gross agricultural output value should increase at a rate of 4%, and the farmers' per capita net income per year should improve at a rate of 6%. In 2005, the contribution of science and technology should account for 60% of the agriculture economical growth. In crop production, the ratio of cereals and cash crops should reach 60:40, and fodder crops should account for 12% of the cereals, gradually forming an appropriate pattern of crop cultivation. The total output of cereals should be controlled at around 27.50 Mt, of which 18.25 Mt will be rice. For cereal production with the total output under control, the acreage of cultivation should be reduced and the quality of products improved. In 2005, the total output of cereals should be adjusted to meet the need for the cereal consumption and seed production. For rice cultivation, the development of quality rice should be intensified to account for 50% of the rice production in the province. The quality of wheat should also be improved. While the cereal production will be reduced, quality oilseed rape production should be expanded. The total output of vegetable oil is planned to be 2.20 Mt. For cotton cultivation, the area of cotton cultivation should be maintained or restored, with emphasis on producing quality cotton. The total output of cotton is planned to be 0.385 Mt. Special-purpose cereals and special cash crops should be developed intensively. For vegetable cultivation, the variety of vegetables should be further diversified and the product quality improved. The planned area of vegetable cultivation should reach 1.0667 M ha. The total output of fruit should be about 2.15 Mt by simultaneous developing the fresh fruit and dry fruit production. The total output of tea should be 0.018 Mt according to the plan. The emphasis of tea production should be on developing high-grade quality famous tea and deep processed tea. The production of flowers should be concentrated on ornamental saplings and bonsais. For animal husbandry, the emphasis is on maintaining the number of pigs and poultry and on increasing the number of goats, dairy cows and special animals. The gross output value of animal husbandry is planned to be 32 billion Yuan (on the basis of the fixed prices of 1990), accounting for 30% of the gross agricultural output value. For forestry, the forest coverage of the province should be increased to up to 12% by afforesting 66,700 ha and by opening up 10,000 ha of hills for forestation. The total output value of forestry is planned to reach 15 billion Yuan. Farmland with slopes of more than 25 degrees in hilly regions and farmland in aeolian-sand-stricken areas in the plains should be afforested instead of being cropped. The input of fertilizers must meet the demand of the production of these agricultural products.

Demand for higher quality of agricultural products and protection of agricultural environment

Currently, the relationship between demand and supply of agricultural products is shifting in nature from quantity to quality and structure. Particularly, the production of cereals has shifted from long-term deficit to surplus in the total quantity coupled with structural shortage. The shift of the demand for agricultural products from quantity to quality and variety is becoming more obvious. Agricultural development used to be limited by one single factor which was the availability of resources. It is now determined by mainly two factors, e.g. the market and the resources, with the former becoming the dominant one. With the development of the economy, the pressure on quality and safety of agricultural products and the deterioration of the environment is increasing. Currently, the issue of pollution damaging the environment in Jiangsu gains in importance, for instance, soil erosion, pollution of agricultural irrigation water and soil, worsening quality of farmland, discharge of wastes in large quantities and overdose of fertilizers and agricultural chemicals, etc.. They cause the aggravation of the eutrophication of the Taihu Lake water and poorer quality of agricultural products by containing for example substances which are detrimental to human health. With the domestic country-wide opening of the market to the world market, the agricultural products of the province are confronted with the ever-growing pressure of competition in the domestic and world markets. Low-priced quality agricultural products from other areas pose a thread to the agricultural products of the province. Therefore, it is urgent for the province to develop new quality fertilizers to optimize the structure of mineral fertilizer products, to raise their quality and grade, to improve their application methods, to make a scientifically based fertilization plan, to reduce fertilization cost, to minimize fertilizer losses, to increase fertilization returns and to improve the quality and safety of agricultural products and to protect the environment.

Sustainable development of agriculture

The central and the provincial governments clearly stated this year that the main work in agricultural and rural areas in the years to come will be to promote the structural readjustment of the agricultural and rural economy and to work on the soil and fertilizer issues. The major problems are inadequate input of quality organic manure, common shortage of P and K in the soil, depletion of other macronutrients (Ca, Mg, S) and micronutrients from the soil, irrational structure of fertilization and fertilization planning, overdose of N in fertilization, low recovery rate of mineral fertilizers and serious agricultural pollution of the environment. Therefore, it is essential and urgent to improve the quality of the farmland by "taking immediate measures in combination with effecting a permanent cure". The extension of balanced fertilization techniques should be intensified and the system of fertilizer input optimized, raising the integrated farmland productivity and promoting a sustainable development of an agriculture, high in quality and efficiency. For the structural readjustment of agriculture, it is urgent to change the core of the work on soils and fertilizers in the following aspects: From the pursuit of high yield towards high quality; from providing technical guidance for the cultivation of cereals, cotton and oil crops towards technical services for introducing and improving the cultivation of vegetables, fruit and tea; from providing mere techniques for agricultural production towards pre- and post- production services; and from basal-based fertilizer formulations to the supply of need-adjusted fertilization concepts. For the input of fertilizers, therefore, it is essential to practice the combination of mineral fertilizers with organic manure, to optimize the NPK ratio and to improve the supply of the remaining macro- and micronutrients needed by crops.

Fertilizer resources and fertilizer production capacity

Jiangsu only produces two-thirds or three-quarters of the fertilizers it needs for supplying its agricultural production. The gap in the supply of high-quality N fertilizers is large; the supply of mineral K fertilizers is extremely short and the supply of P fertilizers is about adequate. The problem of the product structure of N and P fertilizers is serious. The capacity for the production of ammonium bicarbonate and P fertilizers is in surplus, which, however, have a poor grade and have a simple composition. The production capacity for ammonium bicarbonate is 5 Mt a year and for P fertilizers 0.594 Mt (P_2O_5). The output of blended fertilizers in Jiangsu reaches 7 Mt, accounting for 1/10 of the country's production, but it depends heavily on raw materials imported from other provinces and other countries. Moreover, having mainly low concentration fertilizers and irrational fertilizer systems, the market adaptability is difficult and the competitive power weak. It is essential to put more emphasis on readjusting product structures in the fertilizer market, to improve technical development in the processes involved, to provide post-sales services and to adopt operational mechanisms suiting the markets.

Prediction of nutrient demand based on two methodological approaches

There are many methods that can be used to predict the demand for fertilizers. In the following two methods are used: 1. Cultivation experience method and 2. The nutrient balance method.

Cultivation experience method

Based on years of cultivation experience the quantity of fertilizers needed is calculated by multiplying the amount of nutrients required for an expected yield by the area of that respective crop. The total amount is obtained by the sum of nutrient requirement of all crops (area x uptake per unit area).

Results of the prediction

Based on the cultivation experience method, Jiangsu needs 1.7639 Mt N, 0.6138 Mt P_2O_5 and 0.5358 Mt K_2O in 2005, which will result in a NPK ratio of 1:0.34:0.30. The predicted demand for fertilizers increases about 11%, 51% and 89% for N, P_2O_5 and K_2O respectively, in comparison to 1999 (Table 8).

Table 8. Predicted demand of NPK fertilizers for Jiangsu in 2005 based on the cultivation experience method

Crop	Target output (Mt)	Planned area (10^3ha^{-1})	Target yield (kg ha^{-1})	Input of nutrients (kg ha^{-1})			Total demand of nutrients (10^3t)		
				N	P_2O_5	K_2O	N	P_2O_5	K_2O
Rice	18.25	2333	7830	210	53	53	490	123	123
Wheat*	9.0	2000	4500	180	60	45	360	120	90
Corn	2.4	400	6000	203	60	53	81	24	21
Cotton	0.385	367	1050	240	83	68	88	30	25
Oilseed rape	1.675	667	2512	225	113	60	150	75	40
Peanut	0.5	133	3750	34	83	90	5	11	12
Sesame	0.025	17	1500	150	75	75	3	1	1
Yam	1.0	167	6000	68	15	15	11	3	3
Soybean	0.61	213	2850	0	45	15	0	10	3
Vegetables*		1067		450	150	150	480	160	160
Fruit	2.15	167	12900	375	225	225	63	38	38
Tea	0.018	20	900	128	105	150	3	2	3
Green manure	12.0	133	30000	0	68	45	0	9	6
Others*							32	1	12
Total		7684					1764	61	536

*: Wheat actually comprises wheat, barley and rye; for vegetables the data are the mean values of several crops per year, excluding the amount of organic manure applied; and the item of others includes forestry, fisheries, animal husbandry and lawns.

Nutrient balance method

The calculation is performed by multiplying the total amount of nutrients required by a crop to meet the target yield by the amount of nutrients (%) in the fertilizers. Than the result is divided by the recovery rate of the fertilizers. The equation is as follows: $F = A^* (1\text{-}S\%)/Fu$, where F is the predicted amount of a certain nutrient; A the total amount of the nutrients needed to reach a certain target output; S is the percentage of the nutrients supplied by the soil; Fu for the recovery rate of related fertilizers. The contribution from the indigenous supply of the soil ranges between 50% and 70%. In this equation, S has been set as 55%. Fu for N, P and K fertilizers is set as 35%, 30% and 60%, respectively. Based on an economical yield of 100 kg the nutrient requirements by crops have been calculated (Table 9).

Table 9. Predicted demand of NPK fertilizers for Jiangsu in 2005 based on the nutrient balancing method

Crop	Target output (Mt)	Planned acreage (10^3ha^{-1})	Target yield (kg ha^{-1})	Input of nutrients (kg)			Total demand of nutrients (10^3t)		
				N	P_2O_5	K_2O	N	P_2O_5	K_2O
Rice	18.25	2333	7830	1.99	0.98	2.6	415.5	268.6	356
Cereals*	9.0	2000	4500	2.73	0.87	2.18	316	117.5	147.2
Corn	2.4	400	6000	2.21	0.98	2.60	68	35	46.8
Cotton	0.385	367	1050	5.08	1.93	3.18	25.2	7.3	9.2
Oilseed rape	1.675	667	2512.5	4.75	1.90	3.29	102.3	47.7	41.3
Peanut	0.5	133	3750	5.53	0.99	1.88	35.5	7.4	7.1
Sesame	0.025	17	1500	3.47	1.77	3.13	1.1	0.7	0.6
Yam	1.0	167	6000	2.15	0.95	2.31	27.6	16.0	17.3
Soybean	0.61	213	2850	7.56	1.85	3.6	59.1	16.9	16.4
Vegetables*	40.0	1067	0	0.4	0.5	0.5	204.8	112.5	150
Fruit	2.15	167	12900	1.6	1.2	2.2	44	25.8	35.4
Tea	0.018	20	900	4.7	0.8	1.95	1.1	0.2	0.3
Green manure	12.0	133	30000	0.5	0.09	0.37	766.8	16.2	33.3
Others*		7684					31.5	9.0	12.0
Total							1408.5	680.8	872.9

*: "Cereals" comprises wheat, barley and rye; for vegetables the data are the mean values of several crops per year, excluding the amount of organic manure applied; and the item of others includes forestry, fisheries, animal husbandry and lawns.

According to this method, Jiangsu needs about 1.4085 Mt N, 0.6808 Mt P_2O_5 and 0.8729 Mt K_2O in 2005. This differs from the prediction based on the cultivation experience method. For N this is 0.3554 Mt less, for P_2O_5 0.067 Mt more and for K_2O 0.3371 Mt more than current amounts applied. This indicates that there is a potential for saving N by using this method. According to the calculations, the current P application rate can roughly maintain the soil P balance whereas to halt a further decline in soil potassium, K application rate has to be greatly increased. Using the average of both methods, the mean fertilizer demand has been calculated, which is 1.5862 Mt N, 0.6473 Mt P_2O_5 and 0.7044 Mt K_2O with a N : P_2O_5 : K_2O ratio of 1:0.41:0.44 (Table 10).

Table 10. Averaged demand for fertilizers in Jiangsu in 2005 based on the predictions using two different methods (10^3t)

Method	N	P_2O_5	K_2O	N: P_2O_5:K_2O
Cultivation experience	1763.9	613.8	535.8	1:0.34:0.30
Nutrient balance	1408.5	680.8	872.9	1:0.48:0.62
Mean	1586.2	647.3	704.4	1:0.41:0.44

Looking at the fertilizer resources and the production capacity of the province, meeting the target of balancing N and possibly fulfilling the need for P fertilizers is very difficult. However, it is essential to readjust the product structure of N and P fertilizers correspondingly by raising the proportion of highly concentrated fertilizers and improving the quality grade of fertilizers. For N fertilizers, it is necessary to reduce the production of ammonium bicarbonate or modify the product, to develop granular ammonium bicarbonate, granular NK fertilizers or controlled-release ammonium bicarbonate. At the same time, the proportion of highly concentrated N fertilizers (e.g. urea) should be increased. The Jiangsu Province is extremely short of K resources and has to recycle as much of the K as possible by organic manure and by intensifying the practice of returning straw. Due to the increasing reluctance of farmers to handle large quantities of bulky material, possibilities of developing commodity organic manure need to be explored. The Jiangsu Province should develop crop-specific formulated compound or bulk blended fertilizers, containing the three macronutrients NPK and where needed Mg, S and Ca. Furthermore, a mix of organic and inorganic nutrient sources formulated in one compound can help to alleviate deficiencies in other macronutrients (Mg, S, Ca) or micronutrients (B, Cu, Zn etc.). By introducing a fertilizer registration system, the supervision and management of fertilizer quality and the extension of balanced fertilization should be intensified. There is a need for readjusting the structure of the fertilizer input by saving and supplementing K, by improving the nutrient recovery rate (more efficient use of inorganic and organic fertilizer resources) and through promoting a sustainable development of agriculture in Jiangsu.

The status quo of and a strategy for improved farmland nutrient balances in Shanghai

Tian Jilin and Wang Yinhu

Environment Research Institute, Shanghai Academy of Agricultural Science, 201106

Abstract

Investigations were conducted on the application of fertilizer in two rotation systems (rice-wheat and rice-oilseed rape) in the suburbs of Shanghai. Results show that the farmland nutrient balance changed with changing cultivation pattern, mainly because of N dosage. It is, therefore, essential to take practices into consideration, such as lowering N application rate, applying more organic manure and keeping NPK in balance. Based on the status quo of fertilization, the paper suggests the practices of returning straw to the field, recycling of potassium, allocation of organic wastes, lowering application rate of mineral fertilizers and readjusting planting structure by increasing the area of green manure and fallow fields. More P and K will be needed in areas where reduced tillage practices are introduced.

Introduction

The suburbs of Shanghai, as part of the Taihu high yield region in China, have a total of 0.32 million ha cultivated land with the rotation systems rice-wheat and rice-oilseed rape as the major cultivation pattern. The area of paddy rice is maintained at around 0.213-0.22 million ha, that of wheat and barley at 0.08 million ha, that of oilseed rape at 0.053 million ha and that of vegetable at 0.01-0.012 million ha. The agricultural production is increasingly facing the problem of low output : input ratios with regard to fertilizer use. Therefore, the aim of this study was the attempt to assess alternatives to current practices which include the possible readjustment of the cultivation system, especially for summer crops except rice, which will remain unchanged with regard to area. Another aspect which needs attention is the possible changes in the nutrient requirement when the cultivation pattern of paddy fields changes from deep ploughing to non-tillage or direct seeding. The study on the current farmland nutrient balance, therefore, is of great significance for the maintenance of sustained high yields and the rationalization of fertilization in agriculture.

Nutrient balance of farmland for major crops

Rice

Rice has the largest share of cultivated land in the suburbs of Shanghai with high output, accounting for 80% of the total grain output in Shanghai. The agro-ecological region around Shanghai is characterized by rice grain yields which have been maintained above 7,500 kg ha^{-1} for many years and by an intensive consumption of mineral fertilizers which to a great extent has driven the production to the current level. Investigations in the early 1990's revealed that organic manure supplied 66.2 kg ha^{-1} N, 102.8 kg ha^{-1} P_2O_5 and 45.8 kg ha^{-1} K_2O, while mineral fertilizers contributed 222.9 kg ha^{-1} N, 30.6 kg ha^{-1} P_2O_5 and 12 kg ha^{-1} K_2O, leading to a nutrient input of 1:0.46:0.20 in N:P_2O_5:K_2O. The N:P_2O_5 ratio, being close to 1:0.5, is basically according to crops' demand, but K is slightly below the crop requirement. In recent years, changes in the rice cultivation pattern have led to a larger proportion of direct seeding by broadcasting the seed and higher N application rates, leading again to an NP imbalance (Table 1).

Table 1. Current nutrient input and output in irrigated rice based systems in the suburbs of Shanghai

	OM	CR	GM	Subtotal (organic)	MF (kg ha^{-1})	Total (org + MF)	Output	Balance
N	65.0	5.2	5.7	75.9	289.5	365.4	143.7	+221.7
P_2O_5	85.8	1.4	1.7	88.8	12.9	101.7	68.7	+33.0
K_2O	52.0	9.5	5.0	66.5	3.9	70.4	164.3	-93.9
Ratio				1:1.2:0.9	1:0.04:0.01	1:0.28:0.19	1:0.48:1.14	

Note: OM stands for organic manure, CR for crop residues, including rice straw and oilseed rape stalks, GM for green manure crop and MF for mineral fertilizers

The comparison of the input and output ratios indicate the discrepancy between supply and demand which is also reflected by the surplus application of N and the undersupply of K. Whereas in the current fertilizer management in rice P has still a slight surplus of about 33 kg per crop per hectare, there is a negative balance of K and 93.9 kg K_2O ha^{-1} are lost from the soil by the rice crop. N application rate is 2.5 times larger than the amount absorbed by rice. According to several stations, a non-fertilized crop of rice can yield on average 5,385 kg ha^{-1} by relying solely on the soil nutrient supply. This means that at the current application rates the theoretical yield contribution of N fertilizers could be 2,070 kg ha^{-1}. However, the poor N efficiency leads to the fact that 20 kg of mineral nitrogen fertilizers are needed to produce only around 140 kg additional grains. The results of recent studies indicate that the application of 195 ~ 240 kg of mineral fertilizers per hectare seem to be adequate under the current cultivation conditions.

Wheat

The area of wheat cultivation is about one-third of that occupied by rice in the suburbs of Shanghai. With regard to nutrient management, wheat receives a little more organic manure than rice (Table 2) and also more P and K fertilizers, but less N fertilizers. This may be explained by the lower yield of wheat. The N application rate for wheat has increased by 21.9%, over 170.4 kg ha^{-1} from the early 1990's until today. As a result of increased organic manure, the present NPK ratio is 1:0.50:0.36 with P and K well in balance both in rate and ratio. The application rate of N, however, is still very high, about 3.8 times as much as its absorption, which may be related to surface broadcasting of N fertilizers under direct seeding conditions. Due to the large amount of organic manure combined with straw and a small amount of mineral K, the K balance for wheat is positive. With a larger surplus this also relates to P which in the long run, however, may lead to an accumulation. N and P application levels need to be corrected.

Table 2. Current nutrient input and output for wheat in the suburbs of Shanhai

	Organic manure	Straw	Mineral fertilizer	Total	Output	Balance
			(kg ha^{-1})			
N	94.3	16.5	207.8	318.6	83.4	+235.2
P_2O_5	124.7	4.8	31.5	161.0	42.9	+118.1
K_2O	75.6	34.2	6.3	116.1	50.4	+65.7

Note: OM stands for organic manure, SR for straw returned, and MF for mineral fertilizers

Oilseed rape

Table 3 shows fertilization for oilseed rape which is almost similar to that of wheat. Today, organic manure contributes more nutrients to the crop nutrition than it did in the early 1990's. The application rate of mineral N fertilizers has increased by 5.4%. P is adequately supplied and K is kept basically in balance. With these application rates of both mineral and organic sources a positive balance of almost 193 kg N ha^{-1}, 132 kg P_2O_5 and 30 kg K_2O ha^{-1} is observed. It again shows that N and P are largely oversupplied which in case of N may be due to the poor N efficiency caused by large N losses. In case of P, the oversupply may lead to a strong P accumulation in the soil.

Table 3. Nutrient input and output for rape (kg ha^{-1})

	Organic manure	Mineral fertilizers	Total	Output	Balance
		(kg ha^{-1})			
N	86.1	187.4	273.5	80.9	+192.6
P_2O_5	113.7	55.0	168.7	37.1	+131.6
K_2O	69.0	5.3	74.3	45.0	+29.3

Considering the whole rice-wheat or rice-oilseed rape rotation may give a better reflection of the true nutrient balance of the farmland in the region (Table 4 and 5). The figures indicate that both of the two important rotation systems in the suburbs of Shanghai lose substantial amounts of K from their soil reserves every year. The rice-wheat rotation system loses 32.7 kg K_2O per ha and rice-oilseed rape about 64.7 kg ha^{-1}. On the other hand, soils gain to a great extent in N and to a slightly smaller extent in P due to surplus application of both nutrients. The nutrient balances shown here do not include nutrient losses through leaching, volatilisation, denitrification, fixation, etc. The losses of particularly N may be of great importance since it is the behaviour of mineral N that it is easily transported to lower soil depth from where it is lost by leaching or it is denitrified in the irrigated soil (rice) or volatilised.

Table 4. Nutrient balance of the rice-wheat rotation system in Shanghai suburban

	Organic manure	Mineral fertilizers	Total	Output	Balance
		(kg ha^{-1})			
N	186.8	497.2	684.0	227.1	+456.9
P_2O_5	218.3	44.4	262.7	111.6	+151.1
K_2O	176.3	10.2	186.5	219.2	-32.7

Table 5. Nutrient balance of the rice-oilseed rape rotation system in the suburbs of Shanghai

	Organic manure	Mineral fertilizers	Total	Output	Balance
		(kg ha^{-1})			
N	162.0	476.9	638.9	224.6	+414.3
P_2O_5	202.5	68.0	270.5	105.8	+164.7
K_2O	135.4	9.2	144.6	209.3	-64.7

Strategy

Returning straw to the field

Research showed that most, 78.8 - 81.5% of the K absorbed by rice is accumulating in the straw and in the Shanghai suburbs, straw is almost everywhere available. The total output of crop residues (rice, wheat and oilseed rape) may reach 2.60 Mt, equalling to 27,400 t K_2O for the whole region, which is enough to supply every hectare of cultivated land with 75 - 90 kg K_2O every year. Straw also contains a large amount of organic carbon, N and other nutrients. However, a number of problems exist with the practice of returning straw to the field, mainly in regards to the technology used, for instance, under non-tillage conditions whether all or half of the straw output should be returned, how to spread it mechanically or how to accelerate its decomposition. Further investigations in practical methods are definitely needed. If these are found, it will be essential to set up relevant regulations, for instance, to introduce a reward or penalty system so as to promote the practice of returning straws to the field.

Reducing mineral fertilizer application rate by making full use of organic manure resources

Judging from the farmland nutrient balance in the suburbs of Shanghai, the application rate of mineral fertilizers, especially nitrogen, cannot be easily reduced because of its poor use efficiency. Moreover, within the overall ecosystem of Shanghai, large quantities of wastes exist, including night soil in the urban areas, garbage, animal dung from intensive animal farms, which have begun to seriously pollute the environment with their emissions. Therefore, dealing with the waste problem is a real challenge. These organic wastes need to be treated in waste treatment plants before going back to the field as manure, which cannot only help reducing the application rate of mineral N fertilizers and supplement P and K but also to solve environmental problems. Much scientific work has been done in Shanghai in this respect and the results show that significant amounts of P and K from organic manure can be supplied to wheat and oilseed rape. However, no substantial progress to introduce this system to farmers fields has been made so far. Especially, there are no matching policies that can strengthen and promote this kind of environment-friendly practice.

Expansion of green manure fallow land by taking advantage of readjustment of cultivation structure

Due to generally small wheat yields in Shanghai suburban the economic benefits of this crop in the rotation are controversially discussed and therefore arises the question, whether wheat should not be replaced by a green manure as fodder crop. Today China is sufficiently supplied with cereals, Shanghai could hence readjust the structure of summer crop cultivation, for instance, to develop green manure by growing horsebean and leave a certain percentage of land under fallow every year. The practice would not only reduce the costs in agriculture but also increase the income and supply of green manure and fresh grass. And at the same time in combination with deep ploughing, it could prevent a long-term fallow from lowering the effectiveness of N fertilizers. Of course, site-specific research should be carried out as to what extent the cultivation structure should be readjusted.

Fertilization and farmland nutrient balance in Anhui, status quo and outlook

Ye Shijuan and Cao Shuqin

Anhui Province Soil and Fertilizers Head Station 230001

Abstract

Mineral N fertilizers account for 62% of the total fertilizer consumption, while mineral potash accounts for only 10.6% in Anhui. Soil readily available K has decreased by 28.6 mg kg^{-1} from 105.5 mg kg^{-1} in the early 1980's down to 76.9 mg kg^{-1} in the late 1990's. The acreage of K deficient farmland has expanded to 3.172 million ha, about 52% of the actual total cultivated area. Imbalance also exists in fertilizer distribution. The farmland in Jianghuai region accounts only for 38% of the province's total area, but for 50% of the province's total fertilizer consumption. A large proportion of medium- and low-yielding farmland does not have an adequate supply of fertilizers. To solve the problems, the following countermeasures should be taken: 1) Between 2000 and 2010, the total input of fertilizers needs to be increased to 2.70 Mt and 3.10 Mt, respectively, and the application rate for each crop to 220 kg ha^{-1} and 250 kg ha^{-1}, respectively. More fertilizers are required in medium- and low-yield regions, where fertilization can be effective. 2) The large nitrogen application needs to be controlled while K consumption has to be increased as well as the supply of other macronutrients, e.g. Ca, Mg and S, as well as micro-nutrients need to be supplemented. 3) More emphasis should be laid on recycling crop residues, especially straw to the fields, either after animal digestion as farmyard manure or directly through machines and 4) the research on balanced fertilization to be intensified.

Introduction

Positioned in the middle and lower reaches of the Changjiang River, Anhui is an important cereal, vegetable oil and cotton producing region in China. Currently it has a total of 6.100 million ha of cultivated land, of which over 60% are medium- and low-yielding fields, forming a tremendous potential for increased production in the future. The agriculture in the Anhui Province has increased by a large extent in both yield per unit area and total output. In comparison with the production in the early 1950's, the province's total output of cereals has increased 3-fold, that of vegetable oil by 16- fold and that of cotton 12-fold. During the recent two decades, the input of large quantities of fertilizers contributed greatly to the development of the agriculture and the farmland nutrient balance. Improving the use of fertilizers and to study the farmland nutrient balance plays a crucial role in developing sustainable agriculture. Nevertheless, problems are quite serious with farmland nutrient balance, fertilizer distribution and fertilizer application. They are mainly displayed as irrational NPK ratio, inadequacy in the supply of other macro-nutrients than NPK and micro-nutrients as well as an overall imbalance of farmland nutrients. This study has therefore been carried out to have a closer look at the fate of nutrients applied to representative cropping systems in order to improve the nutrient management for large sustainable crop production.

Role of mineral fertilizers in agricultural production

The agricultural production of the Anhui Province used to depend largely on organic manure with application rates reaching more than 30 t ha^{-1}. Organic manure has played an important role in developing agricultural production and ameliorating medium- and low-yielding fields.

Since mineral fertilizer made its debut in the early 1950's, its use has been increasing year by year both in rate and in area. Particularly since 1978, the consumption of mineral fertilizers has been soaring up to 0.11 Mt (on nutrient basis) per year, with significant effects on yields. According to the statistics, in 1997, the yield of cereals, vegetable oil and cotton reached 4,726 kg, 1,806 kg and 754 kg ha^{-1} of harvested products, respectively. Comparing this with figures from 1978, it shows that these yields increased by 103% in cereals, by 74% in vegetable oil and 188% in cotton. Compared to the 1950's the difference is even more impressive, with 3-fold, 16-fold and 12-fold increases in crop yields. The input of mineral fertilizers has played a crucial role in this development. The yields of cereals, cotton and oil crops during the period of 1985 – 1997 were within a certain range closely related to the application rate of mineral fertilizers. The respective correlation coefficients between fertilizer consumption and crop production were 0.7828 for cereals, 0.7983 for cotton and 0.7096 for oil bearing crops, at highly significant level. According to the fertilizer trials (1984 –1997), 40-60% of the achieved yield increments during this period can be directly attributed to the use of mineral fertilizers.

Farmland nutrient balance

Before the 1970's, when agriculture depended mainly on organic manure, the farmland received little inputs and produced small outputs. The lack of fuel and feed forced the farmers to harvest the crops together with the roots. The proportion of straw returned directly or indirectly to the field was not more than one fifth. As a result, the farmland became depleted of its nutrients. The development of the agricultural production and the rise in the multiple-cropping index accelerated decomposition of soil organic matter. For instance, the first soil survey in 1958 discovered that soil organic matter was 10.3 g kg^{-1} and average content of total N was 0.75 g kg^{-1}. But the second soil survey in 1979 revealed that the figures were reduced to 9.5 g kg^{-1} and 0.63 g kg^{-1}, a decline of 8% and 16%, respectively.

In the mid 1970's, the use of mineral fertilizers began to develop and hence the crop output. However, bias towards N fertilizers became common among the farmers, leading to seriously unbalanced NPK ratio ($N:P_2O_5:K_2O$ = 1:0.25:0.025) and deficits of soil P and K (Table 1). By the end of the 1970's, the province had 3.84 million ha farmland deficient in P and 0.64 million ha deficient in K, accounting for 90% and 15%, respectively, of the total. Since the 1980's, with the development of the mineral fertilizer industry in China, the application rate of mineral fertilizers has been increasing to a great extent. Though the total amount of nutrients used increased, the proportional application of organic manure decreased due to the increasing amounts of mineral fertilizers applied. According to the statistics, in the 1980's, the farmland in Anhui received a total nutrient input of 1.799 million tonnes of which 44% were in the form of organic manure. The application of N from organic manure accounted for 29% of the total N input, for 34% of the P and for 87% of the K supplied to the fields. In the 1990's (1990 – 1997), the total nutrient input into the farmland was 2.255 million tonnes of which only 33% were in the form of organic manure, despite further increase in the total amount of organic manure. Today, the nutrient supply through organic manure accounts for 23% of N, 24% of P and 67% of the total N, P and K consumption.

Table 1. Annual farmland soil nutrient balance in Anhui ('000 tonnes)

Period		1950's	1960's	1970's	1980's	1990's
Input						
Total	N	160.1	203.8	429.4	937.7	1218.4
	P_2O_5	78.1	89.2	161.9	420.3	545.4
	K_2O	163.7	162.6	275.6	421.5	491.0
Organic manure	N	151.4	165.3	260.1	273.9	278.6
	P_2O_5	77.4	81.5	119.6	143.9	131.8
	K_2O	163.6	161.9	271.4	366.5	328.2
Mineral fertilizers	N	8.7	38.5	169.3	663.8	939.0
	P_2O_5	0.7	7.7	42.3	276.4	413.6
	K_2O	0.1	0.7	4.2	55.0	162.8
Output						
	N	256.9	244.3	441.6	673.8	672.8
	P_2O_5	118.2	112.8	202.5	306.6	299.5
	K_2O	285.2	272.6	489.3	730.5	722.0
Balance						
	N	-96.8	-40.5	-12.2	+263.9	+545.6
	P_2O_5	-40.1	-23.6	-40.6	+114.0	+245.9
	K_2O	-121.5	-110.0	-213.7	-309.0	-231.1

Note: Mineral fertilizer N was discounted by 45% and organic manure N by 15% due to losses. The nutrient contents in organic manure were worked out in reference to the manure handbook published by the Ministry of Agriculture. The amount of organic manure resources was calculated according to the Anhui Province's survey on organic manure. 1990's refers to the years 1990 to 1997.

Table 1 shows that before the 1980's, farmland nutrient input mainly came in the form of organic manure which was insufficient to balance the inputs with the outputs. After the 1980's, mineral fertilizers supplied most of the N and P nutrients whereas organic manure remained to be the main source of K. Balancing nutrient input with nutrient output showed that farmland soils received a surplus of N and P, but have been clearly undersupplied with K. Years of K deficit led to a prominent problem in the nutrient balance. The increased input and the changes of the farming system also caused a series of changes of the soil nutrient status. In Table 2, the results, summarizing the analysis of 4,520 soil samples collected from plough layers nearby the 275 soil nutrient monitoring posts all over the province, are shown. They reflect the downward trend of soil nutrient contents with the beginning of the 1980's.

Table 2. Trend of the changes in soil organic matter, total N, readily available P and readily available K

Item	Time	Huaibei		Jianghuai		Jiangnan		Province	
		Content	Increment	Content	Increment	Content	Increment	Content	Increment
Organic matter ($g\ kg^{-1}$)	1980's	11.5		17.0		22.5		17.0	
	1990's	13.0	1.5	18.1	1.1	20.3	-2.2	17.1	0.1
	Recent	13.8	2.3	19.0	2.0	20.9	-1.6	17.9	0.8
Total N ($g\ kg^{-1}$)	1980's	0.81		1.03		1.36		1.07	
	1990's	0.96	0.15	1.12	0.09	1.35	-0.01	1.11	0.04
	Recent	0.91	0.10	1.19	0.16	1.38	0.02	1.16	0.09
Readily avail. P ($mg\ kg^{-1}$)	1980's	5.1		7.0		6.1		6.1	
	1990's	9.6	4.5	9.3		8.8	2.7	9.2	3.1
	Recent	13.6	8.5	11.0	1.7	12.0	5.9	12.1	6.0
Readily avail. K ($mg\ kg^{-1}$)	1980's	140.2		117.2		74.6		105.5	
	1990's	120.7	-19.5	98.9	-18.3	67.0	-7.6	95.5	-10.0
	Recent	109.4	-30.8	89.7	-27.5	52.8	-22.6	76.9	-28.6

Note: Samples have been taken early 1980 and early 1990

Increasing trend of soil organic matter, total N and readily available P

Generally, the province displays a trend towards larger soil organic matter contents (excluding Jiangnan, the part along the southern bank of the Changjiang River), total N and readily available P contents. Readily available P has increased by a large margin, about 6 mg kg^{-1} and particularly in Huaibei from 5.1 mg kg^{-1} in the late 1970's to 13.3 mg kg^{-1} in the 1990's.

Organic matter and total N have increased in most soils of the farmlands, but they are decreasing in farmland far away from villages. According to 35 farmland monitoring posts in the Mengcheng County, within the five years from 1993 to 1998, farmland soil nutrients have decreased in a pattern of concentric circles from 15.8 g kg^{-1} to 13.1 g kg^{-1} in organic matter. The critical radius of the concentric circle is around 250 m, which indicates that with development of the market economy, farm labour is running short. Because of the inconvenience of transport, organic manure is applied far more to fields nearby the village than in the remote fields, which have to depend on a limited amount of mineral fertilizers to replenish soil nutrients but not the organic matter.

Drastic decline in readily available K

It is clearly indicated that since the 1980's, readily available K of soils has dropped in all the monitoring posts across the province on average by 28.6 mg kg^{-1} from 105.5 mg kg^{-1} in the early 1980's to the current 76.9 mg kg^{-1}, by 30.8 mg kg^{-1} in Huaibei, by 27.5 mg kg^{-1} in Jianghuai and by 21.8 mg kg^{-1} in Jiangnan (Table 2). The decline of soil K is much more serious in high-yielding cotton and double-cropping rice regions. The scope of K deficiency is expanding from south to north. Symptoms of K deficiency have also begun to appear in Huaibei, which used to be considered as a region with soils rich in K. Therefore, for the whole province, soil K has become the major limiting factor for the development of agricultural production.

Protruding problem of inadequate micronutrient supply

With the increase in crop output, the problem of soils being deficient in micronutrients is becoming more and more apparent. The second soil survey discovered that about 86% of the land was deficient in B, 85.4% of the upland soils and 63.6% of the paddy soils were deficient in Zn, and 89.7% of the soils exhibited small amounts of Mo to a varying extent. The results of 746 micronutrient fertilizer experiments in different soils and on different crops all over the province revealed that in 668 experiments about 89.6% of the total showed significant crop responses, which is another proof that the farmland soils in Anhui are deficient in micronutrients. The experiments also indicated that the crop response of wheat and rice to Zn was greater in Huaibei than in Jianghuai and Jiangnan whereas the crop response of oilseed rape to B was greater in Jiangnan than in Huaibei and Jianghuai.

Problems with soil nutrient balance

Despite the rapid progress made in keeping soils productive, problems exist concerning fertilizer management and the build-up of soil fertility. Although years of higher nutrient application has increased organic matter, total N and readily available P in most of the soils, results from monitoring posts indicate that the basic soil fertility is quite low and the area of medium- and low-yielding fields is quite large. This is the real reason why in most of the medium- and low-yielding fields after rising the fertilizer application rate, average yields of the province still haven't reached satisfactory levels.

Somewhat irrational fertilization structure

Although in recent years attention has been given to the use of organic manure in combination with inorganic fertilizers, problems exist with macroscopic regulation and the ratio of mineral nutrient input. The NPK ratio ($N:P_2O_5:K_2O$ = 1:0.44:0.17) cannot match the nutrient output from the farmland.

Decreased area for green manure crops and under-utilized organic manures combined with poor nutrient recovery from applied fertilizers

Due to the recent expansion in cultivating oilseed rape, the area of green manure cultivation decreased from 0.667 million ha in the 1970's to 0.27 million ha. Investigations showed that only about 60% of the human and animal wastes and crop residues are applied to the fields whereas in some areas burning of straw is very popular. Although for years efforts have been made to extend the practices of deep placement to reduce nutrient losses and balanced fertilization, the recovery rate of nutrients from mineral fertilizers remains in the region of only 38%, far below that in the developed countries.

Fertilizer management and strategy for developing sustainable agriculture

Increase of total amount of fertilizers used and performance of regional macroscopic regulation

The soils in Anhui are inherently poor and the crop production per unit area is much less than that in the neighboring provinces. In 1997, the province consumed 2.406 million tonnes (net nutrient) mineral fertilizers, which is an average of 394 kg ha^{-1} cultivated land and 198 kg ha^{-1} per crop, worked out on the basis of the total acreage of cultivated land in the province, which is 6.10 million ha (figure from the soil survey) and the multiple-cropping index of 1.9. Both consumption figures (per year and per crop) are smaller than the country's average. Furthermore, the allocation of fertilizer within the province is very uneven. The relatively developed agriculture in Jianghuai, though occupying only 38% of the total farmland of the province, consumes over 50% of the total fertilizer. The fertilizer application rates in some of the high-yielding farmland is slightly exceeding the demand, especially in terms of N. It may reach levels up to 450 - 500 kg N ha^{-1} per crop. However, the medium- and low-yielding farmland, accounting for over 60% of the province's total farmland, are inadequately supplied. In some places, the application rate is only 150 kg ha^{-1} per crop, one-third of the former. Nevertheless, practices demonstrate that crop response to fertilization of the medium- and low-yielding farmland is 50% - 100% larger than that in the high-yielding farmland.

In order to benefit from the yield-increasing effect of fertilizers and to improve land productivity, it is essential to further increase the nutrient input into the farmland. Based on the targeted output, the demand for mineral fertilizers in 2010 is estimated to be 3.10 Mt and the average application rate per crop 250 kg ha^{-1}, respectively. While an adequate fertilizer supply is ensured for high-yielding regions, it is essential to supply fertilizer to regions with high crop response, especially to the medium- and low-yielding farmland in the Huanghuaihai region. At the same time, the practice of returning straw to the field and the application of organic manure should be intensified.

Control N over-dosage, increase K input and supplement other macro- as well as micro-nutrients

Of the currently used fertilizers in Anhui, 62% are N fertilizers of which single N fertilizers account for 82%. Despite its yield-increasing effect, nitrogen application alone and the shortage of P and K fertilizers, particularly K, causes some crops to lodge and to delay maturity, so that the full yield potential cannot be tapped. There is also a danger that N fertilizers applied in excess will lead to an adverse impact on the environment. The multi-location experiments on balanced fertilization and 803 experiments in the province showed that in the farmland wheat, rice, maize and some other cereals achieved yields of 7,500 kg grain ha^{-1}, oilseed rape 2,700 kg seed ha^{-1} and cotton 1,800 kg lint ha^{-1}. These large yields are sometimes produced in areas, where the N application rate reached up to 450 - 550 kg ha^{-1}. These high inputs, however, indicate poor N use efficiency and may be partly a waste of resources. Therefore, the demand oriented N application rate, aiming at greater efficiency, should be in the region of 180 kg ha^{-1} for cereals, 180 kg ha^{-1} for oilseed rape and 240 kg ha^{-1} for cotton.

The soil K supply in Anhui is medium and low. Balancing the nutrient input with nutrient output (Table 2) shows that soil N and P have turned from deficit to surplus during the past decades. On the other hand, K has long been neglected and soil K reserves became rapidly depleted. In the process of implementing the "K Supplementation Project", it was found that the area of crops, suffering from K deficiency, reached 3.172 million ha, accounting for 52% of the actual cultivated area. K deficiency is found in 50% of the wheat, 89% of the rice, 60% of the oilseed rape and 79% of the cotton area. Furthermore, there is a certain area of high-yielding farmland that must be supplemented with a substantial amount of K, if large yields should be sustained. It is quite obvious that there is a great potential to increase yield by K application so that the task of supplementing K to the soil is a real challenge.

Mineral K fertilizers have to be used at larger amounts, especially in view of the negative soil nutrient balance. The recommended critical value in the soil for K (on a basis of readily available K) is 100 mg kg^{-1} for cotton, 90 mg kg^{-1} for wheat, maize and soybean, and 80 mg kg^{-1} for oilseed rape. The fact that the critical value of K deficiency of a crop varies with soil should be born in mind. For instance, in Huaibei, the value for wheat in sandy soil is 80 mg kg^{-1} and in clayey soil 110 mg kg^{-1} and for the double-cropping rice alongside the river 60 mg kg^{-1}. Full use should be made of the local experimental and demonstration fields in guiding fertilization. Furthermore, to complement mineral K, it is advisable to also increase the amount of organic manure and to disseminate the practice of recycling crop residues to the field instead of burning or using them for other purposes.

The responses of oilseed rape to B application, of rice and maize to Zn application and of beans to Mo application are widespread in the province. According to investigations, about 4.445 million ha of farmland need an application of micronutrients. Currently only 0.80 million ha, about 18%, are being treated with micronutrients. Some farmlands also showed a different extent of deficiency in other macronutrients such as calcium, magnesium and sulphur. Investigations revealed that about two-thirds of the soils in the province are deficient in S. Of the major soils such as yellow fluvio-aquic soil, grey fluvio-aquic soil and purplish soil about 40 - 60% had an available S content of less than 16 mg kg^{-1}, a problem that needs to be also addressed.

Intensify the study on balanced fertilization and introduce new fertilization techniques

With regard to balanced fertilization, technical criteria have been worked out for Anhui based on soil analysis, basic yield, residual effect of fertilization to the succeeding crop in a crop rotation, production level and different types of fertilizers. Crop-specific fertilization models were established, optimal application rates were recommended, critical values of deficiency in K and other elements (micronutrients) developed and areas for K supplementation defined. Thus, fertilization technology in Anhui has been pushed up onto a new level. Experience has shown that the overall service, e.g. integrating soil analysis, formula designing, production, supply and guided-application of compound fertilizers, is a successful approach to accelerate the transformation of scientific findings into products and to promote balanced fertilization techniques. Today, with the rapid development of the information technology, it is essential to further intensify the study on balanced fertilization techniques, to data processing, geographic information system and remote-sensing technology for "precision fertilization". It is important to combine organic manure with mineral fertilizers, macronutrients with micronutrients and fertilization methods with cultivation management with the purpose of improving the recovery rate of fertilizers.

Actively develop organic manure, intensify mechanization of the recycling of crop residues to the field and follow the road to manufacture of organic manure

Organic manure is an important nutrient source. Currently, in Anhui the nutrient input in the form of organic manure accounts for over 40% of the total nutrient input into the farmland, greatly mitigating the pressure of the shortage of mineral fertilizer supply and the imbalance in the nutrient consumption. The organic manure resources, including human and animal wastes and crop residues, can be converted into more than 3.40 Mt of NPK. However, only less than 60% are utilized, leaving a great potential unused. In view of the common practice of burning straw, it is essential to intensify the effort to develop and extend a technique for mechanized straw recycling. Mechanical operations save time and labour which is a prerequisite that the technique is accepted by farmers.

However, with all the progress made in this respect, manufacturing fertilizers from organic wastes, etc., it should be remembered that organic manures are not adding but just recycling nutrients which originally have been removed from the soil. Net gains in soil fertility have to come either from mineral fertilizers or imported feed staff. Unless nutrients are imported with animal feed or food for humans, it is mainly mineral fertilizer which has to produce more biomass, causing larger amounts of crop residues which can either be directly or after industrial processing recycled to the fields.

K cycle and nutrient balance in farmland of the Hubei Province

Xu Nenghai, Li Jianfu and Zhang Decai

Hubei Province Soil and Fertilizers Working Station 430070

Abstract

In this paper, K cycling and nutrient balances in farmlands of Hubei Province are elaborated in a systematic way based on the data and materials from two soil surveys, long-term soil fertility monitoring and large numbers of field experiments. On one hand, the development of the agricultural production resulted in larger application rates of N and P fertilizers, causing larger yields but also larger K removals from the soil by the harvested crops. Since these cannot be replaced by K application through organic manure, the recycling of straw and the application of K-containing fertilizers is not sufficient, K deficiency in the Province is spreading. Farmland that shows a K deficit has become a major limiting factor for the agricultural development in Hubei. In this paper, some specific measures are brought forward for regulating the K cycle and the nutrient balance of the farmland.

Introduction

Located in the middle reaches of the Changjiang River, Hubei Province covers a total land area of 18.59 million ha, of which 3.34 million ha (1998 statistics) is cultivated farmland with various soils, dominantly red soil, yellow earth, yellow brown earth, fluvio-aquic soil and paddy soils. Hubei Province has a subtropical monsoon climate with ideal light, rain and temperature distribution during the year. Its annual precipitation ranges from 750 mm to 1,600 mm and its annual mean temperature from 15 to 17°C. This makes the province suitable for the development of agricultural production and also propitious to accelerating nutrient cycling in the soil. According to the second soil survey, the sampling investigations in 1997 and long-term monitoring, the soil K content in the plough layer of the farmland is universally low and shows a downward trend. Hubei may be described as a K-deficient province and it was the purpose of this study to provide information and guidelines to improve fertilizer management for better, demand-oriented nutrient supply to Hubei's farmland.

Farmland K status

Soil K content of the farmland

Based on the second soil survey (end of 1970's, beginning of 1980's), about 80% of the farmland soils were paddy soils, fluvio-aquic soil and yellow brown earths. The area covered by paddy soil was 2.04 million ha, accounting for 50.35% of the province's total cultivated land. Being the largest in area and contributing greatly to the province's agricultural production, paddy soil produces 15.54 - 17.90 Mt of rice. This leads to an annual removal of about 0.39 - 0.45 Mt of K_2O from the paddy fields, to which a substantial amount of K lost from the fields through mainly leaching, etc. has to be added. The removal of K led to K deficiency in the soil. Fluvio-aquic soil, mostly cropped by cotton, has the size of 761,700 ha and accounts for 19% of the agricultural land. The soil is deep and fertile but relatively light in texture with about 85%, being sandy loam to loamy sand. Moreover, about 50% of the soils have a sand layer in the solum, making it difficult to conserve nutrients. As a result, K loss in the soil is very serious. According to our survey, about 54% of the fluvio-aquic soil contained less than 100 mg kg^{-1} readily available K. The acreage of yellow brown earth comprises 582,100 ha, accounting for 14.54% of the cultivated land. The soil is heavy in texture and has poor drainage properties. The subtropical humid monsoon climate and the strong influence of southeast monsoon with an annual precipitation of 900 - 1,300 mm and periodically heavy rains, exceeding 100 mm d^{-1}, serious soil K losses through erosion and surface runoff may occur.

Table 1. K contents and their variation in the major soils groups of Hubei Province

	2nd Soil survey (a)		1997 survey (b)		Change (a-b)	
Soil	N	Range	N	Range	±	%
			Total K (g kg^{-1})			
Red soil	186	16.8±4.8	62	15.1±5.2	-1.7	10.1
Yellow earth	41	18.6±5.3	11	16.9±3.7	-1.7	9.1
Yellow brown earth	364	17.3±5.9	92	15.2±6.1	-2.1	12.1
Fluvio aquic soil	351	19.9±3.7	118	16.5±4.3	-3.4	17.0
Paddy soil	1703	17.9±3.7	633	15.3±3.5	-2.6	14.5
Total	2645	18.1±4.9	916	15.5±5.0	-2.6	14.4
			Readily available K (mg kg^{-1})			
Red soil	863	95±43	262	81±37	-14	14.7
Yellow earth	590	117±53	204	97±62	-20	17.1
Yellow brown earth	3167	98±50	988	83±52	-15	15.3
Fluvio aquic soil	6751	109±37	2446	87±41	-22	20.2
Paddy soil	11685	99±31	4369	78±37	-21	21.2
Total	23056	102±47	8269	85±44	-18	16.7

Note: N stands for number of points investigated

On average, from the 2^{nd} soil survey at the end of 1979, early 1980 until 1997, the total K in the plough layer of cultivated farmland decreased by 2.6 g K kg^{-1} or 14.4%. Greatest changes were found in the fluvio aquic soil and smallest in the yellow earth soil. The readily available K which was in the region of slightly above 100 mg K kg^{-1} and hence at the lower margin of adequate supply during the 2^{nd} soil survey declined clearly below the threshold levels of adequate K supply. The order of magnitude of changes with 17% on average was similar to the total K. Slight differences were also observed between the soils, so that the largest decline with 21% occurred in the paddy soil whereas the smallest changes with 15% in the yellow earth soil (Table 1).

The land use, whether as non-irrigated farmland, paddy or so-called upland which is found in the sloping areas of the province may have a distinct influence on the development of the soil K status. The impact on the development from the 2^{nd} soil survey until the 1997 survey is shown in Table 2. The results confirm a.m. observation (see Table 1) of declining contents in available K during this period from the adequate to the below adequate range for all land-use systems. Most serious decline in available K was found in the uplands, followed by non-irrigated farmland and irrigated paddy fields.

Table 2. Changes in readily available K of soils of major land types in Hubei Province from the 2^{nd} soil survey to the 1997 survey

Land use	2^{nd} soil survey (a)		1997 survey (b)		Change (a-b)	
type	Sites (N)	Mean(mg kg^{-1})	Sites (N)	Mean(mg kg^{-1})	(mg kg^{-1})	(%)
Farmland	548	136	204	91	-45	33.1
Paddy	327	125	116	90	-30	28.0
Upland	221	152	88	92	-60	39.5

Across the various counties surveyed, the development in K availability shows a similar picture (Table 3). With only 94 mg K kg-1 the average K contents of the studied counties were already below the level of adequate supply during the 2^{nd} soil survey and further decreased to deficiency levels during the survey in 1997. A reduction of 22% in available K during 20 years reflects the strong K depletion that has taken place in the soils of the various counties. Most severely affected were Huangmei, Xinkai and Yanglu where in 1997 extreme K deficiency could be found. Less extreme was the situation in Xinyan and Ducheng where larger initial K contents prevented the soils from dropping into the K deficiency range .

Table 3. Readily available K and its variation in the plough layer of the surveyed counties (cities) in Hubei Province

Location	Soil type	Sites (N)	2^{nd} survey (a)	1997 survey (b)	Change (a-b) mg kg^{-1}	%
Tangxian, Suizhou	CS, PS	75	98	80	-18	18.4
Xinyan, Hanchuan	FS, PS	30	164	148	-16	9.8
Ducheng, Huangzhou	FS	65	117	107	-10	8.5
Xinkai, Huangmei	FS	70	53	40	-13	24.5
Huangmei, Huangmei	RS, PS	85	51	38	-13	24.5
Yangliu, Yingshan	YBE, PS	60	69	42	-27	39.1
Luoqiao, Daye	RS, PS	120	108	76	-32	29.6
Sike, Daye	RS, PS	122	115	83	-32	27.8
Panwan, Jiayu	FS, PS	121	92	65	-27	29.3
Huaqiao, Wuxue	PS, PS	64	76	51	-25	23.8
Mean		81	94	73	-21	22.3

Note: CS stands for cinnamon soil, PS for paddy soil, FS for fluvio-aquic soil, RS for red soil, YBE for yellow brown earth.

Farmland soil K supply

The low K content of the farmland soil and its general downward trend has led to a significant decline in the ability of the cultivated land to supply K to crops, which manifests itself in expanding acreage of K-deficient farmland and the severity of the observed deficiency.

The area of farmland deficient in K (with soil readily available K below 100 mg kg^{-1}) increased from 1.4 million ha in 1982 to 2.0 million ha in 1996, from 19% to 72% of the total area. The area of farmland seriously deficient in K (with soil readily available K less than 50 mg kg^{-1}) jumped from 0.8 million ha to 1.3 million ha. The farmland, deficient or seriously deficient in K, is widely scattered all over the province. Total soil K of the farmland of the province was in the range 0.6 – 38.6 g K kg^{-1} with an average of 14.5 g kg^{-1}. Soils with soil total K of less than 15 g kg^{-1} were classified as class 3 soils and account for 58.4% of the total cultivated land. The slowly available K varied between 98 - 1635 mg kg^{-1} with a mean of 534 mg kg^{-1}. Using slowly available K as an indicator, soils can be classified as class 3, if the measured contents are < 600 mg K kg^{-1}. The area below this threshold level in slowly available K accounted for 65.7% of the total. With regard to readily available K, class 3 is characterizing soils when exchange K was < 100 mg kg^{-1}. The survey revealed a strong variation of 15 - 343 mg K kg^{-1} with a mean of 105 mg kg^{-1}. The area of farmland in class 3 accounted for 55%. Farmland in and below class 3 is land being deficient and seriously deficient in K (Table 4).

Table 4. Soil K supply potential of the farmland in Hubei Province (1997)

Type	Total K (g kg^{-1})			Slowly available K (g kg^{-1})		
	Sites (N)	Range	Mean	Sites (N)	Range	Mean
Farmland	1124	0.6-38.6	14.5	1109	98-1653	534
Paddy	604	3.7-32.4	14.8	595	147-1394	522
Upland	520	0.6-38.6	14.2	514	98-1653	547

K cycling and balance of farmland and crop response to K application

K cycle of the farmland

K fluxes between crop – soil – fertilizer is subjected to the integrated influence of natural conditions, biological factors and human activities.

Agricultural production removes large amounts of K from the soil and from the K cycle of the farmland. According to the survey during the years 1991 to 1995, in the double rice cropping region, the crops removed a total of 185 kg K_2O ha^{-1} per year, whereas the K input amounted only to 78 kg K_2O ha^{-1}, indicating a loss of 107 kg. In the cotton-wheat regions, the crops took up 111 kg K_2O ha^{-1} while the input was only 38 kg, causing losses of 74 kg K_2O ha^{-1}. In the rice-wheat regions, the removal was 129 kg K_2O ha^{-1} while the input was 29 kg, causing losses of 101 kg K_2O ha^{-1}. In addition, soil erosion has not been accounted for in this balance calculation but, depending on rainfall events, losses of K by this pathway may be substantial. Thus, as consequence, the soils are characterized by a serious K deficit.

Table 5. Soil K balance in Hubei Province (K_2O)

Year	K(OM)	K(MF)	Total input	Area	Crop production	Crop removal	Total Loss	Loss per unit area
	1000t	1000t	1000t	1000 ha^{-1}	1000t	1000t	1000t	kg ha^{-1} yr^{-1}
1950	94.9		94.9	3767.0	6466.9	201.0	105.2	28
1960	150.4		150.4	4271.7	9299.1	285.6	135.3	32
1970	214.6		214.6	3964.0	12776.3	389.8	175.6	44
1980	280.4	23.9	304.3	3738.5	15879.4	489.2	184.9	50
1985	367.8	69.0	426.8	3584.6	23707.0	161.4	334.6	93
1990	388.4	136.7	525.1	3483.4	37456.8	892.0	366.9	105
1995	417.8	137.2	555.0	3443.4	36551.0	890.0	369.1	107
1996	362.7	158.7	521.4	3437.4	36728.7	891.1	369.7	108
1997	376.6	143.0	519.6	3426.8	36615.2	889.7	370.1	108
1998	336.4	161.3	497.7	3342.5	35722.5	868.1	370.4	111

Note: OM stands for organic manure and MF for mineral fertilizers.

Farmland K balance

K input and output

Since there is no closed potassium cycle in the farm or even in the field, soil K reserves are depleted with the duration of production unless soil K is adequately replenished by fertilizers. The study revealed that K input is insufficient to balance the K output, so farmland soil K gradually depleted. Table 5 shows that the K deficit was 105,200 t K_2O (28 kg K_2O ha^{-1}) in 1950 and raised to 370,400 t K_2O (111 kg K_2O
ha^{-1}) in 1998. Second, K is not in balance with N and P. Soil analysis and correlation with crop production showed that an ideal ration of the available nutrients in the soils, using standard extraction methods, is N : P_2O_5 : K_2O of 1 : 0.1 : 1.2. During the 2nd soil survey the ratio was 1 : 0.07 : 1.15, which widened to 1 : 0.08 : 0.96 and further to 1:0.09:0.71 at the time of the survey. This indicates that the imbalance in the supply of N, P and K in the farming systems was getting more serious.

Causes of farmland soil K deficit

The drastic drop of soil K has mainly the following three causes:

1) A higher multiple cropping index increased crop output and hence removal of K from the soil without adequate K return. In 1998, the province had 3.34 million ha of cultivated farmland with a multiple cropping index of 2.3. On about 84% or 2.81 million ha, two or three crops per year were grown. A higher multiple cropping index has increased crop output and hence removal of K from the soil. Moreover, the K absorbed by the crops originates mainly from the soil resources, thus intensifying soil K depletion.
2) Reduction in the amount of organic manure applied leads to inadequacy in K supply. In recent years, the amount of organic manure used has been decreasing significantly, which is mainly caused by: i) A reduction of green manure, an aerea which declined from 1.33 million ha in the 1970's to 0.2 million ha in the late 1990's. ii) Crop residues, particularly cereal straw were not fully or properly recycled. Only less than 30% of the straw is returned to the field and the practice of burning straw is still quite prevalent. According to statistics, every year about 10 Mt of straw are left unused. On a basis that per hectare 3,000 kg of straw are produced on 3.33 million ha, and if used this would equal to 273,000 tonnes of potassium chloride. iii) Less farmyard manure is collected and returned to the fields.
3) Irrational fertilizer application results in inadequate K supplementation. During the period from 1992 to 1997, the NPK ratio ($N:P_2O_5:K_2O$) of the fertilizers applied was 1:0.38:0.25 for paddy fields and 1:0.25:0.16 for upland fields, far different from the ratio of NPK absorbed by the crops (1:0.28:1.2 for rice, 1:0.41:0.8 for wheat, 1:0.35:1.2 for cotton and 1:0.4:0.9 for rape). The total consumption of mineral fertilizers in the province was 129,400 t in 1970 and increased to 1,485,900 t in 1990 or 10-fold within 20 years. N fertilizers increased almost 9-

fold and P fertilizers by 21-fold while the total output of crops increased almost only 2-fold. The combined effect of larger N and P fertilizer application rates, raising crop yields and inappropriate fertilization systems accelerated soil K depletion.

Crop response to K application

Additional application of K fertilizers can build up soil fertility, regulate soil K balance and increase crop output. In 1992 – 1998, soil and fertilizer stations of 32 counties all over the province were organized to carry out stationary experiments on crop response to K application on 12 major crops in 6 major soils. The results showed a significant response of rice, wheat, corn, sweet potato, potato, oilseed rape, sesame, cotton and ramie. K application increased the yield of rice by 725 - 792 kg ha^{-1} or 11 - 15% with an O/I ratio of 7.1 (7.1 kg rice kg^{-1} K_2O applied), of oilseed rape by 305 - 417 kg or 32 - 47% with an O/I ratio of 3.9, of lint by 117 - 182 kg or of cotton by 15 - 21% with an O/I ratio of 1.59 and of wheat by 425 - 520 kg or 15 - 21% with an O/I ratio of 6.

Strategy for management of the farmland soil K balance

The major approach to regulate K cycling in a farming system and to keep K removals in balance with the supply, is to recycle as much K as possible within the farm, back to the field and to add external K resources to the soil. The practice of returning crop residues or straw to the field and the application of organic manure are possibilities to recycle K within the system. The application of K fertilizers on the other hand is the only net application of K, unless large amounts of manure produced from externally purchased animal feed is used. Based on the agricultural production practices in Hubei Province the following management strategies are put forward for regulating the soil K balance in the farmland.

Dissemination of the balanced fertilization principle

Balanced fertilization is an important measure to improve agricultural production since currently the annual K deficit is increasing due to higher N application rates and insufficient K supply. A fixed NPK ratio for balanced fertilization should be continuously adapted based on frequent soil analyses by using a formula worked out by an expert system software. Macroscopic regulation will be exerted to control the flow of K fertilizers to regions with medium and high crop response. Microscopically, one soil sample is taken every 6.67 - 13.3 ha for analysis and recommendation worked out for each administrative unit (village). Thus, K fertilizers should be applied according to soil and crop requirements for each specific region.

Intensifying the practice of returning straw to the field

The practice of returning straw to the field will reduce the removals and hence the K losses from the soil. This is a major approach to economize the use of the urgently needed and scarce nutrient K in the province. Besides leaving high stubs or straw directly in the paddy field, another pattern of returning straw to the field is using crop stalks and stems as mulching for upland crops like wheat, cotton and corn. The beneficial effects of straw mulching in wheat fields are evident from yield increases of 531 kg ha^{-1} or 12%, in corn fields of 706 kg ha^{-1} or 16%, in oilseed rape fields of 347 kg ha^{-1} or 16%, in cotton fields of 137 kg ha^{-1} or 12% additional lint. The various vegetables responded with average yield increases of 10 - 25% through transfer of straw from the rice fields to the vegetable gardens.

Making full use of plant ash and human and animal wastes

Rice straw, wheat straw and cotton stalks are extensively used as fuel in the countryside. The remaining ash contains high K and can be used as basal and side dressing. Human and animal wastes easily get fermented or composted into organic manure, which can be applied to promote crop growth. Composts have the advantage that besides supplying K they can also improve physical and chemical properties of the soil. Statistics show that the total amount of night soils, barnyard manure and compost may reach 76,772,000 t, accounting for 53% of the total of organic manure. An application of 15,000 - 18,000 kg ha^{-1} can increase the yield of cereals by 750 ~ 900 kg.

Making full use of biological K manure

Exploiting biological K manure is another approach to enrich soil K and also an effective method to have K recycled within the system. The province has a huge variety of biological K resources, such as green manure crops, water grass, duckweed, alligator alternanthera, etc., which may reach 36,576,000 t in quantity, containing 139,100 t K_2O. These K-consuming plants have a strong capability of taking up K from soil and water through their root system. Expanding the area of green manure, crops can reduce the soil K losses and improve circulation and recycling of soil K. It needs to be pointed out that an area expansion in these kind of crops unless grown on otherwise non-cultivated areas, are competing with food crops for land and if planted on the same land would even lead to an accelerated K depletion of the soils.

Making full use of K in water

Hubei Province has a huge number of lakes with a vast water surface. In some ponds and pools, the K content ranges between 3.6 and 15.7 mg kg^{-1} (mean = 9.6 mg kg^{-1}, n = 5, C.V. = 55.9%). The K concentration in lake waters is between 3.3 mg kg^{-1} and 8.3 mg kg^{-1} (mean = 6.2 mg kg^{-1}, n = 5, C.V. = 45%), that in rivers and ditches is between 2.0 mg kg^{-1} and 8.3 mg kg^{-1} (mean = 4.3 mg kg^{-1}, n = 7, C.V. = 51.3%). In order to make full use of the K in water, certain growing of aquatic green manure crops could be grown to extract the K from the waters.

Making full use of K in the subsoil layers

The K contents in the subsoil layers are usually in a similar order of magnitude as those in the plough layer, though plants often do not benefit from this reserve due to their shallow root system. Therefore, typical paddy based cropping systems could be enriched with one upland crop during the non-irrigated time to extract K from lower soil depth. For instance, the subsoil layer (usually 30 – 70cm thick) of the fluvio-aquic soil in the Jianghan Plain contains 15.9 g kg^{-1} total K and 96 mg kg^{-1} readily available K which could be tapped by deep-rooted plants and available K in the crop residue could be recycled to the succeeding crops..

Capital construction of farmland

K loss can also be reduced by controlling soil erosion through growing grass and trees on contours of non-cultivated, partly unproductive hills and slopes. 0.4 million ha (20% of the province's paddy field area) consists of so-called cold water paddy fields with intensive water. Measures could be taken to transform the cold water paddy fields into running water paddy fields in order to improve the soil K supply ability.

All these alternative K sources can be tapped though bearing in mind that they can only be regarded as K which is recycled within the agro-ecosystem. Net additions of K to a crop or cropping system only occur when external mineral inputs are applied. Using internal sources of K, such as organic manure, means only minimizing depletion or shifting fertility from one place (upland-lowland or vice versa) to another. An exception to this would be if animal feed is imported from other countries or provinces etc., then this resource would be a real net input as well.

Farmland nutrient cycle and nutrient balances in different eco-regions of the Hunan Province

Dai Pingan, Nie Jun, Liu Xianghua and Yi Guoying

Hunan Province Soil and Fertilizers Institute, 410125

Abstract

Farmland nutrient cycles and balances of typical eco-regions, comprising the lake, mountain and hilly regions of the province are presented. In the hilly regions, nutrient deficits have been observed in the order of K > N > P. In the lake regions, the K balance was negative whereas N and P had a positive balance. In the mountain regions, K balance became increasingly negative whereas N and P maintained their levels. In the whole province, K use is deficient whereas there is surplus supply of N and P (P > N). The results of a farmers' survey were similar to the statistics of the government. Readily available nutrient contents in soils were in the order of mountain regions < hill regions < lake regions. In order to sustain a constant development of the agricultural production, it is essential to supply K to all eco-regions and also to increase N and P inputs to the hill and mountain regions. An estimate of the future fertilizer demand is made.

Introduction

The Hunan Province is located in the central subtropical part of China and has a rather marginal landform for agricultural production. About 64.6% are mountains, 28.7% hills and 6.7% lakes. Locations covering the three major agro-ecological zones of Hunan were selected and surveys on the fate of plant nutrients in the main cropping systems were carried out. Since the physical conditions and the agricultural production levels of the different eco-regions vary strongly, Yongshun, Ningxiang and Nanxian were selected as representative counties for the investigations. The aim of the study of the farmland nutrient cycle and balance was to find a scientific basis for an improved fertilisation to promote a reasonable distribution of mineral fertilizers in the province.

Materials and methods

Investigation

In order to obtain representative results for the whole province, suitable farming systems, production and fertilization practices, three agro-ecological-regions were selected for the investigation and studied in more detail. Four to five key farmers were invited to attend a meeting at which they were individually interviewed and samples from their farms taken. Information about the agriculture in the counties and the province were also gathered from statistical records. The survey was completed at the end of November 1998.

Calculation

Nutrient input

1) The input of nutrients in the form of mineral fertilizers was calculated by multiplying the actual amount of fertilizers used by the standard nutrient content in the fertilizers. 2) The nutrient input in the form of organic manure was determined for each household by multiplying the amount of manure applied by the estimated nutrient content based on tables from published data. For the province and the respective county, the amount of night soil and farmyard manure was estimated on the basis of the excretion per person or per animal per year. The amount of plant ash was calculated on the basis of the straw : grain ratio and the amount of ash taken as 15% of the residual straw. Then the input of these manures was estimated on the basis of a utilization rate of 80%. Besides, about 10% of the total input of mineral fertilizers and organic manure was deducted from the use by the annual grain crops, assuming this proportion was applied to adjacent vegetables, fruit trees and tea gardens. 3) Nutrients brought in with rain and irrigation water and 4) nutrients applied with seeds and seedlings were also taken into consideration by taking published data on nutrient contents in this material.

Nutrient removal

Nutrients removed were calculated as 1) nutrients consumed to produce the respective amount of economic product and 2) nutrients lost through runoff and leaching. 3) The loss of mineral N was estimated at 50% in the irrigated rice fields and 35% in the upland fields whereas the amount of N removed from the organic manure fraction was set at 30% of the applied amount.

Results and analysis

General introduction to the eco-regions

A general information about the three agro-ecological regions is given in Table 1. This clearly shows that the selected regions differ greatly with regard to physical and social economic conditions as well as regarding their farming systems. As a result, these agro-ecological regions also vary in farmland nutrient input, output and balance.

Table 1. Facts about the three eco-regions

Agro-ecological region		Hill region (Ningxiang)	Lake region (Nanxian)	Mountain region (Yongshun)
Altitude (m)		200-500	< 50	> 1000
Mean Temp.(°C)		17.7	17.2	16.5
Rainfall (mm)		1358.6	1201.1	1155.1
Population (10^3)		1299.7	658.6	474.1
Area of cultivated	Paddy	6.861	3.544	2.100
land (M ha)	Upland	0.889	2.191	0.685
Area/capita (ha)		0.075	0.051	0.075
Farming system	Paddy	Rice-rice-green manure	Rice-rice-green manure (rape)	Rice-rape (wheat)
	Upland	Sweet potato-rape Soybean-potato	Cotton-rape Ramie, sugarcane	Tobacco (peanut) Potato

Table 2. Average farmland nutrient balance for 26 farms in the hill regions (kg ha^{-1} yr^{-1})

Item	Paddy			Upland			Mean		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Total input	358.0	126.5	302.6	83.0	24.6	38.0	338.0	119.1	283.3
Mineral fertilizers	276.9	85.8	96.5	29.0	9.0	4.7	258.8	80.2	89.8
Organic manure	75.8	38.7	200.4	36.4	13.7	31.9	73.7	36.9	188.1
Seed	2.3	1.4	0.6	7.6	1.9	1.4	2.7	1.4	0.7
Irrigation rain water	3.0	0.6	5.1				2.8	0.6	4.7
Total removal	383.2	135.2	362.9	66.4	17.3	44.7	360.1	126.6	339.7
Grain crop	184.7	131.6	296.9	23.3	12.1	41.1	172.9	122.9	278.3
Oil crop				20.1	4.3	1.6	1.5	0.3	0.1
Fibre crop				2.8	0.9	2.0	0.2	0.1	0.1
Nutrient loss*	198.5	3.6	66.0	29.2			185.5	3.3	61.2
Balance	-25.2	-8.7	-60.3	16.6	7.3	-6.7	-22.1	-7.5	-56.4

Note:* includes loss from mineral fertilizer, organic manure, runoff and leaching. Numbers in Tab. 3 and Tab 4 are based on the same calculations.

Farmland nutrient balance

Farmland nutrient balance in the hill regions

Table 2 shows that because irrigated rice (paddy fields) constitutes a large proportion of cultivated farmland in the hill region, farmers put great emphasis on fertilization of paddy fields. They apply more fertilizers and larger rates of P and K to paddy fields than to upland fields. The nutrient removal in the paddy fields, however, still exceeds the input which results in a negative nutrient balance, especially for K. In the uplands, the input of nutrients is small and so is the removal. Hence, only K has a negative balance. But the acreage of upland cropping is too small to counteract the nutrient deficit of the whole county. According to the investigation in 24 plots of farmland in the county, soil readily available K decreased by 12.8 mg kg^{-1}, P level remained constant and N increased slightly during 1989-1995. Therefore, in this region, the input of NPK should be increased which could be done by the introduction of an optimised NPK formula. Like that a sustainable agricultural production and a steady build-up of soil fertility can be ensured.

Farmland nutrient balance in the lake regions

Table 3 indicates that in the Dongting Lake region, upland fields occupy a fairly large proportion (38.2%) of the cropped land of which the majority is occupied by cash crops, such as cotton and oil crops. In upland fields, the input of N and K is slightly smaller than in paddy fields, but the input of P is larger, which redounds upon the increasing crop yield and the greater nutrient removal. The nutrient input, however, still exceeds the nutrient removal in upland fields with a surplus of the three major nutrients, being in the order of P > N > K. In paddy fields, the inputs of N and P are larger than their removals whereas it is opposite for K. Therefore, in paddy fields, the annual balances for N and P are positive and negative for K (63.0 kg ha^{-1}). The nutrient balance on the basis of the cultivated farmland for both cropping systems shows an annual deficit in K of 35.1 kg ha^{-1} but a large P and a small N surplus. Hence, it can be concluded that the K application to paddy fields is specifically important. P application rates should be reduced or only applied to every second crop only. N application rate should be reduced in improving the fertilizer recovery rate and also reduce the negative effect of fertilization on the environment.

Table 3. Average farmland nutrient balance for 29 farms in the Dongting Lake regions (kg ha^{-1} yr^{-1})

Item	Paddy			Upland			Mean		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Total input	472	172	281	411	187	197	445	175	246
Mineral fertilizers	375	141	86	317	142	124	356	141	99
Organic manure	91	30	189	85	43	72	89	34	149
Seed	2	1	1	9	2	2	5	2	1
Irrigation rain water	3	1	5				2	0.5	3
Total removal	437	127	344	291	68	159	388	107.	282
Grain crop	181	123	278				120	82	184
Oil crop				53	22	68	18	7	23
Fibre crop				98	39	85	33	13	29
Other crops				4	7	6	2	2	2
Nutrient loss	257	4	66	137			216	2	44
Balance	34	46	-63	120	120	38	57	68	-35

Farmland nutrient balance in the mountain regions

Despite the relative poor soil conditions in the mountain regions, the input of nutrients is not only small but also one-sided in favour of N. Such fertilisation practice cannot meet the nutrient requirement of crops, thus restricting the growth and the output of crops. The nutrient removal in the harvested crop is generally small, keeping the nutrient cycle of the farmland at a low level. In paddy fields, the inputs of P and K are obviously smaller than the amounts removed, leading to a deficit in P and especially in K. In upland fields, both the input and output of nutrients are much smaller than those in paddy fields. However, the N, P and K balance in upland cropping systems improved significantly. Due to the fact that the acreage of paddy fields is quite large, the overall nutrient balance of the cultivated farmland in the county still shows a K deficit of -49 kg ha^{-1} yr^{-1} (Table 4). It is obvious that for developing agricultural production in the mountain regions, firstly K application has to be increased and it is essential to raise the application rates of N and P. For a further improvement of the nutrient cycle in farmland a higher level of field and nutrient management has to be achieved.

Table 4. Average farmland nutrient balance for 30 farms in the mountain regions (kg ha^{-1})

Item	Paddy			Upland			Mean		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Total input	330	92	198	280	90	157	289	92	191
Mineral fertilizers	235	54	38	29	56	61	197	54	42
Organic manure	91	36	156	78	34	96	88	36	145
Seed	2	2	1	1	0.4	0.2	2	2	1
Irrigation rain water	2	0.4	4				2	0.3	4
Total removal	310	94	271	176	38	106	286	84	240
Grain crop	126	88	199	79	37	101	117	78	181
Oil crop	11	5	13				9	4	11
Other crops				4	1	4	1	0.2	1
Nutrient loss	174	2	59	93			159	2	48
Balance	20	-2	-71	104	52	51	3	8	-49

Apparent nutrient balance for the various agro-ecological regions and the whole province

According to the agricultural statistics of the three agro-ecological regions and those of the whole Hunan Province, the hill regions rank first in terms of input and removal of all nutrients (Table 5). They are followed by the lake regions and then the mountain regions, according to the order of productivity. The inputs of P and K, however, follow a different order with hill regions > mountain regions > lake regions. Both nutrients show significantly smaller ratio of input : removal in all three eco-regions, especially K. This nutrient is deficient in all three agro-eco-regions with a range between 29 - 38 kg ha^{-1}. For P still a small surplus was calculated which is related to the relative smaller inputs of K. This is similar to what was found by the farm survey. The province's average N and P input is larger than that of the individual agro-eco-regions, whereas the average K application rate of the province is smaller than that of the lake and mountain regions. The apparent nutrient balance still indicates a deficit in K and a surplus in N and P. Even the high-yielding fields show a similar tendency, indicating that the nutrient imbalance is an important factor, limiting the agricultural production in Hunan.

Table 5. Apparent farmland nutrient balance of the various agro-eco-regions and the whole province

Agro-eco-region	Nutrient	Input		Removal		A. balance (kg ha^{-1})	Intensity of Fertilization (%)
		(kg ha^{-1})	Ratio	(kg ha^{-1})	Ratio		
Hill region	N	628		282		347	223
(Ningxiang)	P_2O_5	213	0.34	188	0.67	25	113
	K_2O	406	0.65	439	1.56	-32	93
Lake region	N	607		249		358	244
(Nanxian)	P_2O_5	190	0.31	155	0.62	35	122
	K_2O	298	0.49	336	1.35	-38	89
Mountain	N	445		230		215	193
regions	P_2O_5	151	0.34	116	0.50	34	130
(Yongshun)	K_2O	266	0.60	338	1.47	-29	79
Province	N	649		265		384	245
	P_2O_5	218	0.34	164	0.62	55	133
	K_2O	397	0.61	397	1.50	-0.2	100

Changes in nutrient input over the years

Table 6 shows that K deficits and inadequacy of P appeared in the hill and mountain regions in 1987. When realizing the seriousness of the situation, Ningxiang county adopted effective measures to increase the fertilizer input. N, P and K use increased by 23.9%, 90.7% and 125.6%, respectively, from 1987 to 1997. As a result, though the farmland area declined by 10% in the same period, the output of cereals rose by 187.1%, that of oil crops by 161.1% and that of cotton increased 7 times. The increased output caused a larger removal of nutrients. The aim of the fertilisation policy was to minimise the deficit of K, to turn the P deficit into a P surplus and to raise the N inputs. In the mountain regions, though the overall fertilizer application rate increased, the inadequate input of K caused a gap in the apparent balance. About 10 years ago, large fertilizer application rates caused a highly positive apparent balance, especially in the lake regions. However, in the following years, the reduced input of P and K fertilizers caused the appearance of K deficit and rapid reduction of the N and P surplus. The evolution of the negative nutrient balance has significantly reduced soil fertility, especially, it caused a decline in the availability of K. The paddy fields all over the province are losing K at a rate of 2 mg kg^{-1} per year. Considering the changes of the farmland nutrient balance of all three eco-regions, the K input needs to be increased to reach an equilibrated nutrient balance.

Table 6 also reveals that the proportion of organic manure in the total nutrient input differed from one agro-eco-region to another and from year to year. In 1987, input from organic manure was largest in the mountain regions, followed by the hill regions and the lake regions. For various reasons, organic manuring receives less attention in the hill regions and the mountain regions during recent years. On the contrary, in the lake regions, organic manuring rapidly increased because of the practice of reaping only the ears and leaving all the straw for soil incorporation on the field. A technique which has been widely disseminated in the meantime. According to stationary experiments of the province, the application of organic manure, amounting to 30 - 40% of the total N input is the most effective. Nitrogen directly increase crop yields and also largely contributes to the maintenance and the improvement of the soil fertility by greater root biomass and larger amounts of plant residues. Both total and readily available nutrients can be raised to a different extent, showing that the application of organic manure promotes the circulation of nutrients within the farmland.

Table 6. Variation of nutrient inputs and balances between agro-eco-regions in different years (kg ha^{-1} yr^{-1})

Agro-eco-region	Nutrient	1987				1997			
		Input	Removal	Balance	OM %	Input	Removal	Balance	OM %
Hill region	N	449	200	249	31	628	282	346	38
(Ningxiang)	P_2O_5	99	139	-40	54	213	188	25	51
	K_2O	159	319	-158	74	406	439	-32	58
Lake region	N	565	122	443	13	607	249	358	29
(Nanxian)	P_2O_5	282	82	200	9	190	155	35	34
	K_2O	417	189	228	16	298	336	-38	60
Mountain	N	265	108	157	61	445	230	215	57
regions	P_2O_5	67	66	1	74	151	116	34	56
(Yongshun)	K_2O	114	160	-46	93	266	338	-71	79

Difference in soil readily available nutrients between agro-eco-regions

The readily available nutrient contents of the soil are directly affected by the annual nutrient balance, the soil parent material and soil conservation measures taken in the previous years. The results of the analyses (Table 7) show that the available nutrient contents in the plough layer varied between the three agro-ecological regions and the cropping system, paddy or upland. Paddy fields of the Lake regions contained the largest amounts followed by the hill regions and the mountain regions. On average over all eco-regions, K availability in paddy fields was poor whereas nitrogen availability was in the sufficiency range. P availability was highest in paddy fields of the lake region and very low to medium in the other two agro-ecological regions. The upland fields revealed a different pattern of nutrient availability.

Table 7. Soil nutrient contents of fields in various agro-ecological regions

Agro-eco-region		Paddy fields			Upland fields		
		Alkalytic N	Readily available P	Readily available K	Alkalytic N	Readily available P	Readily available K
Hill region	Range	133.9-209.7	5.6-19.4	43.8-97.7	89.0-129.5	6.5-46.9	75.5-226.6
(Ningxiang)	Mean	172.6	10.5	70.1	111.1	20.4	133.3
	C.V.%	11.9	36.2	23.0	14.1	75.0	41.9
Lake region	Range	143.5-215.6	8.9-26.7	67.1-92.4	80.2-158.2	4.0-58.2	101.9-184.3
(Nanxian)	Mean	192.5	15.9	81.2	124.2	24.5	144.3
	C.V.%	14.4	38.4	13.8	20.9	71.8	19.1
Mountain regions	Range	86.0-200.8	3.2-18.6	44.8-113.5	108.0-186.0	1.6-37.1	109.0-145.0
	Mean	139.3	7.8	68.9	143.4	15.5	131.7
(Yongshun)	C.V.%	20.3	70.5	31.9	23.7	84.9	10.7
Mean	Range	86.0-215.6	3.2-26.7	43.8-113.5	80.2-186.0	1.6-58.2	75.5-226-6
	Mean	159.3	10.1	71.4	119.3	20.6	136.8
	C.V.%	20.7	57.4	26.4	30.0	73.9	27.9

Whereas all soils of the upland fields could be classified as low to medium in N with slight differences between the agro-eco regions, P availability covered a wide range from very low to high supply. On average, soils of the lake region had the highest P availability, the mountain region the lowest. Similar observations were made in the readily available K contents. Altogether, better K availability in the upland compared to the paddy fields was observed. The numbers, however, show wide ranges from low to high supply. On average, soils of highest K availability in upland soils was found in the lake region.

Prediction of the fertilizers demand and recommendations

Within 20 years from 1977 to 1997, the population of Hunan increased at a rate of 0.677 M yr^{-1}. Based on such a growth rate, the population is estimated to be 70.07 M and 73.45 M, respectively, in 2005 and 2010. Assuming a requirement of 500 kg grain, 20 kg oil and 5 kg cotton per person by 2005, the province will need 35.03 Mt of grain, 1.40 Mt of oil and 0.35 Mt of cotton. By the year 2010, 36.726 Mt of grain, 1.469 Mt of oil and 367,000t of cotton will be needed. Based on the nutrient consumption and the nutrient removal by respective amounts of economical products, the nutrient balance in 1997 and the amount of fertilizers needed to raise soil fertility, it is estimated that the province will need 385,000t N, 113,000t P_2O_5 and 777,000t K_2O in 2005 and 439,000t N, 131,000t P_2O_5 and 830,000t K_2O (from organic manure and mineral fertilizers) in 2010. The nutrient ratio has to be 1 : 0.29-0.30 : 1.98-2.02, N : P_2O_5 : K_2O. Looking at the nutrient balance and the readily available nutrients in the soils of the agro-eco-regions, it is advised that the input of N fertilizers should follow the recommendations for paddy fields in the hill and mountain regions. P fertilizers should be reduced in the lake regions and increased in the hill and mountain regions. K fertilizers should be increased in upland fields in the hill regions and in paddy fields in the mountain and lake regions. Furthermore, it is suggested that all the straw and other crop residues are returned to the field to ensure a closer farmland nutrient cycle.

NPK balance and nutrient management in farmland of Jiangxi

Li Zuzhang, Tao Qixiang, Liu Guangrong and Liu Yiren

Soil and Fertilizers Institute, Jiangxi Province Academy of Agricultural Sciences
330200

Abstract

In retrospect of the history of the farmland nutrient balance, the status and balance of the NPK nutrients in Jiangxi in 1997 were calculated. The outcome is that since the soil survey carried out in 1981, N balance improved by 17%, that of P by 49.7% whereas the K balance deteriorated by 25.4%. Based on the current fertilization practice, measures for managing nutrients in the province's farmlands are suggested. For this study typical agro-ecological regions were selected, consisting of Nanchang (plain), Xingan (plain-hill transitional zone) and Xingguo (mountain). 147 soil samples were collected for chemical analyses in 1997 from the plough layers at the same sites used for the second China-wide soil survey in 1981. The results showed that on average, compared to 1981 the soil organic matter content of the farmland increased by 37.6%. The total N content rose by 23.9%, available (alkaline) N by 9.2%, readily available P by135%, but readily available K decreased by 16.5% and the pH dropped slightly. To explain these observations, a detailed analysis of the nutrient balance of the farmland was carried out.

Evolution of farmland NPK nutrient balance in Jiangxi

Farmland nutrient balances in Jiangxi of the past 50 years clearly indicate that the historical development can roughly be divided into three phases (Table 1):

1) The years before 1960 are set as the first phase, which is characterized by a deficit in all three major nutrients.
2) The period between 1960 and 1980 is the second phase, which witnessed a great change in the farmland nutrient balance, i.e. N shifted from being deficient to being basically in balance and P started to receive some importance. Such a change was the foundation needed for the agriculture in the Jiangxi Province.
3) The last phase stretches from 1980 until now. This phase is characterized by a surplus application of N and P whereas K is undersupplied. This causes widespread K deficiency and reduced crop yields and crop quality.

Table 1. Changes in the history of farmland NPK nutrient balance in Jiangxi

Year	Mean (%)		
	N	P_2O_5	K_2O
1949	-22.1	-14.4	-29.4
1955	-26.0	-20.0	-32.2
1960	-2.3	+4.6	-16.9
1965	-8.8	+30.5	-36.5
1970	+4.4	+47.5	-35.6
1975	+4.2	+27.4	-29.3
1980	+20.7	+45.7	-36.1
1985	+20.6	-19.1	-42.5
1990	+53.3	+14.4	-23.3
1997	+87.4	+98.6	-20.2

Note: The data before 1983 were cited from "Regionalization of chemical fertilizers in the Jiangxi Province"

Farmland nutrient balance in Jiangxi

NPK removal from farmland soil

The nutrient removal from farmland soil is based on total crop production and the amount of nutrients absorbed for the production of a certain unit of crop product. Since these vary with crop, climate, year and fertilization, average values (Basic Parameters for Calculating Farmland Nutrient Cycling and Balance in Jiangxi) were compiled by the Soil and Fertilizers Institute of the Jiangxi Province Academy of Agricultural Science, and the agricultural statistics of Jiangxi (1997) and used for the nutrient balance calculations (Table 2).

Table 2. Amounts of nutrients consumed by major crops in Jiangxi (1997)

Crop	N		P_2O_5		K_2O	
	(×1000 t)	(%)	(×1000 t)	(%)	(×1000 t)	(%)
Grain crops	353.5	73.9	159.1	72.7	388.1	78.0
Cash crops	51.9	10.8	27.3	12.5	41.2	8.3
Oil crops	56.3	11.8	21.8	10.0	44.4	8.9
Melon-fruit	16.5	3.5	10.6	4.8	23.8	4.8
Total	478.2	100	218.8	100	497.5	100

Among the four crops, cereals consumed most of the nutrients, about 72.7% - 78% of the total consumption. Though the share absorbed by the other three crops is comparatively small, crop diversification caused that during the past few years the proportional consumption of especially cash crops, fruit and vegetables increased.. Among the three major nutrients, the absorption from the soil is largest for K, accounting for 41.6% of the total followed by N and P, accounting for 40% and 18%, respectively.

Nutrient resources in the agriculture of Jiangxi

The demand by the crops is supplied by both mineral and organic nutrient sources. Since the latter are difficult to quantify, the method how these were determined is introduced below.

Method for calculating amounts of organic manure

The rate of nutrients in agricultural products that will eventually enter the farmland-crop cycle as organic manure can be worked out by deducting nutrient losses through human and animal digestion, storage and composting from the amount of nutrients contained in the agricultural product at harvest (Figure 1). Based on the recycling rate (%), the amount of nutrients contained in the organic manure can be obtained, according to the formula:
Theoretically, from the 100 kg of N taken up by an agricultural product, about 53.5 (22.5 + 18 + 2.7 + 2.8 + 7.5) kg of N can be collected after the product is consumed by humans or animals. During storage, even under good conditions, it will inevitably suffer a loss of 15%. Thus, the N recycled as percent of the amount absorbed by the plant is 45%.

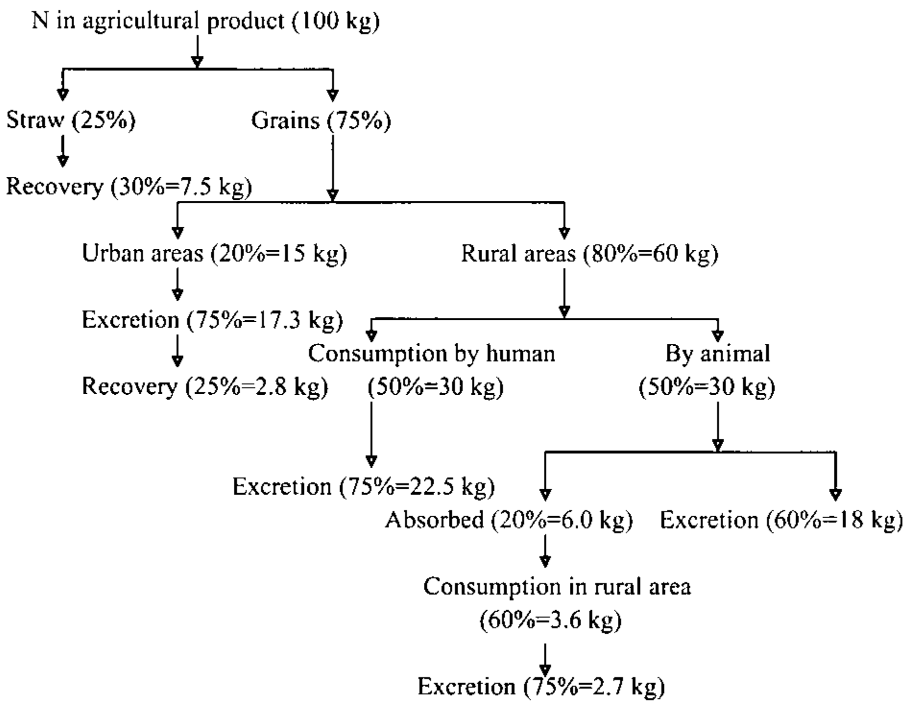


Figure 1. The cycle of nitrogen absorbed by a plant, depending on its use in urban and rural areas

Based on the same calculation, from 100 kg of P taken up by a plant about 69.5 (31.7 + 25.6 + 3.8 + 2.4 + 6) kg can be collected after the product is consumed by humans or animals. During storage, the loss of P is very limited, so that the P recycling rate of a plant can be as high as 65% (Figure 2).

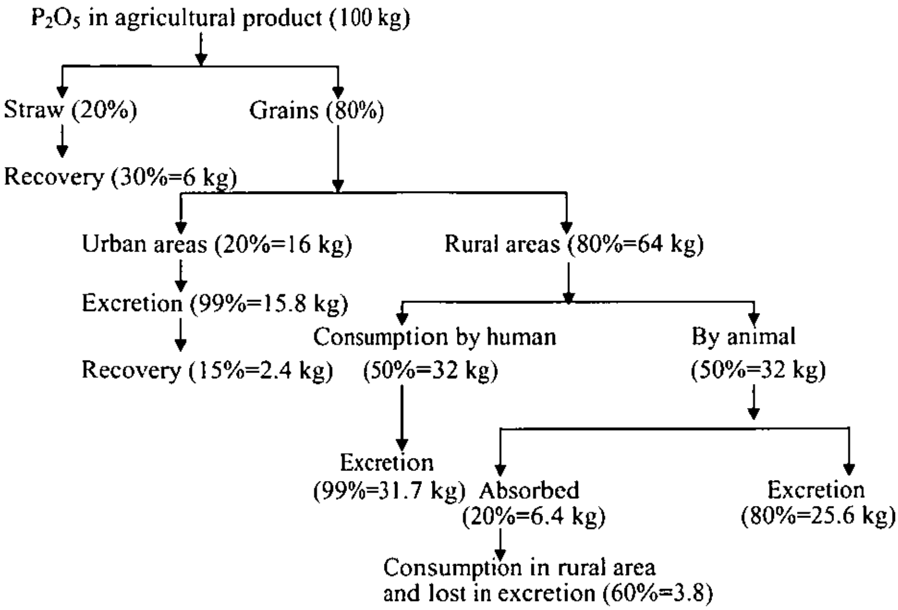


Figure 2. The cycle of phosphorus absorbed by a plant, depending on its use in urban and rural areas

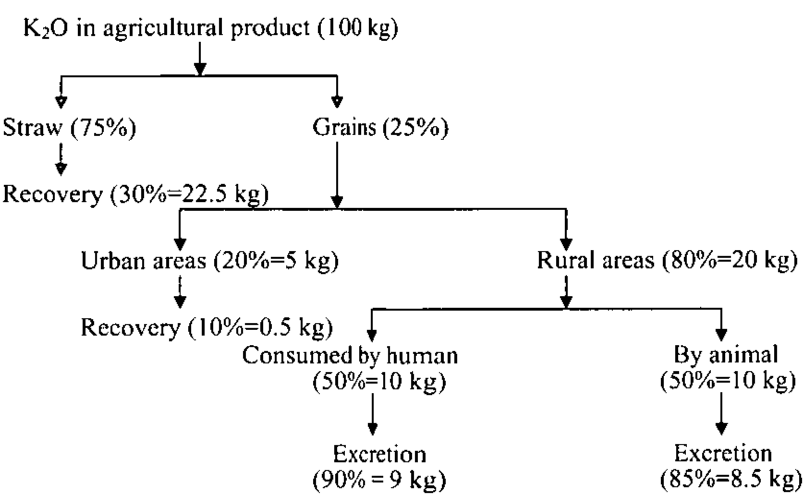


Figure 3. The cycle of potassium absorbed by a plant depending on its use in urban and rural areas

Based on the above-described calculation from 100 kg of K_2O absorbed by a plant about 40.5 (9 + 8.5 + 0.5 + 22.5) kg can be collected after the crop is consumed by humans or animals (Figure 3). During storage in good conditions, certain limited losses have to be taken into account. Thus, the K recycling rate of an agricultural product is estimated at 0.40 % of the total amount absorbed.

Green manure

In 1997, the total area of green manure crops reached 558,380 ha, which theoretically could approximately provide 16,700t N, assuming that each hectare of green manure crops can fix 30 kg N ha^{-1}. The amounts of P and K contained in the green manure are no net gains of nutrients, as they were absorbed from the farmland itself.

Total amount of nutrients in the various sources of organic manure in Jiangxi

Based on the above-estimated nutrient recycling rate (0.45 for N, 0.65 for P and 0.40 for K) the nutrient removal by crops (see Table 2) and the nutrient supply from green manure and the total amount of nutrients contained in the organic manure of Jiangxi in 1997 was estimated at 0.2319 Mt N, 0.1422 Mt P_2O_5 and 0.199 Mt K_2O.

Mineral fertilizers

According to the Statistical Yearbook of the Jiangxi Province in 1997, the province consumed in total 0.602 Mt N, 0.231 Mt P_2O_5 and 0.185 Mt K_2O plus 186×10^3 t of compound fertilizers, totalling 1.204 Mt. Based on the assumption that compound fertilizers contained the same amounts of N, P_2O_5 and K_2O the total consumption of the three major nutrients through mineral fertilizer (including compounds) was 0.664 Mt N, 0.293 Mt P_2O_5 and 0.247 Mt K_2O in 1997. Taking the figures of 2001, the consumption of mineral nutrients declined to 0.561 Mt N, 0.275 Mt P_2O_5 and 0.260 Mt K_2O. This shows that the ratio changed in favour of K consumption in the meantime.

Farmland NPK nutrient input

Based on the nutrient recycling rate of agricultural products and the consumption of mineral fertilizers the farmland nutrient input was determined (Table 3). 74.1% of N, 67.3% of P and 55.4% of K were supplied in the form of mineral fertilizer and the balance in the form of organic manure, indicating the important role of organic manure in the supply of particularly K to farmland. Mineral fertilizers accounted for 67.8% and organic manure for 32.2% of the total nutrient input.

Table 3. Farmland nutrient input in Jiangxi (1997)

	N		P_2O_5		K_2O		Total nutrient	
	(Mt)	(%)	(Mt)	(%)	(Mt)	(%)	(Mt)	(%)
Mineral fertilizers	0.664	74.1	0.293	67.3	0.247	55.4	1.204	67.8
Organic manure	0.2319	25.9	0.1422	32.7	0.1990	44.6	0.5731	32.2
Total	0.8959	100	0.4352	100	0.4460	100	1.7771	100

Farmland nutrient balance in Jiangxi

The results in Table 4 show that the apparent nutrient balance in 1997 was positive for N (+16.98%) and P_2O_5 (49.72%) and negative for K_2O (-25.4%). On the basis of 2.302 million ha farmland in Jiangxi, the nutrient balance for each hectare showed a surplus of 66.1 kg N and 94 kg P_2O_5 and a deficit of 49.2 kg K_2O. Under the humid and warm conditions of Jiangxi, it is very likely that most of the N surplus did not accumulate in the soil but was lost into the air (volatilisation, denitrification) or leached into water-bodies by various pathways. It was observed that most of the surplus applied P, however, accumulated in the soil and became an important P source for the succeeding crops. The current fertilization characterized by an imbalance between K input and output speeds up soil K depletion, leading to a decrease in soil K fertility. This is the major reason for the expanding area with K-deficient soils. The results of the calculation are reflected by soil analyses, showing a decrease in K supply of soils.

Table 4. Farmland nutrient balance in Jiangxi (1997) (Mt)

Item	N	P_2O_5	K_2O
Nutrient input	0.896	0.435	0.446
Nutrient output	0.478	0.219	0.498
Mineral fertilizer N loss (40%)	0.266		
Mineral fertilizer leaching loss (25%)			0.062
Balance	+0.152	+0.216	-0.113
Balance (%) (apparent)	+16.98	+49.72	-25.4

Furthermore, Table 5 reveals that in the farmland ecosystem, the nutrient recycling rate reaches 31.2% for N, 65% for P_2O_5 and 35.6% for K_2O, on average 37.7%. Comparing these results with Figure 1-3, it is evident that there is further potential for N and K recycling. The key lies in rationalizing fertilization, reducing losses, making reasonable use of pig and cattle dung and returning crop residues to the field with special attention to quantity and quality.

Table 5. Nutrient recycling of the farmland in Jiangxi (1997) (Mt)

Nutrient	Total output*	Return	Recycling (%)
N	0.744	0.232	31.18
P_2O_5	0.219	0.142	64.99
K_2O	0.559	0.199	35.58
Total	1.522	0.573	37.66

* Note: including N and K losses

Effect of fertilization on farmland nutrient balance

Stationary experiments were carried out to study the effect of fertilization on farmland nutrient balance for several years. Some data of the experiments are used to explain the effects on farmland nutrient balance caused by applying mineral fertilizers or organic manure.

Effect of successive application of different formulas of mineral fertilizers on farmland nutrient balance

On paddy soils derived from quaternary red clay, granite, pelite, river alluvium, tertiary red sandstone and Xiashu loess, stationary experiments were carried out at six different experimental sites from 1984 to 1994 to investigate the effect of successive applications of different formulas of mineral fertilizers on double-cropped rice. The results (Table 6) indicate that the application of N at a rate of 270 kg ha^{-1} N led to a surplus of 43-72 kg N ha^{-1} annually and the application of P caused a small P surplus of between 4.7 and 22.9 kg P ha^{-1}. Despite an application of 150 kg K_2O ha^{-1}, the negative balance for this nutrient prevailed though it was most severe in the NP plot..

Table 6. Soil nutrient balance during the experiments (mean of six sites)

Treatment	Total nutrient input ($kg\ ha^{-1}$)			Total nutrient output ($kg\ ha^{-1}$)			Balance ($kg\ ha^{-1}$)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
CK	0	0	0	96.8	42.4	131.3	-96.8	-42.4	-131.3
PK	0	90	150	135.1	67.1	242.3	-135.1	+22.9	-92.3
NP	270	90	0	226.5	85.3	214.1	+43.5	+4.7	-214.1
NK	270	0	150	197.5	66.4	265.1	+72.4	-66.5	-115.1
NPK	270	90	150	219.2	94.6	245.3	+50.8	-4.6	-95.3

Effect of application of mineral fertilizers in combination with organic manure on farmland nutrient balance

From 1983 to 1996, stationary experiments were carried out to study the combined effect of mineral fertilizers and organic manure on double-cropped rice in a Chaoshani paddy field in XiangTang (Table 7). Comparing the nutrient input and nutrient output of 26 rice crops during 13 years revealed that in treatments M (organic manure), F (mineral fertilizer) and M + F, nitrogen was in surplus, which rose according to the application rate. P was in surplus in treatment M and M + F and slightly deficient in treatment F, where small amounts of P were applied. K was deficient in treatment M and F but showed a surplus in treatment M + F. All these results indicate that the current application rate of mineral fertilizers or organic manure alone can't keep nutrients in balanced supply. Only when mineral fertilizers are applied in combination with a proper amount of organic manure, the nutrient input and output can be kept in balance.

Table 7. Effect of combined application of chemical fertilizers and organic manure on farmland nutrient balance (mean of 13 years)

Treatment	Total nutrient input ($kg\ ha^{-1}$)			Total nutrient outpu ($kg\ ha^{-1}$)t			Balance ($kg\ ha^{-1}$)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
CK	0	0	0	121	56	193	-121	-56	-193
M*	234	81	249	189	77	315	+45	+4	-66
F*	234	81	249	189	83	322	+45	-3	-73
M + F	468	162	498	233	103	375	+235	+59	+123
(M + F)/2	234	81	249	191	86	345	+43	-5	-96
(M + F)/3	156	54	166	180	80	282	-24	-26	-116

*: M stands for organic manure and F for mineral fertilizers.

Effect of successive application of K at different rates on the K balance in paddy fields

From 1986 to 1990, stationary experiments were conducted with successive applications of K at different rates on rice in Liantang and Gaoan. The results revealed that in Huangni paddy field and Hongni paddy field both low in soil K the annual crop K uptake rate decreased significantly over the years when only N + P fertilizers were applied (Figure 4). After five years, the K uptake of rice at Huangni was reduced by 51% and by 73% in the Hongni soils. This shows that intensive cropping caused the soil K fertility to drop rapidly. If soil K is not replenished K deficiency seriously affects the effectiveness of N and P fertilizers as well as the crop yield and quality.

In the same experiments, the K supply by mineral fertilizer varied from 373.5 - 1120.5 $kg\ ha^{-1}$ (cumulative over 5 years). The cumulative balance shows that the amount of K removed from the soil ranged from 981.0 - 1553.3 $kg\ ha^{-1}$, causing a K deficit of 407.4 -656.8 $kg\ ha^{-1}$ (Table 8). The output of K was always larger than the input. Apparently, the soil made up for the deficit, causing a depletion of soil K reserves which was

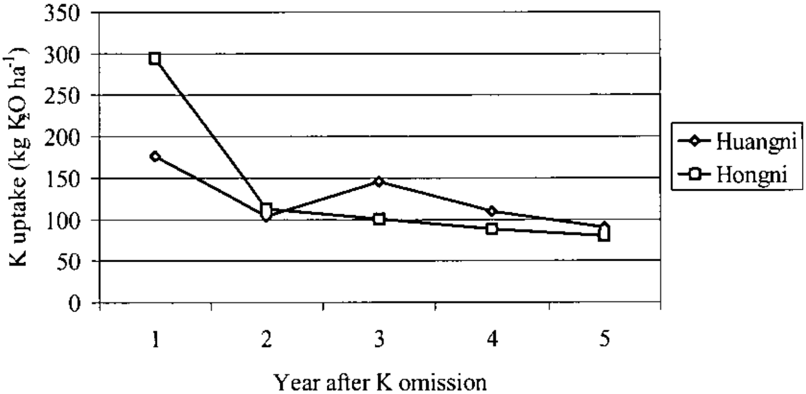


Figure 4. The effect of K omission on K uptake by rice at two locations over a period of 5 years

reduced in the treatments, receiving K application, especially at. the large application rate. Nevertheless, even there a cumulative negative balance of greater than 400 kg ha^{-1} (80 kg ha^{-1} yr^{-1}) indicates soil K mining. Though the deficit declined with the amount of mineral fertilizers and organic manure supplied (see Table 6), the K application rate has to be increased to 450 kg ha^{-1} to maintain or even improve the soil K status. Therefore, the fertilization principle for the years to come should be "reducing N, controlling P and increasing K application rates".

Table 8. Balancing of soil K nutrient (cumulative over 5 years)

Soil	Treatment	Total K uptake (kg K_2O ha^{-1})	Total K input (kg K_2O ha^{-1})	Balance (kg K_2O ha^{-1})
Huangni	NP	624.4	0	-626.4
	NPK_1	981.0	373.5	-607.5
	NPK_2	1275.4	747.0	-528.4
	NPK_3	1553.3	1120.5	-432.8
Hongni	NP	675.5	0	-675.5
	NPK_1	1030.3	373.5	-656.3
	NPK_2	1364.0	747.0	-617.0
	NPK_3	1515.4	1120.5	-407.4

Management of farmland nutrients

Mineral fertilizer consumption in the agriculture of Jiangxi

By reviewing the forty-year history of the development in mineral fertilizer consumption in the agriculture of Jiangxi, three phases can roughly be distinguished. In the years before 1960, Jiangxi used mainly N fertilizers with little P fertilizers and no K fertilizers at all. The NPK ratio during this period was 1: 0.29 : 0 (N : P_2O_5 : K_2O). During the years from 1960 to the early 1980s, the consumption of P fertilizers increased significantly, gradually forming a fertilization system in which N and P are the dominating components and K is only considered as a supplement. The N:P:K ratio during this period changed to 1:0.60:0.05. And during the years from the early 1980's to the late 1990's, the N and K application rates increased drastically, changing the N:P:K ratio from 1:0.58:0.07 in 1980 to 1:0.25:0.32 in 1990 and 1:0.44:0.37 in 1997. The current NPK consumption is 1.332 million t (2001) at a ratio of 1:0.41:0.37 (N : P_2O_5 : K_2O), indicating that nutrient rates stabilize around these figures.

The management of farmland N, P and K nutrients

Based on the set principles of "reducing N, controlling P and increasing K, the demands for mineral fertilizer nutrients in 2005 and 2010 are predicted.
Based on the growth rate of mineral fertilizer consumption in the past 10 years, the current status of farmland nutrient balance (surplus in N, excessive P use and deficit in K) and the changes in the cropping structure in the Jiangxi Province, the demand for mineral fertilizers in 2005 and 2010 are predicted (Table 9).

Table 9. Predicted demand for mineral fertilizers of Jiangxi in 2005 and 2010 (Mt)

Nutrient	Consumption in 1997	Growth rate till 2005	Estimated demand in 2005	Growth rate till 2010	Estimated demand in 2010
N	0.664	1.6	0.792	1.2	0.852
P_2O_5	0.293	0.8	0.357	0.6	0.387
K_2O	0.247	1.7	0.383	1.9	0.478
Total	1.204	4.1	1.532	3.7	1.717
$N:P_2O_5:K_2O$			1:0.45:0.48		1:0.45:0.56

To balance the nutrient demand with the supply, by 2010 Jiangxi will have to double its consumption of K fertilizers to keep the K fertility of its soils and hence the productivity of its cropping systems. The NPK demand for 2005 is estimated at 1.532 million tons of NPK at a ratio of N : P_2O_5 : K_2O of 1:0.45:0.48. Taking into account the changes towards cropping systems with larger K demand in the future, the ratio will even narrow to 1:0.45:0.56 in 2010.

Use of organic manure and raising farmland nutrient recycling rate

The use of organic manure is an optimal system of recycling nutrients within the agricultural production. It is anticipated that the strategy for fertilization, "combining the application of mineral fertilizers and organic manure with the former as main and the latter as supplement", will last for decades to come. The application rate of organic manure of over 15,000 - 18,000 kg ha^{-1} yr^{-1} was able to maintain the soil organic matter content of paddy fields. However, the scenario may change drastically in the uplands, where much faster turnover of soil organic matter, etc. cause a greater demand for soil protective measures, including the recycling of crop residues and farmyard manure. The current recycling of rice straw is still very small, only 30% of what is produced is returned to the field. Emphasis should therefore be laid on returning at least 60% of the straw back to the field.

Popularizing scientific fertilization technique and improving effectiveness of fertilization

Mainly the fertilization techniques such as "adequate N application rates and modified N application" need to be disseminated to farmers to reduce N loss and improve N recovery rate. On the basis of a crop rotation, an integral plan is required for applying P with large amounts during winter and small dressings during summer. More P should be applied to upland fields and less to paddy fields. Leguminous crops should be generously supplied with P, whereas cereals need less. Generally, no or little P fertilizers should be applied to soils, where the readily available P is beyond 35 mg kg^{-1}. Supply levels of 25 mg kg^{-1} available P indicate good P supply of the soils, depending on soil types. To keep this status of availability, P should be applied to every second crop in the rotation or every second year. In view of the fact that K resources are inadequate in China, great efforts should be devoted to safe K by putting great emphasis on returning crops residues, especially cereal straw back to the field. Nevertheless, greater amounts of mineral K fertilizers have to be used to supplement and maintain soil K levels at a high availability. Therefore, besides stressing the need of applying K to paddy rice, attention should also be given to upland fields and cash crops. In the rotation oil crops-rice-rice, more K fertilizers should be allocated to oil crops and late rice and less to early rice to make full use of the after-effect of K fertilizers.

Developing with vigour special-purposed blended fertilizers or granular compound fertilizers

Special-purpose blended fertilizers and granular compound fertilizers are promoted to disseminate and implement the idea of balanced fertilization techniques. In 1998, Jiangxi consumed 0.526 Mt blended fertilizers, of which 0.09 Mt were compound fertilizers, over an area of 0.22 million ha. The survey indicated that as a consequence the crop output increased by 8.2% or 99.245 million kg of grain and by 98.16 million Yuan (RMB). Considering the economic and social benefits, it is essential to design soil-specific and crop-specific formulas of fertilizers which can include fertilizer-manure blends that are fit to better supply the crop demand.

Farmland nutrient balance, a strategy for its improvement and the prediction of future fertilizer demand in the Guangdong Province

Zhang Yucan and Zheng Huidian

Soil and Fertilizers Head Station, Agriculture Bureau, Guangdong Province, 510500

Abstract

A study was carried out to assess the nutrient balance in the farmland of Guangdong. For this purpose, data from the second soil survey, from long-term stationary monitoring of soil nutrients, parameters of crop demand for fertilizers, the actual fertilizer consumption and the status of farmland nutrients were analysed. The results reveal that in Guangdong Province N is generally in low, P in surplus and K in marginal supply. The paper proposes to close the gap between K removal and input and to increase the application of organic manure, intensify the dissemination of the principles of balanced fertilization techniques and improve farmers' understanding of a science based fertilization practice. The paper concludes with a prediction of future fertilizer demand.

Introduction

Guangdong Province located in the south of China enjoys an abundance of temperature, light, soil and water resources. The total output of agricultural crops in 1998 increased by 1.6 times over that in 1978. Among all the crops, fruits exhibit the fastest growth in production by 1,556 % whereas sugar crops show an increase of 110 %, rice of 27 % and groundnut around 12 % (Table 1). The total output of vegetables reached 21.492 Mt in 1998, accounting for 5.6% of the country's total. The output of fruits and sugar crops ranked second in the country and that of vegetables, groundnut and rice fifth. All this indicates that Guangdong is a province with a well-developed agriculture. The increased production has also created a stronger demand on nutrients and it is the purpose of this study to shed more light into the relationship between nutrient demand and supply to better understand the needs of balanced fertilization.

As the output of agricultural crops has a large volume, there is a great removal of nutrients from the soil in the province. Emphasis is laid on assessing whether the input of nutrients is matching the requirements for crop growth. Furthermore, the aspect of whether nutrients are applied in appropriate ratios and to determine whether the province's farmland nutrient status as a whole shows imbalances which need to be corrected. Main focus received the macronutrients N, P and K whereas other nutrients, e.g. Mg, S and micro-nutrients were not specifically analysed, the issue, however, was taken into account to see whether current fertilization practices fail to meet the crop demand in this respect.

Table 1. Output (1000t) of the major agricultural products in Guangdong in the past 20 years in comparison to fertilizer consumption (1000t)

Item	Year 1978	Year 1998	Growth rate (%)	Rank*
Grains	15095.1	20077.4	133	--
Rice	13285.6	16885.3	127	5
Vegetables	--	21492.0		5
Fruits	291.0	4531.2	1557	2
Sugar crops	8354.2	17569.0	210	2
Groundnut	351.7	780.5	222	5
Consumption of fertilizers	2862.9	6015.2	210	9

*Note: Rank indicates the position of Guangdong in terms of respective production or fertilizer consumer among all provinces in China

Farmland nutrient balance

At the end of the 1970's and the beginning of the 1980's, Guangdong Province carried out the second soil survey with results, showing that the farmland soil was moderate in organic matter and N, deficient in P, low in K, short of B and Mo, moderately well supplied with Cu and Zn and rich in Fe and Mn. The nutrient management was characterized by a nutrient imbalance which lasted for the past 20 years, especially until the early 1990's. According to the investigations conducted in the winter of 1990, the 419 soil surveys and soil fertility monitoring posts all over the province revealed that soil organic matter decreased slightly by about 3% during these ten years. Total N decreased by 7%, total K by 4% and the readily available K which was already low with 69.73 mg kg^{-1} decreased further by about 9%. During the same period, there was also a slight decline in soil pH slightly whereas total P and readily available P increased (Table 2).

Table 2. Changes in soil nutrient status in paddy fields in Guangdong Province (n = 419)

Parameter	Early 1980's	1990	Percentage of monitoring posts: Increasing	Decreasing	No change
O.M, g kg^{-1}	26.6	25.9	48.1	51.4	0.5
Total N, g kg^{-1}	1.43	1.33	46.4	53.3	0.3
Alkalytic N, mg kg^{-1}	105.5	108.8	51.4	47.6	1.0
Total P, g kg^{-1}	1.02	1.06	61.3	36.2	2.5
Readily available P, mg kg^{-1}	19.7	22.2	53.3	43.5	2.5
Total K, g kg^{-1}	19.5	18.8	48.5	51.5	0
Readily available K, mg kg^{-1}	69.73	65.37	45.2	0.5	54.3
pH	5.76	5.47	29.8	61.7	8.5

*Alcalytic N: 1.0 M NaOH incubation at 40 °C for 24 h, reflecting the available N

These results differed greatly from the ones obtained during the second soil survey carried out ten years earlier. It is clearly shown in Table 2 that out of 419 monitoring posts about half display a downward trend in soil organic matter, total N, total K and pH, a significant increase in total and readily available P and no changes in readily available K. This indicates that after 10 years of supplementing P and K fertilizers, total and readily available P as well as readily available K in the farmland soil were improved in comparison to the second soil survey (early 1980's).

According to the long-term stationary monitoring of soil fertility initiated in 1984, from the 151 posts under all-year-round monitoring in paddy fields, about 65.6%, 62.3%, 85.4% and 63.6% revealed an upward trend in soil organic matter, alkaline N, readily available P and K, respectively. The upward trend of readily available P was the most obvious (Table 3).

With the exception that less increases were recorded, the studies in the upland fields showed a very similar pattern as the paddy fields (Table 3). Largest differences occurred in organic matter and in readily available K.

Table 3. Changes in farmland nutrient balance in Guangdong Province (1984-1998)

Parameter	Paddy fields				Upland fields			
	Increase		Decrease		Increase		Decrease	
	Posts	%	Posts	%	Posts	%	Posts	%
O.M, g kg^{-1}	99	65.6	51	33.8	6	50	6	50
Total N, g kg^{-1}	107	70.9	39	25.8	9	75	3	25
*Alkalytic N, mg kg^{-1}	94	62.3	54	35.8	8	67	4	33
Readily available P, mg kg^{-1}	129	85.4	22	14.6	11	92	1	8
Readily available K, mg kg^{-1}	96	63.6	53	35.1	7	58	5	42
pH	51	33.8	86	57.0	7	58	4	33

*Alcalytic N: 1.0 M NaOH incubation at 40 °C for 24 h, reflecting the available N pool

The reason for this observation is that during the period from 1980 to 1995, the consumption of mineral fertilizers in Guangdong increased by a factor of 1.36 and the application rate from 301.5 kg ha^{-1} to 844.5 kg ha^{-1}. The consumption of P fertilizers increased by 62.9%, reaching 0.272 Mt in 1995, and the consumption of K fertilizers reached 0.341 Mt, four times as much as in 1980. This increased the proportion of K in the total fertilizer consumption from 8.2% in 1980 to 17.4% in 1995. The consumption of N fertilizers also rose from 0.58 Mt to 0.995 Mt (Table 4). During this period, the amount of organic manure applied also increased, contributing to the increase in soil organic matter, alkalytic N, readily available P and readily available K contents to a varying extent. The consumption figures in Table 4 do not include the nutrients from compound fertilizers. The consumption of compound fertilizers in 2001 was 390,400 t. Assuming an $N:P_2O_5:K_2O$ ratio of 15:15:15, the consumption figures for 2001 were N = 1.03 Mt, P_2O_5 = 0.260 Mt and K_2O = 0.425 Mt.

Table 4. Consumption of mineral fertilizers in Guangdong

Year	Consumption . ×1000 t Total	N	P_2O_5	K_2O	$N:P_2O_5:K_2O$	Proportion of K %	NPK application rate kg ha^{-1}
1980	828	580	167	68	1:0.28:0.12	8.2	301.5
1985	1104	743	161	143	1:0.22:0.19	12.9	424.5
1990	1624	958	201	278	1:0.21:0.29	17.1	643.5
1995	1957	995	272	341	1:0.27:0.34	17.4	844.5
1998	1695	969	193	340	1:0.20:0.35	20.0	739.5
2001	1951	974	201	386	1:0.21:0.40	19.8	859.5

It was just because of the steady increase in the consumption of mineral fertilizers that the returns per unit of input began to diminish. During the late 1980's, the production of 100 kg of rice required 4.84 kg of mineral fertilizer (N, P and K in total) whereas in the early 1990's the requirement rose to 5.76 kg per 100 kg grain or by 19% (Table 5).

Table 5. Amount of nutrients needed to produce one t of husked rice in Guangdong

Time period	N	P_2O_5	K_2O	$N+P_2O_5+K_2O$
	kg nutrient t^{-1} grain			
Late 1980's	29.2	7.4	11.8	48.4
Early 1990's	31.4	8.8	17.4	57.6

According to the long-term stationary monitoring, the NPK ratio of the nutrient input into paddy fields is 1:0.28:0.47. When the application of organic manure is taken into account, the ratio changes to 1:0.28:0.52. The application of organic manure is still out of proportion with that of mineral fertilizers, with the former accounting only for 14% of the total. In terms of nitrogen, only 11% of the input comes from organic manure (Table 6). The disproportion between organic and inorganic nutrients show that more attention needs to be given to the application of organic manure.

Table 6. Nutrient input to paddy fields at the perennial monitoring posts in 1995

Nutrient	Total input	Mineral fertilizers		Organic manure	
	kg ha^{-1}	kg ha^{-1}	%	kg ha^{-1}	%
N	405.8	361.6	89.1	44.1	10.9
P_2O_5	115.0	97.2	84.5	17.8	15.5
K_2O	212.4	171.6	80.8	40.8	19.2
$N+P_2O_5+K_2O$	733.2	630.4	86.0	102.7	14.0
$N:P_2O_5:K_2O$ ratio	1:0.28:0.52	1:0.27:0.47		1:0.40:0.92	

Thanks to the changes in farming, fertilization and some other factors in the past twelve years, Guangdong has basically turned the soil P status from deficient to surplus. Table 7 shows that in 1985 the P balance was still negative, but in 1991 P there was already a positive balance as confirmed by the analyses of the 419 monitoring posts. The rising N application rate has left the farmland with a large surplus of N, especially in the Zhujiang River Delta and the suburbs of large cities where vegetables are grown in former paddy fields. Although the K application rate has increased to a great extent since the 1980's, there is still an negative K balance. According to the long-term stationary monitoring, the K deficit reached -183.4 kg ha^{-1}, -138.0 kg ha^{-1} and -108.0 kg ha^{-1} in 1985, 1991 and 1995, respectively. The results demonstrate that an increased K application rate has reduced the K deficit at the monitoring posts, but much larger K application rates are needed to realize a balanced K household in the farmland (Table 7).

Table 7. Development of the nutrient balance at the monitoring posts in Guangdong

Year		1985	1991 kg ha^{-1}	1995
Input	N	332.0	354.0	405.8
	P_2O_5	31.2	58.4	115.1
	K_2O	87.9	159.0	212.4
Removal	N	250.8	274.5	204.9
	P_2O_5	37.6	41.2	98.6
	K_2O	271.4	297.0	320.4
Balance	N	81.2	79.5	200.9
	P_2O_5	-6.4	17.2	16.5
	K_2O	-183.5	-138.0	-108.0
O/I	N	0.75	0.78	0.50
	P_2O_5	1.21	0.71	0.87
	K_2O	3.08	1.87	1.51

Strategy for improvement

Implementing the soil fertility building project and increasing the application rate of organic manure

As the issue of the disproportion between mineral fertilizers and organic manure is rather obvious due to the reduced organic manure application, the latter will be a major task for the fertility management in the long run. The main focus should be on the practice of returning straw to the field and on growing green manure crops. Returning straw to the field for 3 years in a row can raise soil organic matter by 2 – 4 g kg^{-1}. Therefore, returning straw, groundnut stems, bean stalks and melon vines to the field is an effective approach to raise the soil organic matter content and to build up soil fertility. Moreover, it is essential to increase the application rate year by year to meet the crops' need for nutrients.

Intensifying the extension of balanced and complete fertilization techniques

In view of the current farmland nutrient status of the province, the following tasks must be followed up:

1) In regions with suitable conditions, crop-specific fertilizers should be introduced. As a result of the extension of techniques for multi-nutrient fertilizer, the consumption of compounds and fertilizer blends has been increasing steadily. Locally-made compound fertilizers (mainly compacted blends) are gradually displacing imported ones, sharing 80% of the total. In 1998 the province consumed 1.214 Mt of nutrients, 32 times more than in 1980. In recent years the area of cash crops in the province has increased rapidly. Cash crops demand high application rates of fertilizers. In order to keep farmland nutrients in balance, crop-specific fertilizer application has to be extended. In regions where the farmland nutrients are close to balance, the area of a single crop cultivation is large, the potential of the fertilizer market is great. Farmers are ready to accept crop-specific fertilizer types, for instance in regions where sugarcane, tobacco, litchi, longan, grapefruit or vegetable (i.e. hazard-free vegetables gardens in the suburbs of larger and medium cities) are intensively grown.
2) K, N and P fertilizers must be supplemented according to the crop demands. Considering the farmland nutrient status, K fertilizers must be supplemented in the years to come. This applies especially to the northern and western parts of the province, where the soil is deficient in K and K-demanding crops like yam, banana, etc. are grown. The application rates of N and P fertilizers should be adjusted to an adequate level to rice. In fruit trees, N and P fertilizers need to be supplemented whereas for vegetables a more demand-oriented application has to be implemented.
3) Other macronutrients, such as Ca, Mg, S and micro-nutrients, e.g. Si, B, Mo, Zn, Cu, Mn, Fe, etc. should be supplemented according to the crop and farmland nutrient status. With the output of agricultural crops rising steadily, the removal of these nutrients in the harvested crop also increases. Therefore, it is essential to supplement those fertilizers which keep Ca, Mg and S and micronutrients in balance in the soil.

Sticking to high standard in farmland capital construction and remolding medium- and low-yield fields

According to the investigations in 1994, the acreage of medium- and low-yielding fields with a yield below 12,000 kg ha^{-1} was 1.14 million ha, accounting for two-thirds of the total farmland. Of that portion, 0.706 million ha of farmland produced yields, ranging between 10,500 - 12,000 kg ha^{-1} and 0.434 million ha had yields below 10,500 kg ha^{-1}. Remoulding of medium- and low-yielding fields could increase the yield by 900 kg ha^{-1} and some by 1,500 kg ha^{-1}. The remoulding of each hectare of medium- and low-yielding fields costs about 2,910 Yuan (partially invested by the farmers), but the crop immediately after the remoulding may bring about an additional income of

2,178 Yuan (265 USD) due to the obtained yield increment. Therefore, the potential of remoulding the medium- and low-yielding fields is great.

Speeding up the readjustment of the cropping structure and improving the farmers' knowledge and understanding of scientific based fertilization

In regions with suitable conditions, idle fields should to be concentrated in hands of expert farmers. They should become shareholders with their idle land as investment, thus facilitating the realization of larger-scale intensive farming management. With China's entrance to WTO, the farmers need to be guided into growing high value crops, competitive with regard to quality. An increased use of organic manure and the extension of balanced and complete fertilization cannot only keep farmland nutrients in balance, but is also able to significantly improve quality and crop output. Meanwhile, it is vital to train farmers and raise their awareness and understanding of scientific fertilization and hence to reduce production cost and increase the benefit of cultivation.

Prediction of future demand for fertilizers in Guangdong Province

The prediction of future demand for fertilizers has been made on the basis of the province's agricultural development plans for the next 5 and 10 years, in compliance with the needs of sustainable agricultural production (Table 8).

Table 8. Predicted demand for chemical fertilizers in Guangdong Province (1000 t)

Fertilizer	2001*	2005	2010
N	1104	1200	1250
P_2O_5	330	300	350
K_2O	515	600	800
Total	1951	2100	2400
$N:P_2O_5:K_2O$	1:0.29:0.47	1:0.25:0.5	1:0.28:0.64

*actual consumption including nutrients from compound fertilizers with a ratio of 1 : 1 : 1 in N: P2O5 : K2O.

The future demand depends also on the government's fertilizers policies and on various factors, such as market price of fertilizers, market price of agricultural products, farmers' ability of acceptance, growers' benefit in cultivation, etc. The prediction puts emphasis on increasing K application rate and the use of organic manure whilst other macro-nutrients (Ca, Mg, S) and micro-nutrient fertilizers are supplemented. It is estimated that the demand for K fertilizers (K_2O) will rise from 0.34 Mt in 1998 to 0.60 Mt in 2005 and to 0.80 Mt in 2010. The demand for nutrients from mineral fertilizers will increase from 1.95 Mt in 2001 to 2.10 Mt in 2005 and to 2.40 Mt in 2010 with a ratio of 1 : 0.25 : 0.50 in 2005 and to 1 : 0.28 : 0.64 in 2010.

Farmland nutrient cycle and nutrient balance in Sichuan

Feng Wenqiang, Tu Shihua, Fu Tao, Chen Qingrui and Liao Minglan

Soil and Fertilizers Research Institute,
Sichuan Province Academy of Agricultural Science, 610066

Abstract

Three typical regions of Sichuan, Chongzhou City in the Chuanxi Plain, Jianyang City located on the calcareous purplish soils of the mountainous region and Fushun County located on the neutral purplish soils of the hilly region, were studied with regard to nutrient cycling in their main cropping systems. Furthermore, statistical data from the agricultural yearbooks were used to analyse nutrient inputs and outputs of the province. Based on the latter it was found that fertilization in Sichuan was unbalanced, showing that N and P inputs greatly exceeded outputs whereas the opposite was observed for K, showing that outputs by far exceeded the K inputs. The nutrient balance for the whole province was positive for nitrogen with +460,000 tons of N (73.5 kg N ha^{-1}), for phosphorus with +329,000 tons of P_2O_5 (54 kg ha^{-1} P_2O_5) whereas it was negative for K at an amount of –748,000 tons of K_2O (122 kg ha^{-1} K_2O). Down to farm level, the observations varied strongly from region to region and from farm to farm, though dramatic negative balances were also found on this level. However, the overall conclusions that N and P are applied in excess is not universally applicable and a stronger differentiation is needed. The paper nevertheless tries to conclude and suggest fertilizer management practices for a more balanced and sustainable agricultural production in the future. The recommendation includes to reduce inefficient use of N and P which is partly caused by the nutrient imbalance, causing limitations to yield formation by reduced uptake and large losses of these nutrients. It is further proposed to improve the supply of mineral K and, in case needed, other limiting macronutrients, e.g. Ca, Mg and S as well as micronutrients. The improvement of the recycling of organic residues and manure to the fields to supplement the mineral nutrient application is also suggested.

Introduction

With the population, rising steadily and the area of cultivated farmland continuously shrinking, the gap between population and land availability for crop production widens. To meet the people's growing demand for agricultural products, it is essential to continuously improve the utilization of the cultivated farmland and its multiple-cropping index. This will inevitably aggravate the depletion of soil nutrients, especially of those which are not applied to the soil by means of fertilization, thus leading to an imbalance between the supply and demand of nutrients in the various cropping systems. To ensure a sustainable productivity of the farmland and to promote agricultural development, the study on the farmland nutrient cycle and balance was an excellent opportunity to provide us with a scientific basis for formulating plans for a sound and environmental friendly fertilization. The purpose of this paper is therefore to suggest improvements in the fertilization practice.

General conditions of the agriculture

General conditions of the agriculture of the province (excluding Chongqing)

The Sichuan Province, lying in the hinterland of Southwest China, covers a total land area of 48.5 million hectare, being the fifth largest province in the country. In 2001, it had a total population of approximately 84 million people, of which more than 80% were living in the rural areas. The sown area during this time was 9.5 million hectares, which translates into 4.3 million hectares of farmland due to a cropping index which is currently about 2.2, meaning that 2.2 crops can be grown on the same field during one year. From this area, the province produced a total of 23.99 Mt grain, which comprised 14.29 Mt rice, 4.48 Mt wheat, 4.52 Mt maize, 4.29 Mt (grain equivalents) of tuber crops, mainly sweet potato, 1.81 Mt oil, 15.57 MT sugar and approximately 30,000 tons of cotton. The soils in the province are mainly purplish soils and yellow earths, and about 80% of the farmland is on agric-purplish soil and purplish paddy soil.

General conditions at the investigation sites

The study sites were selected in Chongzhou City, Jianyang City and Fushun County, representing the major double-cropping rice growing areas in the province.

Chongzhou City is situated in the Chengdu Plain, the western part of the Sichuan Basin. It has a total of 36,700 ha of cultivated farmland, of which 33,300 ha grow two crops per year. About 0.4 Mt of grain and 0.013 Mt of oilseed rape are produced and 0.55 million pigs and 0.01 million cattle are raised. The major soil is grey fluvio-aquic soil derived from grey alluvium of the Minjiang River and is mainly cultivated by a rice-wheat (or rice-oilseed rape) rotation system. The annual precipitation is around 1,000 mm and the annual mean temperature 16°C.

Jianyang City located in the mountainous region in the middle of the Sichuan Basin has a total of 0.1 million ha of cultivated farmland, of which 66,700 ha are on upland. About 0.7 Mt of grain, 0.03 Mt of oilseed rape and peanuts and 0.02 Mt cotton are produced and 1.0 million pigs and over 0.1 M sheep and goats are raised. The major soils are brown purplish soils and red purplish soils derived from purplish sedimentary rock of Penglai Town Group and Suining Group in the Jurrasic System and are mainly cultivated by the three cropping systems wheat-maize-sweet potato or oil seed-cotton rotations in upland fields and rice-wheat (rice-oilseed rape) rotations in the paddy fields. The annual precipitation is around 880 mm and the annual mean temperature 17°C.

Fushun County, lying in the hilly area of the southern part of the Sichuan Basin, has a total of 53,300 ha of cultivated farmland, of which over 40,000 ha are paddy fields. About 0.5 Mt of grain and 0.1 Mt of oil seeds are produced and 0.90 million pigs and over 0.30 million sheep are raised. The major soils are grey brown purplish soils and red brown purplish soils derived from purplish sedimentary rock of Shaximiao Group and Suining Group in the Jurrasic System. The agricultural production comprises wheat-sorghum (maize)-sweet potato rotations in the upland and fallow-rice-regenerative rice rotations in the paddy fields. The annual precipitation is around 900 mm and the annual mean temperature 18°C. A detailed description of the 3 sites studied, including the average structure and yields of the households is given in Table 1.

Table 1. General conditions of the three investigation sites

Item	Chongzhou	Jianyang	Fushun
Number of farms surveyed	30	27	29
Number of people covered	109	112	127
People per family	3.63	4.15	4.38
Land per family (ha)	0.2300	0.2700	0.3047
Paddy (ha)	0.2300	0.1933	0.1000
Upland (ha)		0.0777	0.2047
Land per capita (ha)	0.0634	0.0651	0.0696
Total output (kg family^{-1})	2151	2246	2119
Yield (kg ha^{-1} yr^{-1})	9438	8455.5	7281

Results and discussion

Results of the investigation sites

In the plain (Chongzhou City), the hilly region (Fushun County) and mountainous region (Jianyang City), the number of family members and the size of farmland per capita increased whereas the grain yield per unit area decreased in the order Chongzhou < Fushun < Jianyang. This is determined by their respective agricultural production conditions (see Table 1).

Table 2 shows that the fertilizer application rate was the largest in Fushun County and the smallest in Jianyang City while the K application rate was the largest in Chongzhou City, much larger than in Fushun County and Jianyang City.

With regard to soil nutrient balance, all the three sites revealed a deficit for K and had a surplus of P. N was in surplus in Fushun County and deficient in Chongzhou City and Jianyang City with the latter being more serious. Farms with an N, P and K deficit were observed in Chongzhou City, only differing slightly. About 85% of the farmers in Fushun County manage their farmland with a strong deficit in K. The deficits of N and P were both quite large whereas K was extreme, reaching 96% in Jianyang City.

Among the three study sites, the largest amounts of organic manure were applied in Fushun County followed by Chongzhou City and Jianyang City. The sites followed the same order with respect to mineral fertilizer consumption. In Fushun County and Jianyang City, the application rate of N was larger and that of K smaller. In Chongzhou City the application rate of K reached as much as 75 kg K_2O ha^{-1}. Therefore, the proportion of farmland suffering nutrient deficiency differed slightly between N, P and K. In Jianyang City, about 96 % of the farmland was deficient in K and 79% in N. In Fushun County, the proportion of farmland, showing a nitrogen deficit, was small whereas 85% suffered from a K deficit. The nutrient P showed a surplus in Fushun. The results clearly indicate that farmers in the Chuanxi Plain had a greater awareness of balanced fertilization whereas in the mountainous and hilly regions, where general economy is also less developed, such as Jianyang City and Fushun County, less awareness about a balanced fertilization approach exists. Although Fushun County had the largest fertilizer application rates, the nutrients were not applied in a balanced manner by taking into account demand and supply.

Table 2. Nutrient balance of the three investigation sites

Site	Item*	N	P_2O_5	K_2O
Chongzhou City	Input (kg ha^{-1})			
	Mineral fertilizer	217.5	59.3	75.2
	Organic manure	59.3	53.3	99.3
	Total	276.7	112.5	174.5
	Output (kg ha^{-1})	197.8	88.1	265.7
	Balance (kg ha^{-1})	-4.1	24.5	-91.2
	Farmers in deficit (%)	26.7	30.0	40.0
Fushun County	Input (kg ha^{-1})			
	Mineral fertilizer	251.5	81.0	3.5
	Organic manure	76.5	63.5	78.9
	Total	328.1	144.5	82.4
	Output (kg ha^{-1})	114.6	51.3	161.4
	Balance (kg ha^{-1})	115.0	93.2	-79.1
	Farmers in deficit (%)	3.7	0.0	85.2
Jianyang City	Input (kg ha^{-1})			
	Mineral fertilizer	127.2	66.8	7.4
	Organic manure	45.6	39.2	32.3
	Total	172.8	105.9	39.6
	Output (kg ha^{-1})	213.2	88.8	233.1
	Balance (kg ha^{-1})	-92.2	17.1	-193.5
	Farmers in deficit (%)	79.3	41.4	96.6

* N loss is estimated at 30%

Agriculture of the past 20 years in the Sichuan Province (including Chonqing)

The development in the agriculture of Sichuan during the last 20 years indicates that the population increased by 15.1%, the acreage of farmland decreased by 7.7%, the area of farmland per capita dropped by 18.5% and the multiple cropping index increased by 18.3%. This is explained by a compensation for the lost agricultural land during the same period. Furthermore, animal husbandry increased by 29.9% more cattle, 33.1% more pigs and 45.1% more sheep and goat (Table 3).

Table 3. Selected statistical data of agriculture in Sichuan (including Chongqing*) in the last 20 years

Year	**1982**	**1987**	**1992**	**1996**	**2001**	**Difference **(%)**
Population (M)	100.2	104.583	109.429	112.382	115.345	15.1
Farmland (10^3 ha)	6563	6326	6255	6165	6085	-7.7
Land per capita (ha)	0.065	0.061	0.057	0.055	0.053	-18.5
Multiple cropping index %	185.9	188.9	206.1	210.4	220.0	+18.3
Cattle (M heads)	9.180	9.730	10.193	11.339	11.930	+29.9
Pig (M heads)	51.900	60.230	66.542	70.816	69.070	+33.1
Goat (M heads)	10.030	8.850	9.452	13.354	14.550	+45.1

*Chongqing with a current population of approx. 30 M inhabitants has become municipality in 1997 and is listed independently from Sichuan in the latest statistical books.

**Difference between 2001 and 1982 (%)

Development in the output of cereals, tubers, oil crops and cotton

There was a steep increase in the overall crop production from 1982 until 1996 followed by a decline until 2001 (Table 4). The year 2001 was exceptional with regard to weather conditions when severe droughts affected the production.

Nevertheless, the comparison between the years shows a clear trend towards a stabilization of the grain production, increased tuber and oil seed production as well as increasing the animal husbandry. Taking the up-to-date production of 2001 as reference, grain output only slightly increased by 2.8% on average with 5.2% increase in rice, a decrease in wheat and maize production which may be clearly a result of poor water availability in 2001. Tuber output with sweet potato as major crop increased by 53.7% compared to 1982, which may only be partly attributed to direct consumption but largely to the fast development in pig raising (see Table 3). Oil production also increased by 78.4% whereas cotton further declined in 2001, being only 36% of that what was produced in 1982.

Table 4. Cereal, tuber, cotton and oil production in Sichuan (including Chongqing) in the last 20 years

Year	1982	1987	1992	1996	2001	Difference* (%)
Total grain yield (Mt)	38.42	39.213	44.311	47.417	39.500	+2.8
Wheat (Mt)	6.405	6.584	7.845	10.048	5.400	-15.7
Rice (Mt)	18.065	19.797	22.295	22.888	19.010	+5.2
Corn (Mt)	6.39	5.214	6.445	7.612	6.330	-1.0
Sweet potato (Mt)	4.36	4.884	4.517	5.237	6.700	+53.7
Oil (Mt)	1.177	1.335	1.326	1.234	2.109	+78.4
Cotton (1000 t)	0.820	0.102	0.151	0.126	0.030	-64.5

*: Difference between 2001 and 1982 (%)

Development of the fertilization practice

The mineral N fertilizer application rate rose steadily from 148.6 kg ha^{-1} in 1982 to 276.6 kg ha^{-1} in 2001. Before 1982, mineral P and K fertilizers were rarely used. In the meantime, mineral P application reached 96.6 kg ha^{-1} P_2O_5 and that of mineral K reached 21.3 kg ha^{-1} K_2O. The consumption of compound fertilizers developed rapidly during the past decade. In 2001, the nutrient input in the form of compound fertilizers reached 75.3 kg ha^{-1}. The application of organic manure also rose steadily but by a smaller margin than that of mineral fertilizers. In 2001, the recycling of nutrients from this nutrient source was in the region of 62 kg ha^{-1} N, 38 kg ha^{-1} P_2O_5 and 62 kg ha^{-1} K_2O (Table 5).

Table 5. Changes in nutrient application in Sichuan (including Chongqing), distinguished between mineral fertilizers and organic manure during the last 20 years

Year	1982		1987		1992		1996		2001	
	kg ha^{-1}	10^3 t	kg ha^{-1}	10^3 t	kg ha^{-1}	10^3 t	kg ha^{-1}	10^3 t	kg ha^{-1}	10^3 t
Compound fertilizer			7.80	49	31.8	199	56.0	345	75.3	456
Mineral N	148.6	976	173.4	1097	224.4	138	262.6	1619	276.3	1676
Mineral P_2O_5	44.4	291	49.7	314	70.4	440	85.5	527	96.6	585
Mineral K_2O	0	0	3.2	20	8.3	52	15.2	93	21.3	129
Organic N	44.4	291	50.6	322	55.5	347	60.0	369	62.4	378
Organic P_2O_5	25.5	167	29.9	189	33.0	206	35.9	221	38.1	231
Organic K_2O	44.1	289	49.8	315	54.0	338	60.0	369	62.4	378

Farmland nutrient balance

The nutrient balance of 1996 for the whole province (including Chongqing) was calculated using yields, respective calculated nutrient removals by crops as output and nutrient application by mineral fertilizers and organic manure as inputs (Table 6).
Losses were only estimated for nitrogen, assuming that no losses for P and K occurred. This is due to the fact that no figures were available regarding leaching and runoff losses which may be severe for both nutrients in very light soils and on sloping land, respectively. Taking this into account, the real balances for P and K therefore can be assumed to be considerably less positive for P and more negative for K.
In Table 6 the nutrients used in cash crops like fruits and vegetables were not taken into account, assuming that these were covered by the compound fertilizers (see Table 5) which were not included in the nutrient balance calculations of Table 6. Based on these figures it is evident that N and P inputs exceeded the outputs by the crops and positive balances were calculated for N at the amount of 73 kg^{-1} N ha^{-1} and for P at the amount of 54 kg P_2O_5 ha^{-1}. These balances imply large over-supply of N and P and poor efficiency of both nutrients, which could be partly due to poor uptake caused by deficiency of other nutrients, limiting biomass production of the plants which was hence inhibiting the uptake of N and P. The large deficit of K could be a reason for this observation, since continuous large K removals from the soil without adequate replacement has caused an annual deficit of –122 kg K_2O ha^{-1}. Potassium therefore may be the major nutrient that limits crop production in Sichuan, however, also other macronutrients, e.g. Ca, Mg and S, or micronutrients could be limiting in the intensive cultivated soils with more than two crops per year.

Table 6. Farmland Nutrient Balance in Sichuan (including Chongqing) (1996)

Nutrient I/O	Item	N		P_2O_5		K_2O	
		kg ha^{-1}	10^3 t	kg ha^{-1}	10^3t	kg ha^{-1}	10^3 t
Input	Min. fertilizers	262.5	1619	85.5	527	15.2	93
	Manure	60.0	369	36.0	221	60.0	369
	Total	322.5	1989	121.5	748	75.0	463
	$N:P_2O_5:K_2O$ ratio	1		0.38		0.23	
output	Removal by crop	151.5	932	67.5	419	196.5	1211
	Loss of min. fertilizers.	79.5	486				
	Loss of manure	18.0	111				
	Total	249.0	1529	67.5	419	196.5	1211
	$N:P_2O_5:K_2O$ ratio	1		0.27		0.79	
Balance		73.5	460	54.0	329	-121.5	-748

Current fertilizer use and recommended requirement based on nutrient input : output ratios in Sichuan

Based on changes in the population, acreage of farmland and grain output in the period from 1982 to 2001, the fertilizer demand of Sichuan for the next 10 years was estimated (Table 7). Comparing the actual demand with the prediction for 2005 and 2010, it is evident that today nitrogen and phosphorus are obviously already consumed at amounts close to those predicted in the future, which means that the growth potential for the use of these two nutrients is regarded as limited and that focus has to be laid on the increase of their use efficiency. On the other hand, there is a huge gap between current and predicted use of K based on good agricultural practice. More than ten times as much mineral K would be needed to achieve this goal.

Table 7. Comparison between actual consumption (2001) and prediction of fertilizer demand depending on population, land and yield development (including Chongqing)

Year	Population (M)	Land (M ha)	Yield (kg ha^{-1})	N* (Mt)	P_2O_5 (Mt)	K_2O (Mt)
**2001	115.345	60.58	5047	1.676	0.585	0.129
2005	120.248	58.86	5443	1.589	0.501	1.454
2010	124.582	57.46	5839	1.735	0.547	1.586

Note: *N loss is assumed as 30%, **current figures from the China Agric. Yearbook 2002, excluding the nutrients from compound fertilizers

After the flooding in 1998, in response to the state policy of controlling soil erosion in the upper streams of the Changjiang River, the province has decided to restore grassland and forests on 0.7693 million ha of farmland. At the same time, it was decided to readjust the agricultural production structure by implementing the concept of eco-agriculture and by keeping the grain production per capita at the same level as in 1998. Therefore, prediction of fertilizer demands based on the above changes is rather conservative, assuming that the large discrepancy between K input and removal will be overcome by the implementation of above regulations.

Suggestions for fertilizer management in the province

The investigation at county and farm level has shown that a stronger differentiation for the conclusions and recommendations is required and that the calculated province-wide nutrient balances may only serve as a relatively rough guideline to determine the real nutrient requirement. In the absence of better data on efficiency and losses for the various nutrients, it is therefore advised not to generalise with respect to over-supply of N and P. Efficiency in uptake of both nutrients may be inhibited due to insufficient supply of especially K and other macro- and micronutrients, promoting either their losses or, especially in case of P, an accumulation in the soil. It is certain that the neglect of K due to an imbalance in fertilization over many years caused a decrease in soil fertility and productivity. In order to ensure the sustainable development of the agriculture while setting aside 0.7693 million ha farmland for restoring grassland and forests, balanced fertilization must be implemented. This does not only apply to the three macronutrients N, P and K, but also to all the other nutrients needed by crops. Consequently, the following priorities are proposed:

1) Improving N and P efficiency and maintaining or, in case of less demand, through better efficiency, reducing their application. This can be done by the approach of balanced nutrient supply, better timing for N and better sources of fertilizers which are less prone to losses (e.g. volatilisation, denitrification, leaching or fixation).
2) Improving the mineral K supply and promotion of recycling K in the straw and in the organic residues from animal husbandry.
3) Creating awareness for the importance of other macronutrients, e.g. Ca, Mg and S as well as micronutrients, to avoid that those are becoming limiting for growth and hence reducing uptake and efficiency of N and P in particular.
4) Standardizing the production of raw material fertilizers to produce high quality, highly concentrated compound fertilizers or site-/ crop specific bulk-blends.
5) Setting up a county-based integrated advisory service, providing farmers with guidelines based on research results. Based on the combination of soil monitoring with experimental results of research institutions, formulas for crop-specific and site-specific fertilizers should be developed for the fertilizer industry and then popularised among the users.

Farmland nutrient cycle and nutrient balances in Guangxi

Tan Hongwei, Zhou Liuqiang and Xie Rulin

Soil and Fertilizers Institute, Guangxi Academy of Agricultural Science, 530007

Abstract

A study on nutrient cycling and nutrient balances at different scales in the autonomous region of Guangxi was carried out. Using data from a survey in representative cropping systems in different counties and nutrient input : output calculations based on published data, the agricultural statistics revealed a detailed knowledge about the nutrient inputs from organic and inorganic resources to the main cropping systems on lowland and upland. The overall consumption of N and K was not sufficient to cover the demand of the crops whereas the P balance showed a positive value. In lowlands, N inputs clearly exceeded outputs whereas on the uplands the balance of N was negative, leading to an overall negative balance for nitrogen. Substantially more potash fertilizer is required to overcome the negative balance and the severe K deficit observed. The prediction for future mineral fertilizer consumption indicates 7-10% annual increase to meet the growing demand and to establish balanced nutrient budgets in the farmlands.

Introduction

With a total population of more than 47 million, the autonomous region of Guangxi is the tenth most populous province in China. In terms of area under cultivation, Guangxi also occupies rank 10 among the provinces. With a beneficial climate all year round cultivation is possible, posing a particular strain on the nutrient supply of the soils which are inherently poor in all the major nutrients. The crop production of the province therefore increasingly depends on the use of mineral fertilizer inputs, especially to produce the required food for the continuously growing population. On the other hand, Guangxi is gaining importance in the production of tropical cash crops, fruits and vegetables for the export to other provinces and to abroad. This type of high-input-demanding agriculture, however, bears a number of risks to product quality, resource protection, especially to the soils, surface and ground waters. It is therefore important to introduce an agricultural management system that relies on a knowledge based input of nutrients. With this in mind, the study on the farmland nutrient cycle, to quantify in a precise way inputs and outputs of nutrients to the various cropping system, deserves high priority. Through a survey and by using the available data from scientific publications and the statistics of the province, this study undertakes the attempt to assess the nutrient balance for representative cropping systems at various scales to develop a recommendation system for the fertilizer use of Guangxi .

Materials and methods

According to the characteristics of the agricultural production in Guangxi, five typical counties (including one city), i.e. Hepu County, Hezhou City, Laibin County, Dahua County and Tianyang County, were selected for the survey. In each county, two townships, in each township three villages and in each village 5 farms were selected for the survey, so that in total five counties, ten townships, thirty villages and one hundred and fifty farms were studied. During the investigation, statistics of the agricultural production of the related units were collected for analysis.

- Hezhou City represents the agricultural zone in the northeast of Guangxi, growing mainly rice, vegetables and tobacco.
- Laibin County represents the agricultural zone in the centre of Guangxi, growing mainly rice, sugar cane, maize, soybean and peanut.
- Hepu County represents the agricultural zone in the south of Guangxi, growing mainly rice, yam, sugar cane, peanut and tropical fruits.
- Dahua County represents the agricultural zone in the northwest of Guangxi, growing mainly maize, soybean and yam.
- Tianyang County represents the agricultural zone in the west of Guangxi, growing rice, winter vegetables, sugarcane, banana and mango.

Farmland nutrient input

Farmland nutrient input is closely associated with fertilization, nutrient supply via rainfall and irrigation water. For calculating the nutrient contents in farmyard manure, it was referred to the data provided in the Agro-chemistry volume of the Chinese Agricultural Encyclopaedia and the data collected in field experiments. For the nutrient contents in rain and irrigation water, published data from field experiments were used.

Farmland nutrient output

Absorption of nutrients by crops and the proportion removed at harvest usually accounts for the largest nutrient output from the farmland. Another important output are losses of indigenous and fertilizer nutrients by leaching, runoff and volatilisation (nitrogen only). The calculation of the removal of nutrients by crops was based on results from field experiments. Nutrient leaching losses and fertilizer N losses from the farmland were calculated on the basis of published data from China.

Results and discussion

General conditions of the agricultural production.

Guangxi is an autonomous region located in the south of China. According to the statistics in 2001, the province had a population of 47.58 million, of which 39.12 million live in the rural areas, working on a total of 2.646 million ha farmland, of which 1.519 million ha were paddy fields and 1.129 million ha upland fields. In 2001, Guangxi had a total cultivated area of 6.288 million ha, of which 3.642 million ha were cultivated with cereals, 574,600 ha with sugar cane, 2.071 million ha with other crops. In the same year, the province produced 14.04 M t of grain and 36.53 M t of sugar cane. In addition, Guangxi had 814,300 ha of orchards, producing 3.155 M t of fruits (Table 1 and 2).

Table 1. Major agricultural crops, their planted area, total output and yields in Guangxi (1997-2001)

	Planted area ($\times 10^3$ ha)		Total output ($\times 10^3$t)		Yield (kg ha^{-1})	
Year: Crop	1997	2001	1997	2001	1997	2001
Early rice	1156.2	1141.5	7422.1	5877.0	6419	5149
Late rice	1143.5	1147.3	5786.9	5640.0	5060	4916
Maize	561.1	556.9	1661.2	1685.0	2961	3026
Soybean	267.5	250.0	324.6	344.0	1214	1376
Sweet potato	331.4	306.9	*601.5	*646.0	*1815	*2105
Peanut	216.7	240.4	423.5	487.8	1954	2029
Oil seed	133.4	76.1	123.0	73.1	922	961
Sesame	8.8	7.3	5.9	5.7	670	779
Kenaf	8.9	6.1	18.4	11.9	2067	1954
Ramie	1.3	0.6	3.2	1.3	2462	2130
Sugar cane	549.3	574.6	32428.3	36533.0	59033	63580
Tabacco	39.9	21.9	66.9	3.8	1677	1747
Cassava	273.3	n.a.**	1295.3	n.a.	4739	n.a.

*=grain equivalents, **=not available

In 2001, the province raised 54.34 million pigs of which 27.68 million were slaughtered. The stock in cattle, buffaloes, horses and donkeys was 15.73 million. In 2001, Guangxi consumed 1.681 M t of mineral fertilizers (net nutrients), of which 575,000 t were N fertilizers, 233,000 t P fertilizers, 394,000 t K fertilizers and 479,000 t compound fertilizers. Compared to 1997 this is a decrease in N consumption by 1.1%, an increase of 2.6% in P, an increase of 25% in K and a 47% increase in the consumption of compound fertilizers.

Farmers survey

General conditions of the farms

The survey of the 150 farms revealed that on average each farm had 4.8 family members and 0.366 ha of farmland, of which 0.34 ha were paddy fields and 0.025 ha upland fields. The prevalent farming systems were early rice – late rice, early rice – late rice – winter vegetable, kenaf – late rice and early rice – peanut for paddy fields and sugarcane, peanut – sweet potato, kenaf – sweet potato and maize – sweet potato for upland fields. In the cereal production areas, the average grain output of each farm was 3,645 kg, of which 829 kg were delivered to the state as agricultural tax and 1,264 kg were sold on the market. Each farmer applied on average 1,448 kg of farm-yard manure (pig, cattle, goat and horse manure) per year and used up to 766 kg of mineral fertilizers, of which 446 kg were N, 223 kg P_2O_5 and 97 kg K_2O.

Agricultural production in Guangxi

The statistics of Guangxi shows that cereals like rice and maize occupy the largest area (see Table 1). Comparing the figures of 2001 with those of 1997, it is obvious that there was no expansion in area during the last four years and also production and yields stagnated. This was observed for most of the crops, with the exception of peanut and sugar cane in both area and yield.

This is different for the major tropical fruits that are grown in Guangxi (Table 2). The production of fruits had a significant expansion in the cultivated area as well as in yields and even during the last four years the production further expanded. Banana production increased by almost 35% and that of citrus by 31%. Other fruits which are not shown in Table 2, such as mango, also went through an expansion during the last 10 years and are today important sources of income for farmers on the uplands.

Table 2. Major fruits and their total production in Guangxi (1997-2001)

Fruit	Banana	Pomelo	Citrus	Pineapple	Longan	Litchi
	1000 t					
1997	839.5	152.0	1007.0	79.5	137.6	162.0
2001	1129.5	n.a.*	1320.7	63.1	n.a.*	210.3

*=not available

Fertilizer application to major crops

Staple food crops

In 1997, the autonomous region of Guangxi had 6.203 M ha of cultivated land of which 3.738 M ha were used for the production of staple food crops. The total cultivated area expanded slightly to 6.288 M ha in 2001, whereof 3.641 M ha were grain crops, showing that the latter lost in importance compared to other crops, which may indicate a trend towards the production of more valuable crops by farmers. Using the average application rates (Table 3) of mineral fertilizer nutrients, the total nutrient consumption for the food crops was calculated (Table 4). Based on this it was estimated that in 1997, grain crops consumed 944,900 t nutrients in form of mineral fertilizers or 64.7% of the total, amounting to 1.461 M t. Due to double cropping of rice and the relatively large application to this crop, rice has the by far greatest consumption (72% of the nutrient consumption can be attributed to this crop) (Table 4). Maize with only about 18% is second, followed by sweet potato and soybean.

Table 3. Average fertilizer application rate to major staple food crops in Guangxi

Crop	Application rate (kg ha^{-1})		
	N	P_2O_5	K_2O
Rice	159.65	62.53	76.17
Maize	169.31	68.98	70.17
Sweet potato	54.19	43.86	36.57
Soybean	53.10	52.89	47.12

Table 4. Consumption of mineral fertilizers in major staple food crops in Guangxi in 1997

Crop	Mineral fertilizer consumption							
	N		P_2O_5		K_2O		Total	
	(10^3 t)	(%)	(10^3 t)	(%)	(10^3 t)	(%)	(10^3 t)	(%)
Rice	367.1	74.3	143.8	68.1	175.2	73.2	686.1	72.6
Maize	95.0	19.2	38.7	18.3	39.4	16.5	173.1	18.3
Sweet potato	18.0	3.6	14.5	6.9	12.1	5.1	44.6	4.7
Soybean	14.2	2.9	14.1	6.7	12.8	5.3	41.1	4.3
Total	494.3	100.0	211.1	100.0	239.5	100.0	944.9	100.0

Cash crops

It is evident from above that approximately 35% of the nutrients were used both in cash crops (16% of the cultivated area) and other crops (24% of the cultivated area). According to our study, the average fertilizer application rates on major cash crops in 1997 revealed that sugar cane received by far the largest amounts of N, P and K followed by kenaf (Table 5). Multiplying the application rates by the area, sugar cane, being produced on a larger area, is also the largest nutrient consumer among the cash crops. The consumption of mineral fertilizers by cash crops reached 240,400 t, accounting for 16% of the province's total. This means that approximately 277,000 t of nutrients were used by other crops than the food and cash crops listed in Tables 4 and 5. It may be assumed that these nutrients are mainly consumed by the strengthening sector of fruits and vegetables which were not taken into account. From 1997 until 2001, the total fertilizer nutrient consumption increased from 1.461 M t to 1.681 M t and with the stagnation in area and production in the food crop sector (see Table 1) it may be assumed that cash crops and other crops were increasingly responsible for increased fertilizer consumption of the province. Current fertilizer use by crops (2001) can be estimated as 980,000 t in the staple food sector, 300,000 t in the cash crops (as defined in Table 5) and approximately 400,000 t in fruits, vegetables and other crops. This assumption is supported by the fact that the consumption of nutrients in form of compound fertilizers has increased to 470,000 t and the compounds are usually the preferred nutrient sources for these crops in Guangxi.

Table 5. Average fertilizer application rates and consumption of mineral fertilizer nutrients by cash crops in Guangxi

Crop	Application rate (kg ha^{-1})			Fertilizer consumption ($\times 10^3$t)			
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	Total
Sugar cane	168.5	85.8	115.4	92.5	47.2	63.4	203.1
Peanut	52.9	55.3	53.2	11.4	12.0	11.5	35.0
Kenaf	120.0	75.0	90.0	1.1	0.7	0.8	2.5

Organic manure applied to major crops

The organic manure used in Guangxi includes mainly farmyard manure and crop residues recycled to the field after harvest.

Farmyard manure

According to our survey during the study period, Guangxi had 8.393 million of cattle, producing 65.470 M t manure, 343,200 horses, producing 1.819 M t manure, 27 million pigs, producing 25.650 M t manure, and 2.574 million goats, producing 645,300 t manure. 93.580 M t of farmyard manure were applied to farmland supplying 491,200 t N, 192,100 t P_2O_5 and 441,600 t K_2O (Table 7). Table 8 shows the application of farmyard manure to major crops.

Table 7. Nutrients applied by the different types of animal manure

Type of manure	N	P_2O_5 1000 t	K_2O
Pig dung	138.5	82.9	170.1
Goat droppings	5.9	2.7	3.3
Cattle manure	335.2	102.1	259.2
Horse manure	11.6	4.4	9.0
Total	491.2	192.1	441.6

Recycling of crop residues to the field

In 1997, early rice produced 8.906 M t of straw, of which 70% or 6.235 M t were returned to the field. For late rice, only 20% or 38,900 t of straw were recycled to the fields. Maize produced 2.774 Mt of stalks, of which 20% or 554,800 t were returned. 584,300 t of soybean stalks were produced, of which 30% or 173,500 t were returned and 889,400 t of peanut stems were produced, of which 30% or 266,800 t were returned. In total, the recycling of crop residues returned 47,198 t N, 5,778 t P_2O_5 and 72,542 t K_2O of the nutrients removed at harvest to the fields (Table 9).

Table 8. Application of farmyard manure to major crops

Crop	Amount applied ($\times 10^3$t)	Application rate (t ha^{-1})	Proportion (%)
Rice	18,177.0	7.9	20
Corn	14,037.8	25.0	15
Peanut	4,679.3	21.6	5
Sugarcane	9,359.0	17.0	10
Soybean	4,679.3	17.5	5
Sweet potato	4,679.3	14.1	5
Vegetable	14,037.8	--	15
Fruit	14,037.8	21.0	15
Other crops	9,359.0	20.5	10

Table 9. Nutrients returned to the farmland via recycled crop residues

Crop	N	P_2O_5 tons	K_2O
Early rice straw	31,173	3,865	49,877
Late rice straw	6,945	1,111	11,112
Sub-total	38,118	4,977	60,989
Maize stalks	3,052	444	7,823
Soybean stalks	2,761	158	2,069
Peanut stems	3,268	200	1,662
Total	47,199	5,778	72,542

The vines of sweet potato were returned to the field after being fed to animals, whereas the leaves of sugar cane were used as fuel.

Nutrients supplied by rain and irrigation water and nutrient losses from farmland

1) Analysis of collected rainwater showed that it supplied the farmland with 10.13 kg ha^{-1} N, 0.20 kg ha^{-1} P_2O_5 and 6.83 kg ha^{-1} K_2O per year.
2) Analysis of the irrigation water showed that on average paddy fields received 3.3 kg ha^{-1} N, 0.03 kg ha^{-1} P_2O_5 and 4.8 kg ha^{-1} K_2O per crop from this source.
3) Nutrient loss through leaching and gaseous losses (nitrogen) from paddy fields can be considerable, depending on soil properties (light soils > heavy soils) and fertilizer type and application technique, regarding the gaseous losses of N.
4) On upland soils, especially on sloping land, runoff losses may be considerable.
5) Estimated average losses of only 8 kg ha^{-1} N, < 0.1 kg ha^{-1} P_2O_5 and 11 kg ha^{-1} K_2O appear clearly on the low side and are probably an underestimation.
6) More and a better quantification of real nutrient losses in the different cropping systems on paddy and on upland fields are required.

The nutrient balance of farmland in the whole province

Based on the survey and published data related to nutrient input and output, a farmland nutrient balance for the whole Guangxi province was assessed (Table 10). This nutrient balance is characterized by a deficit of 280,400 t N and 507,900 t K_2O in 1997 whereas a surplus of 241,100 t of P_2O_5 was recorded. The fertilization in vegetable gardens, orchards and forestland was not taken into account. Since these latter crops play an increasingly important role in the agricultural production and fertilizer consumption, the balances shown in Table 10 may underestimate the deficit in N and K and overestimate the surplus of P in Guangxi..

Table 10. Farmland nutrient cycle and balance in Guangxi (10^3t)

	Source	N	P_2O_5 1000 t	K_2O
Nutrient input	Mineral fertilizer	599.4	271.0	315.1
	Organic manure	291.9	192.1	262.4
	Straw	47.2	5.8	72.5
	Symbiotically fixed N	94.4		
	Crop seeds	10.9	3.0	3.7
	Rain and irrigation water	20.4	0.3	11.8
	Total	1064.2	472.2	665.5
Nutrient output	Removal at harvest	987.4	230.3	1160.1
	Loss from fertilizer	239.7		
	Loss from manure	108.0		
	Leaching loss	9.5	0.8	13.3
	Total	1344.6	231.1	1173.4
Balance		-280.4	241.1	-507.9

Nutrient balance in paddy fields

According to our estimation, paddy fields received about 525,400 t N, 187,800 t P_2O_5 and 334,000 t K_2O in 1997. The total N input originated to about 69.9% from mineral fertilizer, 18.2% from organic manure and 7.3% from straw recycled to the field. Another 1.0% came from crop seeds and 3. 7% from rainfall and irrigation. On the output side 57.8% could be ascribed to the removal by rice, 31.0% to losses from mineral fertilizers, 9.2% to losses from organic manure and 2.0% to losses from the soil pool. In the whole province, the paddy fields were characterized by a surplus of 51,900 t yr^{-1} N, a surplus of 139,600 t yr^{-1} P_2O_5 and a deficit of 4,400 t yr^{-1} K_2O (Table 11).

Nutrient balance in upland fields

The survey revealed that about 232,300 t N, 127,200 t P_2O_5 and 139,900 t K_2O were applied to upland fields (Table 12). The input of N reached 538,800 t, of which 43.1% were supplied by mineral fertilizers, 36.5% by farmyard manure, 1.7% by recycled straw, 1.0% by seeds, 0.2% by rainfall and 17.5% were symbiotically fixed. The N output amounted to 860,200 t, of which 82.4% were removed with the harvested crop, 10.8% lost from fertilizers and 6.85% lost from organic manure. The comparison between input and output revealed a deficit in the balance of 331,300 t N yr^{-1}.

Table 11. Balance of nutrients in paddy fields (10^3t)

	Source	N	P_2O_5 1000 t	K_2O
Nutrient input	Mineral fertilizer	367.1	143.8	175.2
	Organic manure	95.4	37.3	85.8
	Straws returned to the field	38.1	4.9	60.9
	Crop seed	5.5	1.5	1.1
	Rain and irrigation water	19.3	0.3	11.0
	Total	525.4	187.8	334.0
Nutrient output	Removal with rice	273.5	47.4	325.1
	Loss with fertilizer	146.9		
	Loss with manure	43.6		
	Leaching loss	9.5	0.8	13.3
	Total	473.5	48.2	338.4
Balance		+51.9	+139.6	-4.4

Table 12. Nutrient balance in upland fields in Guangxi

	Source	N	P_2O_5 1000 t	K_2O
Nutrient input	Mineral fertilizer	232..3	127.2	139.9
	Organic manure	196.5	76.8	176.7
	Straws	9.1	5.8	11.5
	Symbiotically fixed N	94.4		
	Crop seeds	5.4	0.7	2.6
	Rainfall	1.1	0.02	0.8
	Total	538.8	210.5	331.5
Nutrient output	Removal with harvest	708.3	174.4	835.0
	Loss with fertilizer	92.9		
	Loss with manure	68.9		
	Total	870.1	174.4	835.0
Balance		-331.3	+36.1	-503.5

The input of P reached 210,500 t, of which 60.3 % were supplied by mineral fertilizers, 36.5% by farmyard manure, 2.7% by recycled straw, 0.3% by seeds and minor amounts by rainfall. The P output amounted to 174,400 t, which was mainly the amount removed in the harvested crops. Under the assumption that no losses of P, especially by erosion and runoff on the sloping uplands occurred, the nutrient balance for P had a surplus of 36,100 t yr^{-1}(Table 12).

The input of K reached 331,500 t, of which 42.2 % were supplied by mineral fertilizers, 53.3 % by farmyard manure, 3.5% by recycled straw, 0.8 % by seeds and 0.2% by rainfall. The K output amounted to 835,000 t, mainly removed in the harvested crops, assuming no losses by runoff or leaching. Based on this assumption the difference between input and output revealed a deficit of 503,500 t K_2O yr^{-1} (see Table 12).

Conclusion

Based on a survey of the farmland nutrient cycle, current fertilization practice to major crops and the nutrient balance in paddy and upland fields was studied. The following aspects were observed and discussed in this paper:

1) A systematic knowledge was acquired about the application rate of mineral fertilizers, organic manure and straw per hectare for the major crops and their respective proportion in the total nutrient input to paddy and upland fields.
2) The farmland nutrient balance of the whole autonomous region of Guangxi indicates that the application rate of N and K was not enough to meet the crop demand. The deficit was 280,400 t and 507,900 t for N and K2O, respectively. P was tentatively oversupplied with a surplus of 241,100 t.
3) Considering the nutrient balance for the two main agricultural systems, paddy fields and upland fields separately, large differences occurred between the two systems.
4) The paddy fields had an apparent surplus of 51,900 t N and 139,600 t P2O5 and a deficit of 4,400 t K2O. This suggests that there was an excess of N and P which may have been additionally lost to the environment, posing certain risks of pollution.
5) In the upland fields, only a P surplus of 36,100 t was estimated whereas both N (-321,400 t) and K (-503,500 t) revealed a significant deficit in nutrient supply to crops.
6) The surplus of P may be overestimated and the deficit of N and K underestimated, taking into consideration that especially in the uplands, substantial nutrient losses by leaching, runoff and erosion generally occur which were not taken into account.
7) A large sector of other crops, e.g. fruits and vegetables which enjoyed a good growth in production during the past years, has not been taken into consideration in the nutrient balance calculations and may further affect the results of the survey, hence underestimate the total amount of the nutrients required.
8) Emphasis in future should hence be laid on a more precise anticipation of the nutrient cycles in the various cropping systems to improve and maintain the productivity and raise the efficiency of nutrient use.
9) The technique of balanced fertilization for sustainable agriculture needs to be further extended, so that the autonomous region of Guangxi needs additional 280,400 t N and 507,900 t K2O to maintain its current yields and to reach a nutrient balance.
10) It is predicted that Guangxi will have to increase the supply of mineral fertilizers by 7 - 10% annually to meet the demand for a sustainable crop production.

Changes in the supply of major nutrients in paddy soils and rational fertilization in Guangxi

Li Shaoquan, Zhang Jielu and Huang Shaofu

Guangxi Zhuang Autonomous Region Soil and fertilizers Station 530007

Abstract

The statistical analysis of 15 years of monitoring paddy soil fertility at 47 long-term monitoring posts in Guangxi revealed that under the current conventional production and management conditions, all the major nutrients in paddy soils show an upward trend, except for readily available K and slowly available K. Total N and alkali extractable N fraction rose the fastest. In calcareous paddy soils nutrients increased to a large extent whereas in high-yielding fields, soil nutrient contents mostly stagnated and some dropped slightly. The application rate of mineral fertilizers grew annually while that of organic manure decreased year by year. The ratio of mineral fertilizers vs. organic manure was 1:0.56 in the early 1980's and declined to 1:0.18 in the late 1990's. The N surplus in the soil was increasing and P changed from slightly deficient into a slight surplus during this period. The input of K had long been inadequate, increasing the K deficit in the soil substantially. On such a basis, it is suggested that the input of N and P has to be maintained and the K input has to be increased accordingly. The practice of growing green manure crops and of returning crop straw to the field has to be developed by taking advantage of the natural conditions. Furthermore, the technique of fertilization based on soil diagnosis has to be improved in order to increase the recovery of nutrients from fertilizers.

Introduction

Paddy soils constitute the majority of cereal producing land in Guangxi and accounts for 58.2% of the total cultivated land or 65.8% of the total area of cereal crops. The output of rice, however, comprises only 87.9% of the region's total grain output. It is therefore of important practical significance to build up a high-yielding paddy soil for promoting agricultural development. Guangxi has a climate which is characterized by warm temperatures and high precipitation, both occurring simultaneously, thus promoting plant growth but also intensifying mineralization, mobility and hence the leaching of soil nutrients. However, distinct regional characteristics in the climatic and soil conditions also lead to a variation in the cycling and balance of soil nutrients. Therefore, this paper attempts to describe the characteristics of the variation and cycling of the major nutrients in paddy soils for the typical agro-ecological regions where paddy is grown. For this purpose, 47 long-term experiments over a period of 15 years (beginning in 1984) were established to exploring approaches for rational fertilization.

Trend of changes in soil nutrients

The 15 years of soil fertility monitoring showed that under the current conventional production and management conditions the contents of all the major nutrients in paddy soils show an upward trend. With year as an independent variable and contents of soil nutrients as dependent variables, correlation analyses were carried out. Significant differences ($p = 0.01$) in the changes in nutrient contents over the years were identified (Table 1). Posts in which soil organic matter was rising accounted for 36.2% with an average rise of 0.06 % per year. Posts where total soil N was rising accounted for 66.6% with an average rise by 0.004 % per year; posts where soil alkali extractable N was rising accounted for 48.9% with an average rise of 6.3 mg kg^{-1} per year. The posts where soil readily available P increased accounted for 38.3 % with an average rise of 0.33 mg kg^{-1} per year. The content of alkali extractable N, readily available P, readily available K and slowly available K did not change much in soils of more than half of the posts. The average content of slowly available K even declined to a certain extend.

Table 1. Variation of major nutrients in paddy soils at 47 soil-fertility-monitoring posts

Parameter*	1984		1998		Increase		no change		Decrease	
	Range	Mean	Range	Mean	n	%	n	%	n	%
OM (g kg^{-1})	16.7-88.4	39.5	18.0~70.7	48.5	17	36.2	24	51.1	6	12.8
Total N (g kg^{-1})	0.93-3.52	2.38	0.95~4.41	3.0	31	66.0	14	29.8	2	4.2
Alkalytic N (mg kg^{-1})	92-257	181.5	112~607	275.2	23	48.9	24	51.1	0	0
Readily avail. P(mg kg^{-1})	1.4-56.5	11.9	3.0~54.0	16.9	18	38.3	26	55.3	3	6.4
Readily avail. K(mg kg^{-1})	1.0-195.0	65.6	29.0~337.0	82.2	11	23.4	29	61.7	7	14.9
Slowly avail. K(mg kg^{-1})	13.0-666.0	152.2	30.0~346.0	139.6	5	10.6	39	83.0	3	6.4

*: OM = organic manure, alcalytic N = 1.0 M NaOH incubation at 40 °C for 24 h, reflecting the available N pool

Nutrient contents in calcareous paddy fields are rising to a large extent

The soils in calcareous paddy fields are characterized by large amounts of calcium carbonate, high alkalinity and high clay content, thus having the ability to conserve nutrients. However, under conventional cultivation and management conditions, rice yields are low as affected by adverse factors, e.g. soil compaction imbalance Ca : K ratio, etc. As a result, the amount of nutrients removed in the harvested crop are relatively small and much of the nutrients accumulate in the soil. During the 15 years, soil nutrients in calcareous paddy fields increased to a great extent (Table 2). On the other hand, certain zonal paddy soils derived from similar parent material showed that conventional cultivation and management led to a removal of a large proportion of nutrients with the harvested crop, so that under these circumstances a nutrient accumulation did not occur.

Table 2. Variation of soil nutrients in paddy fields of different soils

Soil type	No. of posts	Year	pH	OM g kg^{-1}	Total N g kg^{-1}	Alkaline N mg kg^{-1}	R. a. P mg kg^{-1}	R.a. K mg kg^{-1}	S.a. K mg kg^{-1}
Calcareous soil	14	1984	7.9	39.5	2.38	181.5	11.9	65.6	152.2
		1998	7.8	48.5	3.00	275.2	16.9	82.2	139.0
Zonal soil	33	1984	6.0	33.0	1.73	151.5	12.3	44.3	104.9
		1998	6.0	34.6	2.00	234.3	14.3	73.1	116.1

Note: OM stands for organic manure, R.a. for readily available and S.a. for slowly available.

Nutrients in the soils of North-Eastern Guangxi are increasing to a large extent

In the north-eastern part of the province, it was the tradition that farmers used to grow green manure crops (like milk vetch, common vetch etc.) followed by ploughing the crop entirely or partly under before replanting in spring of the following year. This is an effective measure to build up soil fertility and soil nutrients. For instance, in Guilin in 35% of the paddy fields green manure crops are grown during winter. At the 4 monitoring posts in the area, soil organic matter increased from 3.11 in 1984 to 4.14% in 1998, and readily available P increased from 7.0 mg kg^{-1} to 15.6 mg kg^{-1}. In areas with little attention paid to growing green manure crops in winter and applying organic manure instead, soil nutrients in the paddy fields were on the decline. For instance, at Gusan monitoring post in Laibin County, a region that lagged behind in agricultural development, farmers used to manure traditionally before they began to use mineral fertilizers in 1984. Since then, they have replaced green manure and organic manure with mineral fertilizers. As a result, soil organic matter decreased from 3.57% in 1984 to 3.04% in 1998 or by 15%. Similar observations were made for the other nutrients to a varying extent.

Soil nutrients mostly stagnating or declining in high-yielding paddy fields

In 1995, the Beiliu City was named "Ton-Grain City" because its rice yields exceeded 15,000 kg ha^{-1}. In 1998, the city's rice yields averaged 15,825 kg ha^{-1}. High-yielding rice removes large amounts of nutrients from the soil. Fifteen years of monitoring showed that though the annual application rate of organic manure reached 18,000 kg ha^{-1} and that of mineral fertilizers 728.4 - 756.2 kg ha^{-1}, little changes in the soil nutrient status occurred (Table 3). The observation indicates that in high-yielding regions, soil management should not only maintain an adequate nutrient supply but also take care of the nutrient balance in order to secure the land's productivity for a sustainable farmland development.

Table 3. Changes in soil nutrients in high-yielding paddy fields in Beiliu City

Site	Year	OM ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Alkalytic N ($mg\ kg^{-1}$)	R.avail. P ($mg\ kg^{-1}$)	R.avail. K ($mg\ kg^{-1}$)	S.avail. K ($mg\ kg^{-1}$)
Longsheng	1984	39.8	1.49	153	20.0	49.0	127
	1998	31.6	1.66	201	17.0	52.0	270
Goulou	1984	28.5	1.49	107	13.6	28.0	37.0
	1998	28.5	1.60	165	16.0	53.0	71.0

*: OM stands for organic manure, R. avail. for readily available and S. avail. for slowly available.

Soil nutrient contents are increasing to a great extent in the suburbs of cities and economically developed regions

The monitoring of the soil fertility revealed that soil nutrients of paddy fields increased to a great extent in the vicinity of suburbs of cities and economically-developed regions. Because there the farmers have a high income and good access to agricultural inputs (especially to mineral fertilizers). The cities demand a wide range of agricultural products, which stimulates reasonable rotations and interrow cultivation. Rapid development of stock-raising widens the sources of manure. All this contributes to the build up of soil fertility in the suburban fields compared to those far from suburbs and the fields in the mountainous regions.

Law of the nutrient cycling and balance

The survey of 47 monitoring posts (Table 4) showed that with the rise in the application rate of mineral fertilizers, the rate of organic manure decreased simultaneously. The ratio between mineral fertilizers and organic manure dropped from 1:0.56 in the early 1980's to 1:0.18 in the late 1990's and at the same time, the returns from fertilization also declined. It was calculated that the crop response per kg of applied mineral nutrient dropped slightly from 8.57 kg in the early 1980's to 8.19 kg in the late 1980's, 7.78 kg in the early 1990's and 7.62 kg in the late 1990's, following the rule of diminishing yields with increased inputs.

Nutrient cycling

The degree of nutrient recycling is usually expressed by the percentage of nutrients returned in the form of organic material (including organic manure) to the field in relation to the total amount of nutrients consumed by the crop. The results of the monitoring posts revealed that in the early 1980's the proportion of organic material recycled to the paddy field was fairly high, about 35.59% of the total biomass produced and the mean nutrient recycling rate was 34.5%. The amounts of N, P and K applied in the form of organic manure accounted for 22.0%, 57.3% and 51.6%, respectively, of the total nutrient input. 27.9% of the N, 56.9% of the P and 36.1% of the K removed by the plants was returned to the field. In the late 1990's, however, the nutrient input in the form of organic manure accounted for only 15.2% and the nutrient recycling rate was declined to 15.0%. Then the amount of N, P and K applied in the form of organic manure accounted for only 8.8%, 18.2% and 25.9%, respectively, of the total nutrient input. At this time, only 11.9% of the N, 19.2% of the P and 17.0% of the K removed by the crops was recycled to the field.

Table 4. Nutrient input and nutrient removal during different periods

Period	Item		N	P_2O_5	K_2O	Total	$N:P_2O_5:K_2O$
				kg ha^{-1} yr^{-1}			
1984-1985	Input	Fertilizer	225.6	20.0	93.2	338.8	
		Manure	63.6	26.8	99.3	189.7	
		Total	289.2	46.8	192.5	528.5	1:0.16:0.67
	Removal (grains & straw)		228.3	47.1	274.8	550.2	1:0.21:1.2
1986-1990	Input	Fertilizer	253.4	24.8	114.3	392.5	
		Manure	63.3	21.8	100.4	185.5	
		Total	316.7	46.6	214.7	578.0	1:0.15:0.68
	Removal (grains & straw)		244.5	52.4	297.3	594.2	1:0.21:1.22
1991-1995	Input	Fertilizer	307.5	39.3	141.6	488.4	
		Manure	40.7	10.8	61.4	112.9	
		Total	348.2	50.1	203.0	601.3	1:0.14:0.58
	Removal (grains & straw)		252.3	49.4	300.1	601.8	1:0.20:1.19
1996-1998	Input	Fertilizer	318.8	39.9	144.0	502.7	
		Manure	30.6	8.9	50.4	89.9	
		Total	349.4	48.8	194.4	592.6	1:0.14:0.56
	Removal (grains & straw)		256.6	46.3	296.3	599.2	1:0.18:1.15

Table 5. Nutrient recycling in paddy fields in Guangxi

Period	NPK input by organic manure	NPK removal*	Nutrient recycling rate(%)			
			Total	N	P_2O_5	K_2O
	kg ha^{-1}					
1984-1985	189.7	550.2	34.5	27.9	56.9	36.1
1986-1990	185.5	594.2	31.2	25.9	41.6	33.8
1991-1995	112.9	601.8	18.8	16.1	21.8	20.5
1996-1998	89.9	599.2	15.0	11.9	19.2	17.0

Nutrient balance

The nutrient balance was calculated, using the nutrients removed by the crop as nutrient output and nutrients applied to the field (including mineral fertilizers and organic manure) as input. Results indicate that the $N:P_2O_5:K_2O$ ratio of the nutrient input in paddy fields in Guangxi was 1:0.14~0.16:0.56-0.67 (Table 4). Since 1984, the input of N has always been greater than the removal of N with the tendency that the surplus is becoming larger. By 1998, the N surplus reached 92.8 kg ha^{-1} yr^{-1}. Though the losses through volatilization and leaching were not assessed, the long-term effect of N lost to the environment cannot be ignored. Before 1990, the input of P was inadequate and now shows a slight surplus. The change has contributed to a positive P balance. Nevertheless, the recovery rate of P is still very small and the crop growth often shows that P supply is inadequate. The K input has long been inadequate. Although the problem of insufficient K supply slightly declined, the K deficit is still fairly large and was 101.9 kg K_2O ha^{-1} yr^{-1} in 1998. In many places, the application rate of organic manure has dropped rapidly and caused that an important K source, e.g. by recycling straw, is ignored. As a result, soil K did not accumulate, causing that the soil K fertility is fluctuating around the medium to low supply level.
The monitoring in the recent years has also shown that the application of more organic manure has increased the K uptake by the crop (particularly in the rice straw) and also the P uptake (particularly in grains), indicating the important effect of organic manure in improving the fertilizer recovery and the grain-formation of rice.

Rational fertilization

Rational fertilization is the integration of soil, crop and fertilizers designed to achieve an optimal output with an input level that is both the most economical and the most reasonable. Based on the long-term monitoring of soil fertility, crop responses of different crops to different fertilization systems in different soils can be assessed.

High-yielding soils and fertilization

The results of 23 monitoring posts in paddy fields (termed locally as Ton-Grain Field) with rice output beyond 15,000 kg ha^{-1} revealed that the soils from the paddy fields had a pH of 6.38 contained 3.83% organic matter, 0.219% total N, 18.3 mg kg^{-1} readily available P, 76.0 mg kg^{-1} readily available K. The features of high-yielding fertilization (Table 6) are: 1) The total application rate is high, about 34.1% larger than the average of all the monitoring posts. The larger nutrient application increased yields by about 35.3%. 2) The proportion of nutrients applied in the form of organic manure is high, especially P and K, accounting for about 50%, respectively. 3) The K application rate is high, with an N:K ratio of 1:0.75-0.78, significantly larger than that in other monitoring posts.

Table 6. Fertilization practice in high-yielding paddy fields

Crop	Yield (kg ha^{-1})	Nutri-ent source	Application rate (kg ha^{-1})				$N : P_2O_5 : K_2O$
			N	P_2O_5	K_2O	Total	
Early rice	8380.5	M.F.	156.3	21.0	72.0	249.3	1 : 0.13 : 0.46
		O.M.	57.6	18.8	88.2	164.6	1 : 0.33 : 1.53
		Total	213.9	39.8	158.9	413.9	1 : 0.18 : 0.75
Late rice	7837.5	M.F.	155.9	19.8	74.1	249.8	1 : 0.13 : 0.48
		O.M.	39.8	12.5	78.8	131.1	1 : 0.31 : 1.98
		Total	195.7	32.3	152.9	380.9	1 : 0.16 : 0.78

O. M. = organic manure, M. F. = mineral fertilizer

Major problems in the current fertilization practice

Significant difference in fertilization between regions

The study reveals that in the eastern part of the province, Yulin, Guilin and Wuzhou, 600 - 700 kg ha^{-1} of nutrients were applied to high-yielding paddy fields whereas in the western part of the province (Baise and Hechi), application rates were much reduced and even less than 200 kg ha^{-1} in certain places. The paddy fields in the western part were accordingly much smaller. On the other hand, high fertilizer application rates, especially large blanket dressings of N and P, may lead to poor nutrient recovery and can cause environmental pollution. This was observed in Lingui County, where the readily available P content were already reaching 28.1 mg kg^{-1} and only very insignificant response of 1.8% yield increase compared to the NK treatment was found.

Low proportion of organic manure in fertilization

In the past twelve years, the amount of organic manure used in the province decreased at a rate of 15% annually. For instance, the monitoring post at Pingguo County Agricultural Research Institute reported that before 1990, the annual application rate of organic manure reached 12,600 kg ha^{-1} and dropped to 4,950 kg ha^{-1} in 1995. The inadequate application of organic manure reduced soil fertility and affected returns from mineral fertilization, probably due to a combination of unbalanced nutrient supply and reduced nutrient retention capacity of the soil.

Inadequacy of K nutrient and nutrient imbalance

In Guangxi, poor K availability in paddy soils in addition to inadequate K input disturbs the NPK balance of the soil-plant system, which mainly causes reductions in yields. Recent field experiments revealed that a production of 12,000 kg grain ha^{-1} of a hybrid rice variety needs to absorb at least 278.4 kg K_2O whereas the average K application rate in the studied area was only 192.5-214.7 kg K_2O. By continuously removing more nutrients from the field than replacing by fertilizers, soils become depleted of K and K deficiency becomes increasingly prominent.

Recommendations for rational fertilization

Though Guangxi's fertilization level of paddy fields exceeds that of the country's average and inputs of N and P seem to be in balance with the outputs. Nevertheless, additional efforts have to be paid to improve the nutrient supply to paddy. This particularly applies to the poor P recovery rate and to the fact that soil P varies strongly from place to place and the P deficient area is still quite large. Therefore, P application needs to be further improved both in quantity and quality of application. The inadequate use of K fertilizer calls for an improved K supply both through mineral fertilizer and through organic manure. The strategy for future fertilization has to put emphasis on increasing K input while keeping up N and P application rate and readjusting the N:P:K ratio from the current 1:0.12:0.45 to 1:0.14~0.15:0.48~0.50. In Guangxi, the natural conditions are favourable for developing green manure and for returning straw to recycle the nutrients to the field. It is expected that through the development of dual-purpose green manure, such as "green manure cereals, green manure oil crops and green manure vegetables", the area of green manure grown in winter can reach over 500,000 ha and the area used for returning straw over 1,000,000 ha. Together with the application of farmyard manure, the recycling rate of nutrients can reach around 40% of the total nutrient removed by the crops.
In view of differences in soil and crop type, full use should be made of modern soil and plant testing methods towards a diagnosis-based fertilization. Through fertilizer experiments and the soil fertility monitoring during the past 24 years, the soil and fertilizers administration in Guangxi has developed the "Guangxi Soil Diagnosis and Fertilization Software System". With such a system, predictions of target yields and fertilization recommendation can be conducted. During the four years of practice, from 1995 onwards, it was demonstrated that the technology of soil diagnosis and fertilization based on this system can increase the fertilizer recovery rate by 7.2 % and the economic benefit by about 10%.

Trends of changes in the farmland nutrient status in the Hainan Province and suggested methods for improvement

Chen Li

Hainan Province Soil and Fertilizers Station 570203

Farmland nutrient status

Organic matter and nitrogen contents

Of the farmland in the province, about 49.9% is relatively poor in soil organic matter. Soils are mainly percogenic paddy soils along the coast derived from shallow marine sediments and submerged paddy soils in the mountainous region in the center of the province. Paddy soils with poor total N status account for 52% of the cultivated land whereas areas deficient in readily available N are in the order of 55% (Table 1).

Table 1. Farmland soil organic matter and N contents in the Hainan Province (1000 ha)

Item	O.M. (g kg^{-1})			Total N (g kg^{-1})			Alkalytic N (mg kg^{-1})		
	> 20 high	10- 20 med.	< 10 low	>1 high	1- 0.5 med.	< 0.5 low	> 90 high	60-90 med.	< 60 low
Area (1000 ha)*	381.8	280.0	100.6	360.4	311.6	89.9	410.0	176.0	196.6
Area (%)	50.1	36.7	13.2	47.3	40.9	11.8	53.8	23.1	25.8

* based on a total sown area of 762 000 ha in 2001

Phosphorus contents

Analysis revealed that overall farmland has a relatively poor P status. The total soil P pool is inadequate and readily available P can be classified as insufficient. The farmland, deficient in soil P, accounts for 68% of the total acreage (Table 2).

Table 2. Farmland soil P in the Hainan Province (1000 ha)

Item	Total P (g kg^{-1})			Readily available P (mg kg^{-1})		
	> 0.14 high	0.9 - 0.14 med.	< 0.9 low	> 20 high	10 - 20 med.	< 10 low
Area (1000 ha)*	48.0	71.6	642.4	67.1	173.7	521.2
Area (%)	6.3	9.4	84.3	8.8	22.8	68.4

* based on a total sown area of 762 000 ha in 2001

Potassium contents

Total K in the province's farmland varies between < 9 and > 18 g kg^{-1} of which the majority of 44.6% of the area has a poor K status. These soils, poor in K, are derived mainly from basalt and shallow marine sediments. Looking at the readily availably K in the soil indicates that only 13% can be classified as being high (>100 mg kg^{-1}) whereas more than 86% of the soils show a medium or poor K availability (<100 mg kg^{-1}). 61% of the area may be regarded as seriously K deficient (Table 3).

Table 3. Farmland soil K in the Hainan Province (1000 ha)

Item	Total K (g kg^{-1})			Readily available K (mg kg^{-1})		
	>18 high	9 – 18 med.	<9 low	>100 high	50 - 100 med.	<50 low
Area (1000 ha)*	282.7	139.4	339.8	100.6	195.1	466.3
Percentage	37.1	18.3	44.6	13.2	25.6	61.2

* based on a total sown area of 762 000 ha in 2001

Separate analysis for P and K has been carried out in the irrigated lowland soils meant for rice cultivation (Table 4). The results indicate a very poor supply of the lowland soils with P and K. Only one soil, Honghetu, derived from granite substantially exceeded in the critical soil P levels for poor supply of > 10 mg kg^{-1} as given in Table 2.

Table 4. Nutrients in submerged paddy soils in the Hainan Province

Soil genus	Parent material	*N**	Total P g kg^{-1}	Avail. P mg kg^{-1}	Total K g kg^{-1}	Avail. K mg kg^{-1}
Zini	Purplish sandshale	9	0.5	14.3	10.6	52
Carboniferous Heini	Shallow marine sediments	25	0.25	4.4	3.7	26
Chitu	Basalt	270	1.17	7.9	2.8	35
Huoshanhui	Pumilith	17	0.8	12.1	3.2	51.9
Heshani	River alluvium	120	0.4	14	16	44
Chashani	River alluvium	341	1.02	14	22.7	44
Niruo	River alluvium	121	0.86	11	19	44
Hongchitu	Granite	419	0.45	12.8	23.3	56.3
Honghetu	Granite	10	0.36	80	32.2	163
Yechitu	Sandshale	438	0.64	6.5	10.1	51.3
Yehechitu	Sandshale	3	0.26	9	3.08	66
Anchitu	Andesite	2	0.35	6	36.3	60
Anhechitu	Andesite	1	0.36	4	3.12	46

*Number of sites analysed

The same is true for potassium, where only the Honghetu soil significantly exceeded the critical level of > 50 mg kg-1 (as classified in Table 3), all the other soils analysed were clearly below or just at that level of K supply.

Trend of changes in farmland soil nutrients

The long-term stationary monitoring of soil fertility in the province showed that soil organic matter and soil K have been declining in recent years. In areas, such as Qionghai and Haikou, where the rotation of rice-vegetables is popular, successive years of applying highly-concentrated compound fertilizers (15-15-15) has caused that P accumulated in the soil, showing an upward trend. In double-cropping rice growing areas, such as Dingan and Qiongzhong, soil P displays a downward trend. The major cause for the difference is whether or not P straight fertilizers and/or compound fertilizers, containing P were used (Table 5).

Table 5. Changes in soil nutrients

Site	Year	Drop in O.M.		Drop in readily available P		Drop in readily available K	
		%	g kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}
Qionghai	1991-1995	69	0.78	38	1.96	77	6.22
Province	1990-1992	55	1.3	62.7	2.64	70.6	5.24

Table 6. Effect of cultivation system on farmland soil nutrients in BeiPo,Wanning City

Location	Rotation	Year	O.M.	Total N	Alkaline N	R.avail. P	R.avail. K	pH
			----- g kg^{-1} -----		--------- mg kg^{-1} -----------			
Shuibianyang	Rice-fruit	1989	31.7	1.77	129	10	60	5.5
		1995	20.1	1.04	90.3	28.8	34.9	5.2
		Rate*	1.93	-0.12	-6.45	3.13	-4.18	-0.05
Danaiyang	Rice-cash crop (sugarcane)	1990	21.5	1.62	109.0	13	53	5.3
		1995	16.2	0.89	87.8	13.7	51.7	5.4
		Rate*	-1.06	-0.146	-4.24	0.14	-0.26	0.02
Shuibianyang	Double rice	1985	31.7	1.77	129	10	60	5.5
		1995	24.9	1.06	87.3	4.4	34.2	4.8
		Rate*	-0.68	-0.071	-4.17	-0.56	-2.58	-0.07
Lichunyang	Double rice	1985	32.1	1.52	163	9.9	90	5.4
		1995	24.3	1.42	122	4.6	74.3	5.1
		Rate*	-0.78	-0.01	-4.1	-0.53	-1.57	-0.03

The effect of the cultivation pattern on soil nutrients (Table 6) also clearly explains the trend of changes. For instance, in Shuibianyang, Beipo Town, Wanning City, in the rice-fruit rotation, after guava was grown on the farmland of Chaoshani, all the soil fertility parameters showed a deteriorating trend. Except readily available P, which increased due to the use of compound fertilizer in fruits, the other soil fertility indicators decreased greatly with an annual rate of 1.93 g kg^{-1} in organic matter, 0.12 g kg^{-1} in total N, 6.45 mg kg^{-1} in alkalytic N and 4.18 mg kg^{-1} in readily available K. The rotation of rice-fruit or rice-cash crop (sugarcane) and double cropping rice produced a similar effect.

The change of farmland into orchard or sugarcane field improves the soil nutrient status temporarily. As a result, soil bioactivity is strengthened, thus accelerating decomposition and mineralization of soil organic matter, total N and K. At the same time, the two types of crops demand large amounts of K and farmers do not pay much attention to the application of N and K fertilizers, so N and K contents in the soil often show a downward trend.

Analysis of the fertilisation in the province shows that the gap between areas well and those poorly supplied with nutrients is widening. In 1997, the application rate was the highest in the coastal area and the suburbs of cities, such as Nongken (1,166 kg ha^{-1}), Wanning (965 kg ha^{-1}) and Sanya (864 kg ha^{-1}), and the lowest in the minority regions and poverty-stricken areas, such as Tongshi (182 kg ha^{-1}) and Changjiang (148 kg ha^{-1}), where nutrient deficiency is rather common. The average application rate in the province was 520 kg ha^{-1}.

The application rate also varies with the crop. At the time of the survey, it was 352 kg ha^{-1} for cereals, 880 - 1,500 kg ha^{-1} for vegetable and 3,246 kg ha^{-1} for banana. Farmland nutrients are likely to display a declining trend in paddy fields that have long been cultivated with rice but have not received enough fertilizers in the past. Soils of land cultivated by crops like winter melon, vegetable and banana may also show a downward trend in nutrients where fertilizers are not duly supplemented (Table 7).

Table 7. Application rate, varying according to crops (kg ha^{-1})

Crop	Yield (kg ha^{-1})	Application rate (kg ha^{-1})				$N : P_2O_5 : K_2O$ ratio
		Total	N	P_2O_5	K_2O	
Rice	4,500	352	161	69	122	1 : 0.42 : 0.75
Pepper	52,500	1,470	682	428	360	1 : 0.62 : 0.53
Wax melon	90,000	1,015	295	304	417	1 : 1.03 : 1.4
Water melon	30,000	880	295	259	326	1 : 0.9 : 1.1
Banana	60,000	3,247	716	506	203	1 : 0.7 : 2.8

Approaches to improve farmland nutrient management

Principle

The aim of improving the soil supply of nutrients is to increase the yield of crops and build up soil fertility as well as to reduce possible pollution to the soil and environment at the same time. Therefore, the following aspects should be taken into consideration:

Characteristics of the nutrient demand of crops (temporal and quantitative requirement during the cropping season), soil nutrient supply capacity, nutrient availability, the nutrient balance (input : output) and replacing the nutrient removals/losses by a combined application of organic manure and mineral fertilizers.

Measures

To improve nutrient supply by the soil, it is necessary to increase nutrient input by fertilisation and to increase the effectiveness of nutrients applied by taking into account the nutrient pools and the nutrient retention capacity of the soil. Through this nutrient losses can be avoided.

Extension of the technique of returning straw to the field

Currently, in the coastal regions, in combination with the extension in the use of harvesting machines, the technique of returning chopped straw to the field through the harvester is studied. In hilly and mountainous regions, straw is returned to the field by leaving long stubs (over 40 cm) in the field to reduce soil and nutrient losses by runoff and erosion. The long stubs are either plowed into the soil or used as mulch. In the light of the characteristics of the farming system of "three crops per year", emphasis is placed on techniques to speed up the decomposition of the straw in the field, mainly by extending the use of bacterial agents, such as *Fugenling* and *saccharomycetes*.

In the period from 1994 to 1998, the Hainan Province Soil and Fertilizers Station carried out demonstration experiments on returning straw to the field in a paddy field of Shani in WenYuan Dongyang, Longgun Town, Wanning City. The field of the demonstration experiment with an area of 26.7 ha received 4,500 kg ha^{-1} fresh straw, 600 kg ha^{-1} quality lime and 150 kg ha^{-1} potassium chloride. The yields were 7,162 kg ha^{-1} rice, about 757 kg ha^{-1} or 10.5% larger than in the adjacent fields without straw return (6,405 kg ha^{-1}). Pot experiments showed that rice yields could be increased between 3.9% and 17.4% by the use of rice straw (Table 8).

Table 8. Effect of returning straw to the field on yield and economic properties of rice

Treatment*	P. height cm	Effective ears ha^{-1} x 1000	Grains/ear	Bearing rate %	Yield kg ha^{-1}	Yield increment %	
A	115	280.8	97.3	97.3	7507.5	1111.5	17.4
B	113	288	85.2	68.3	6771	375	5.9
C	110	262.8	89.7	72.4	6646.5	250.5	3.9
CK	103	255.6	82	66.8	6396		

*Note: Treatment A: 4,500 kg straw + 600 kg lime powder + N=138 kg; P_2O_5=42 kg; K_2O=90 kg ha^{-1}; Treatment B: 4,500 kg straw + 600 kg lime powder + N=82.5 kg; P_2O_5 22.5=kg; K_2O 54=kg ha^{-1}; Treatment C: 4,500 kg straw + 600 kg lime powder + N=138 kg; P_2O_5=42 kg ha^{-1}; CK: N=138 kg; P_2O_5=42 kg; K_2O=90 kg ha^{-1}.

After four successive years of returning straw to the field, the soil organic matter content, total N and readily available K increased by 14.5%, 3.8% and 22.6%, respectively, whereas soil pH slightly decreased.

Extension of wet–dry cultivation patterns mainly as rice-winter melon (vegetable)

Many years of practice have shown that by taking advantage of climate (radiation and temperature) in Hainan Province, the extension of multi-cropping cultivation patterns such as "rice-rice-vegetable" or "rice- winter melon (vegetable)" can lead to benefits in the following aspects:

1) Increase in returns. According to preliminary statistics, in the period from the winter of 1985 to the spring of 1996, the rotation system of "rice-vegetable" over an area of 47,466 ha produced a total output value of 3.05 billion Yuan (372 M USD) and a net profit of 1.68 billion Yuan (205 M USD), about 1.41 billion Yuan (172 M USD) more than the rotation system of "rice-rice". The annual total output value of the rotation system of rice-winter melon (vegetable) can reach 64,338 Yuan ha^{-1} (7846 USD ha^{-1}) whereas that of "rice-rice" only achieves 11,393 Yuan ha^{-1} (1389 USD ha^{-1}).
2) Increase in fertilizer input. According to a survey, in the rotation system of "rice-rice" the mean annual application rate of organic manure was approx. 13 t ha^{-1}. It dropped below 4.5 t ha^{-1} or even to zero application in certain areas. On the other hand, in rice-vegetable rotation system, the annual application rate of organic manure was 25 t or even 37 t per hectare and year. In the winter crop alone 11.35 - 22.5 t ha^{-1} of manure were applied. Mineral fertilizers show a similar pattern. In the rotation system "rice-vegetable", the application rate per crop was 377 kg, about 142 kg or 60% more than in the "rice-rice" rotation. The use of compound fertilizers increased to the greatest extent, reaching 112 kg ha^{-1}, comprising 17 kg ha^{-1} in N, 8 kg ha^{-1} in K and 4 kg ha^{-1} in P.
3) Increase in soil nutrients. The increase in input of organic manure significantly improved the soil nutrient status. According to the analysis of soil samples from Sanya, Danzhou, Chengmai and Wanning, in fields cultivated for 5 - 8 years by a rice-winter vegetable rotation, soil organic matter increased at a rate of 0.06 - 0.68 g kg^{-1}, readily available P at 0.02 - 3 mg kg^{-1} and readily available K at 0.42 - 11.5 mg kg^{-1} annually (Table 9).

Table 9. Effect of duration of cropping by different rotation systems on the changes in the soil nutrient status (expressed as change compared to the beginning of the rotation)

Site	No. of	O.M.		Total N		Readily av. N		Readily av. P		Readily av. K	
	years	g kg^{-1}	%	g kg-1	%	mg kg^{-1}	%	mg kg	%	mg kg	%
Sanya	5	0.3	1.54	0.08	4.9	0	n.d.	0.1	3.1	2.8	2.2
Danzhou	7	1.9	14.1	0.18	29.0	0	n.d.	0.9	29.0	3.0	15.0
Chengmai	6	1.3	4.9	0.3	20.0	5.0	7.4	8.0	114.0	69.0	627
Wanning	8	4.9	35.3	0	n.d.*	24.6	31.5	24.1	142.0	80.0	1333

Note: O.M. stands for organic matter, and R.A. for readily available.

Fertilization guided by scientific principles

Currently the recommended formula for fertilization of farmland in the Hainan Province is 90 - 120 kg N, 45 - 75 kg P_2O_5 and 69 kg K_2O per crop ha^{-1} at an N : P_2O_5 : K_2O ratio of 1:0.45:0.8, depending on crop type and yield expectation. Though this is a very rough method, the recommended fertilizer rates usually lead to larger yields than the conventional practice by farmers (Table 10).

Table 10. Demonstration of fertilization based on recommended formula

Site	Year	*n*	NPK ratio	Yield	Increment over conventional	
			N : P_2O_5 : K_2O	kg ha^{-1}	kg ha^{-1}	%
Qionghai	1990	12	1 : 0.46 : 0.9	5430	675	14.4
	1991	111	1 : 0.56 : 0.7	5946	563	10.5
Dongfang	1991	3	1 : 0.12 : 0.8	5910	1080	22.4
Lingao	1988-1991	37	1 : 0.46 : 0.65	5818	515	9.7
Tunchang	1991	2	1 : 0.41 : 0.7	4347	458	11.8
Chengmai	1991	1	1 : 0.5 : 0.8	7770	503	6.9
Qiongshan	1991	4	1 : 0.44 : 0.72	5814	781	15.5
Dingan	1991	1	1 : 0.53 : 0.93	5850	810	16

To improve and maintain the soil nutrient status of farmland in the Hainan Province, the following recommendations are made:

1) application rate for one crop of rice should be adjusted to 120 - 150 kg N, 60 - 75 kg P_2O_5 and 150 -180 kg K_2O per hectare with a ratio of 1:0.5:1.2, which has shown to be more appropriate than the above.
2) In the fields under the rice-winter vegetable rotation, the preference of the farmers for 15-15-15 compound fertilizers has caused P accumulation in the soil. It is therefore recommended to control the rate of P and increase the rate of K by either additional straight fertilizer application or a change in the formulas towards larger K and smaller P contents.
3) A rotational fertilizer application system is recommended that puts greater emphasis on the supply of P and K to the vegetable crop in the rotation which is more nutrient demanding than the cereal preceding or succeeding the vegetables. In this respect, larger amounts of K can especially improve quality of the seedlings, the flowering rate and hence increase yields.

In order to improve fertilization techniques and to raise the recovery rate of fertilizers, the following points deserve more attention:

4) Raising the proportion of mineral fertilizers as basal dressing and mixing them well with the soil to ensure a continuous nutrient supply and higher recovery rate. Extending fertilisation techniques like deep placement.
5) Applying N with in water suspensions or watering immediately after broadcasting of N fertilizer to reduce volatilisation losses of nitrogen fertilizers.

6) Larger amounts of P should be applied to the upland crops and less to lowland irrigated rice cultivation. Blending of organic material with P fertilizers in composts has shown good results and should therefore be extended.
7) Using site-specific fertilizer forms, e.g. ammonium-N-based mineral fertilizers to irrigated rice fields and nitrate-N-fertilizers to upland fields.

Prediction of the fertilizer demand

The prediction of the demand for fertilizers depends on the need of agriculture for sustainable development and the economics of fertilizer use (fertilizer prices, crop prices etc.). According to the statistics in the province from 1985 to 2001, the consumption of N fertilizers rose by 29%, that of P fertilizers by 182%, that of K fertilizers by 420% and that of compound fertilizers by 840% (Table 11).

Table 11. Consumption of mineral fertilizers in the Hainan Province (1000 t)

Year	Total	N	P_2O_5	K_2O	Compound fertilizer	$N : P_2O_5 : K_2O$
1985	105.6	69.0	21.6	5.0	10.0	1 : 0.31 : 0.07
1990	136.4	78.2	13.2	15.0	30.0	1 : 0.17 : 0.19
1995	172.6	78.2	14.2	18.9	60.0	1 : 0.18 : 0.26
1997	211.9	92.9	30.0	23.6	75.4	1 : 0.32 : 0.25
2001	270.0	89.0	61.0	26.0	94.0	1:0.68:0.29

Based on the increase in fertilizer consumption of the past, the orientation of the agriculture in the province in the years to come, it is predicted that the supply of mineral fertilizers will reach 349,000 t in 2005, of which N fertilizers will be 110,000 t, P fertilizers 44,000 t, K fertilizers 55,000 t and compound fertilizers 140,000 t at an $N : P_2O_5 : K_2O$ ratio of 1:0.40:0.50.

Chapter IV

On-site studies of farmland nutrient balances and rational fertilization

Balanced nutrition and nutrient balances in irrigated rice: A case study in the Zhejiang Province, PR China

C. Witt[1], G. Wang[2], A. Dobermann[1,3], Q. Sun[4], and R. Fu[5]

[1] International Rice Research Institute (IRRI), DAPO Box 7777, Metro Manila, Philippines
[2] Zhejiang University, Hangzhou, P.R. China
[3] University of Nebraska, Department of Agronomy, Lincoln, NE 68583-0915, USA
[4] Agricultural Research Station, Jinhua, Zhejiang, P.R. China
[5] Agricultural Technical Extension Station, Jinhua, Zhejiang, P.R. China

Abstract

Plant based performance indicators were successfully used in on-farm and on-station experiments to develop, evaluate and refine a novel site-specific nutrient management (SSNM) strategy in Jinhua, Zhejiang Province. With SSNM, current average rice yields of about 6 t ha^{-1}, representing only 60% of the yield potential, were raised in farmers' fields by about 0.5 t ha^{-1}, resulting in profit increases of 88 US$ ha^{-1} $crop^{-1}$. Yield increases were achieved with improved splitting and timing of N applications reducing fertilizer N needs by 21%. In contrast to the farmers' fertilizer practice, less N was applied with SSNM early in the season while fertilizer N supply was increased during the time of greatest plant demand between tillering and panicle initiation. Results indicate that several parameters would need to be measured to fully evaluate and fine-tune balanced nutrient management strategies. Fertilizer N, P and K requirements in the SSNM approach are largely based on the attainable yield gain over a plot without application of the fertilizer nutrient of interest (omission plot). We consider the agronomic N efficiency (grain yield increase per unit fertilizer N) as the most practical parameter for the development and evaluation of N management strategies in extension. Omission plots can be used to both relate fertilizer requirements to yield increases and visually demonstrate nutrient limitations to farmers. Where a direct yield response to fertilizer P and K application is less clear, the SSNM approach recommends maintenance rates that are based on a simple nutrient balance model for irrigated rice. On-farm measurements of nutrient balances, however, probably supply limited information, regarding the risk of nutrient depletion, unless combined with estimates of medium- or long-term changes in indigenous nutrient supplies.

Introduction

Considerable progress has been made in recent years in developing field- and season-specific nutrient management approaches, as alternatives to blanket recommendations for NPK fertilizers (Dobermann and White, 1999; Balasubramanian et al., 1999; Dobermann and Fairhurst, 2000; Wang et al., 2001; Dobermann et al., 2002). These site-specific nutrient management (SSNM) approaches have been widely evaluated in farmers' fields in Asia and were recently refined and simplified into tools and guidelines for the participatory development of improved nutrient management in Asia's irrigated rice systems (Witt et al., 2002b; Dobermann et al., 2003c). Wider scale delivery will also require a framework for participatory evaluation used by extension to ensure that disseminated nutrient recommendations are scientifically sound and meet farmers' needs. A large number of well defined criteria have been used by researchers in the evaluation of nutrient management strategies in irrigated rice (Cassman et al., 1998; Dobermann et al., 2003a). A major challenge for the extension sector is to select those criteria which are crucial for both the development and bio-physical evaluation of improved SSNM management strategies.

Thus, the major objectives of this paper are:

- to summarize the principles of site-specific nutrient management,
- to present the conceptual framework of plant based indicators used by researcher in the evaluation of nutrient management strategies, and
- to evaluate the proposed framework of plant based indicators comparing the site-specific nutrient management approach with the farmers' fertilizer practice, using data from on-station and on-farm experiments in Jinhua, Zhejiang Province.

The principles of site-specific nutrient management (SSNM)

The SSNM principles offer a basic plan for a pre-season calculation of balanced fertilizer rates, considering the deficit between plant nutrient requirement and soil nutrient supply. Soil nutrient supplies can be indirectly estimated as plant nutrient uptake or grain yield in nutrient omission plots (Dobermann et al., 2003b; Dobermann et al., 2003c). A nutrient omission plot receives all nutrients applied as fertilizer in ample amounts except for the nutrient of interest. For example, a nitrogen omission plot would receive fertilizer P and K in sufficient amounts but no fertilizer N. Plant based estimates of soil nutrient supply integrate the supply of all indigenous sources estimated *under field conditions* and also offer the possibility for estimating the nutrient supplying power of organic manures, irrigation water and biological N_2 fixation. A major advantage of this approach is that the soil supply is expressed as nutrient limited yield, i.e. in a unit that can be directly used in the calculation of fertilizer requirements. Fertilizer requirements largely depend on the expected yield gain, which we define as the required yield increase over the nutrient limited yield to reach a season-specific yield goal. To consider differences in soil supply among nutrients, yield gains have to be estimated for N, P and K separately. For example, if the nutrient limited yield was 5 t ha^{-1} for P and 6 t ha^{-1} for K as measured in omission plots, the required yield increases to achieve a yield goal of 6 t ha^{-1} would be 1 t ha^{-1} for P and 0 t ha^{-1} for K. Thus, fertilizer P rates would have to be sufficiently high to support the required yield increase whereas preventive fertilizer strategies would focus on replenishing most of the crop nutrient removal to maintain soil K supplies. As a 'rule of thumb', we estimate that 40-50 kg fertilizer N, 20 kg P_2O_5 or 30 kg K_2O would be required to raise the respective nutrient limited yield by 1 t ha^{-1} (Witt et al., 2002b; Witt and Dobermann, 2003). The fertilizer N requirement was based on field measurements, indicating that an agronomic efficiency of 20-25 kg grain kg^{-1} fertilizer N can be achieved with good N management. For comparison, about 60 kg fertilizer N per ton grain yield increase would be required, if an agronomic efficiency of only 16-17 kg grain per kg fertilizer N can be achieved due to less favorable growing conditions.

These principles only provide a basic plan for the development of balanced fertilizer rates. Local adaptation and participatory evaluation is particularly required for the development of suitable N management strategies. Asian farmers generally apply fertilizer N in several split applications, but the number of splits, amount of N applied per split and the time of application varies substantially even within small domains. The apparent flexibility of rice farmers in adjusting the time and amount of fertilizer application offers great potential to synchronize N application with the real-time demand of the rice crop. There are probably three major practical forms of N management recommendations, namely (a) location-specific split schedules for preventive N management, (b) corrective N management using a leaf color chart (LCC) or chlorophyll meter (SPAD), and (c) a combination of both in which LCC or SPAD are used at certain growth stages to identify the need for fertilizer N ('split N + LCC' or 'split N + SPAD'). Details of these approaches are described elsewhere (Balasubramanian et al., 1999; Dobermann and Fairhurst, 2000; Yang et al., 2003). The most suitable strategy for a particular site probably depends as much on bio-physical conditions (e.g., season-to-season variation in climate) as on socio-economic factors (e.g. number of field visits, labor input).

Finally, information on soil nutrient supply is of particular importance for the commonly less limiting macronutrients P and K, because of i) uncertainties in short- and medium-term crop responses to P and K application and ii) limited options for an immediate correction of these deficiencies within one season as compared to N. In general, P and most K should be applied early in the season for greatest efficiency and to avoid nutrient deficiencies at early growth stages. We propose to install a limited number of nutrient omission plots in recommendation domains, i.e. areas with a common cropping system and similar soil types and topography to help extension workers in developing an improved understanding of the local distribution of soil fertility in partnership with farmers (Dobermann et al., 2003b; Dobermann et al 2003c). Furthermore, the yield gain concept was refined to offer simple rules on fertilizer requirements that aim at medium-term strategies in the adjustment of soil P and K supplies (Witt and Dobermann, 2003). This improved approach considers the soil indigenous nutrient supply as the status quo and takes more information (e.g. on straw management) into account when developing fertilizer P and K requirements. Local adaptation and refinement of these generic principles may be required integrating other research findings, e.g. on the soil P and K supplying capacity as determined in long-term experiments.

Conceptual framework for the development and evaluation of SSNM

In the following, we briefly discuss the conceptual framework used by researchers to assess the agronomic and economic performance of site-specific nutrient management (SSNM) in comparison to the farmers' fertilizer practice (FFP). Further information is provided elsewhere (Cassman et al., 1998; Dobermann et al., 2003a). In addition to yield and gross return over fertilizer cost (GRF, revenue minus fertilizer cost), we used plant nutrient accumulation, nitrogen use efficiencies and nutrient balances in treatment and/or nutrient omission plots to answer the following, more specific questions:

1. What is the respective yield response to fertilizer N, P and K application?
   Yield response to fertilizer application is an important indicator for the need to apply fertilizer nutrients particularly for fertilizer N. It may be advisable to apply fertilizer P and K even if a yield response was not expected (maintenance application), e.g. if there is evidence that soil indigenous nutrient supply would rapidly decline without replenishing P and K removed with grain and straw.
2. Is the plant uptake of N, P and K sufficient to achieve the targeted yield?
   The plant N, P and K requirements of rice have been described using the model

"Quantitative Evaluation of Fertility of Tropical Soils" (QUEFTS) (Janssen et al., 1990; Witt et al., 1999). Under optimal conditions, the nutrient requirement of rice is about 14.7 kg N, 2.6 kg P and 14.5 kg K per 1000 kg of grain. Nutrient requirements will increase for yields beyond 70-80% of the yield potential. Nutrient requirements can also be expressed as grain yield per unit plant nutrient accumulation at physiological maturity (internal nutrient efficiencies):

- Internal nutrient efficiencies for grain yield production (IEN, IEP, IEK)

$$IEX = GY / UX \qquad \text{[equation 1]}$$

  where IEX is the internal nutrient efficiency in kg grain kg^{-1} plant nutrient; X is the nutrient N, P or K, GY is grain yield in kg ha^{-1} and UX is the plant nutrient in the above-ground dry-matter in kg ha^{-1} at physiological maturity of rice. The corresponding optimal values are 68 kg grain kg^{-1} plant N, 385 kg grain kg^{-1} plant P and 69 kg grain kg^{-1} plant K.

3. Are fertilizer nutrients used efficiently?

   Fertilizer use efficiencies include agronomic, physiological and recovery efficiencies and are most important for the evaluation of fertilizer N management strategies. Fertilizer use efficiencies are less crucial for the evaluation of fertilizer P and K strategies, because their management may not only aim at overcoming a nutrient deficit, e.g. if maintenance applications are required to avoid medium- or long-term nutrient depletion term. However, fertilizer P and K recovery efficiencies were important input parameters for the development of the generic SSNM approach for P and K (Witt et al., 2002b; Witt and Dobermann, 2003). The physiological and agronomic efficiencies are commonly only used to evaluate N management strategies. The following definitions on nutrient use efficiency are based on a framework described by Cassman et al., (1998):

- Recovery efficiency of applied fertilizer nutrients (REN, REP, REK)

$$REX = (UX_{+X} - UX_{-X})/FX \qquad \text{[equation 2]}$$

  where REX is the recovery efficiency in kg plant nutrient kg^{-1} fertilizer nutrient (for other abbreviations, see above). The REN largely depends on the congruence between plant N demand and quantity of N released from applied fertilizer N. With good crop and nutrient management, REN of > 0.5 kg kg^{-1} can be achieved. The recovery efficiencies of fertilizer P and K can vary widely as they are influenced by a number of factors including the amount of fertilizer applied, the difference between yield in fertilized and unfertilized plots, application method including splitting and timing of applications and soil properties. Interquartile ranges of recovery efficiencies measured across five tropical Asian countries in 1997-1998 ranged from 0.11 to 0.35 kg kg^{-1} for P and 0.16 to 0.66 kg kg^{-1} for K (Witt, 2003).

- Physiological N efficiency for grain yield production (PEN, PEP, PEK)

$$PEN = (GY_{+N} - GY_{-N})/(UN_{+N} - UN_{-N}) \qquad \text{[equation 3]}$$

  where PEN is the physiological N efficiency in kg grain increase per kg increase in plant N accumulation due to fertilizer N application. In a healthy rice crop with no significant constraints to growth, PEN should be close to 50 kg grain kg^{-1} N taken up from fertilizer.

- Agronomic N use efficiency (AEN) or yield increase per unit fertilizer N:

$$AEN = (GY_{+N} - GY_{-N})/FN \qquad \text{[equation 4]}$$

where AEN is the agronomic N use efficiency in kg grain kg^{-1} fertilizer N; GY is the grain yield in kg ha^{-1} and +N and –N are treatments with and without fertilizer N application, respectively, and FN is the amount of fertilizer N in kg ha^{-1}. With proper nutrient and crop management, AEN should be ≥ 20 kg kg^{-1}. Note that AEN = REN × PEN.

4. Are there any indications of substantial net removal of P and K with grain and straw that might result in long-term reduction of soil indigenous P and K supply? Nutrient balances can be used to obtain a first indication whether a nutrient management strategy bears the risk of causing a decline of soil indigenous P and K supply in the long-term.
We used the following general formula for estimating the nutrient budget (B) for each rice crop:

$$B = M + A + W + N_2 - C - PS - G \qquad \text{[equation 5]}$$

where (all components measured in kg elemental nutrient ha^{-1}) M = added inorganic and organic nutrient sources, A = atmospheric deposition (rainfall and dust), W = irrigation, floodwater and sediments, N_2 = biological N_2 fixation (BNF), C = net crop removal with grain and straw (total uptake – nutrients in crop residues returned to the soil), PS = percolation and seepage losses, and G = gaseous losses (denitrification, NH_3 volatilization).
5. Is there evidence from long-term experiments, suggesting a rapid decline in soil indigenous P or K supplies, if fertilizer P or K was not applied?
The effect of negative nutrient balances on the degree of soil nutrient depletion can only be reliably estimated, if data from long-term experiments are available. If immediate crop responses to fertilizer P or K application are not expected and do not develop within 5-10 cropping seasons, maintenance rates may not even be necessary. Conditions should be re-evaluated every 5-10 years or sooner, if the crop management changes or current yield levels are exceeded by about 0.5 t ha^{-1} compared to current yield levels.

Materials and methods

The study site

Experimental sites were located in the Jinhua District, Zhejiang. The district has an irrigated rice area of about 146,000 ha which is about 87% of the total cultivated land. The climate is humid, warm continental with an annual rainfall of 1,300–1,500 mm. The selected 21 farms with sizes of 0.2 to 5 ha were located in seven villages and covered a wide range of biophysical and socioeconomic conditions. Soils were mostly fertile with a clay loam to silty clay texture and a relatively high soil organic C content of 15.5-23.0 g kg^{-1}. The pH ranged from 4.8-6.3 (median 5.3). The average cation exchange capacity was low to moderate (6.9-16.3cmol$_c$ kg^{-1}). All farmers followed a double rice-cropping system with early rice (ER, April to July, mostly inbred varieties) and late rice (LR, July to October, mostly hybrid rice). Rice is predominantly transplanted with a density of 25 hills m^{-2} for early rice and 18 hills m^{-2} for late rice. The climate-adjusted yield potential is lower for ER than for LR (9–10 t ha^{-1} for early inbred varieties versus 10–12 t ha^{-1} for late hybrid rice) (ten Berge et al 1997; Zheng et al 1997). Crops are harvested by hand (sickle), leaving only a little straw in the field or combine-harvested, leaving moderate amounts of straw in the field, which is incorporated.

On-farm experiments

In 1998 and 1999, on-farm experiments included a farmer's fertilizer practice (FFP) and a site-specific nutrient management (SSNM) treatment. General crop and pest management was performed entirely by farmers, and researchers only interfered by managing fertilizer nutrients in the experimental SSNM plot of 300-1000 m^2 embedded in the farmer's field. Fertilizer recommendations for SSNM were based on the model QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) (Janssen et al., 1990; Witt et al., 1999), and calculated on a field- and crop-specific basis, considering indigenous nutrient supply, economically sensible grain yield targets, corresponding nutrient demand, nutrient balance and estimates of fertilizer nutrient recovery efficiencies (Wang et al., 2001; Dobermann et al., 2003d). Briefly, estimates of indigenous nutrient supplies of N, P and K (INS, IPS, IKS) were derived from the nutrient accumulation in the aboveground plant dry matter at physiological maturity as measured in nutrient omission plots embedded in farmers' fields measured in the 1998 ER and LR. For example, plant N uptake in a +PK plot is used as an integrative measure of the indigenous N supply (INS, kg N ha^{-1}). These INS, IPS, and IKS estimates were used as model inputs and target yields were set at 7.2–8.0 t ha^{-1} in ER and 7.5–8.5 t ha^{-1} in LR. This is equivalent to about 83–88% of the yield potential in ER and 75-85% in LR. The climatic yield potential was assumed to be 9 t ha^{-1} for ER and 10 t ha^{-1} for LR (Zheng et al., 1997). First crop recovery efficiencies of 0.4, 0.2 and 0.5 kg kg^{-1} were assumed for fertilizer N, P and K, respectively. Fertilizer sources used were urea (46% N), single superphosphate (6.1% P) and muriate of potash (50% K). All P fertilizer was incorporated into the soil before transplanting (100% basal). K fertilizer was split into 50% basal plus 50% at PI.

In 1998, N (urea) was applied in three splits at fixed growth stages (40% at 1 or 2 d before transplanting incorporated into soil, 20% topdressed at 14 DAT and 40% topdressed at PI). Compared with most farmers' practices (two early applications only), this splitting already represented a more evenly distributed N application scheme. Results obtained in 1998, however, suggested that further fine-tuning could be achieved by a more dynamic, plant-based N management. In 1999, therefore, fertilizer N was applied as two fixed applications and one or two more topdressings, depending on chlorophyll meter readings at the critical growth stages.

Nutrient balances were calculated for P and K based on equation 5 given above. Since only three of 21 farmers occasionally applied organic manure, the estimation of fertilizer nutrient input (M) was entirely based on measured values of inorganic fertilizer nutrients. Inputs from atmosphere (A) or water (W) were unknown, but we assumed that they were equivalent to losses by leaching (PS) so that these three terms were not considered in our calculations. Farmers at the study site used river or reservoir water with presumably low nutrient concentrations for irrigation. Crop removal with grain and straw was measured for each crop cycle. The net amount of P and K returned to the field from crop residues was deducted from the total removal assuming (1) a typical percentage of straw remaining in the field and (2) a typical percentage of nutrients lost from the crop residues due to burning or leaching.

The agronomic performance of SSNM was tested against the FFP in four cropping seasons in 1998 and 1999. Plant sampling followed a standard procedure (Witt et al., 1999). Further details are given elsewhere (Wang et al., 2001; Dobermann et al., 2003a).

The long-term experiment

A long-term experiment was started at the Agricultural Research Station in Jinhua, Zhejiang, in the 1997 early rice cropping season. A split-plot design with 3 replicates included fertilizer treatments in main plots and variety in sub-plots (inbred vs. hybrid) with a size of 45 m^2. Fertilizer treatments included a control (zero fertilizer N, P and K), +PK, +NK, +NPK1 and NPK2. General fertilizer rates were 150 kg N ha^{-1} in early rice and 180 kg N ha^{-1} in late rice while 25 kg P ha^{-1} and 100 kg K ha^{-1} were applied to both early and late rice. The NPK2 treatment received additional 20% fertilizer N, P and K compared to NPK1. In ER, fertilizer N was applied as basal dose (50%), at early tillering (25% at about 20 DAT) and at PI (25%). The basal dose in LR was 30% followed by N topdressings at 10 DAT (30%), PI (20%) and at panicle emergence/first flowering (20%). All fertilizer P and 50% of fertilizer K was applied basal, and the remaining K was topdressed at PI. Plant sampling followed a standard procedure (Witt et al.,1999).

Results and discussion

Yield response to fertilizer application and performance of SSNM

There was a clear yield response to the application of all three nutrients N, P and K in the on-farm experiments in both early and late rice in 1998 (Figure 1). As expected, N was the most limiting nutrient and the attainable yield gain in response to fertilizer N application averaged 1.3 t ha^{-1} in ER and 1.7 t ha^{-1} in LR. Yield responses to fertilizer P and K application were smaller and ranged from 0.3 to 1.0 t ha^{-1} (25^{th} and 75^{th} percentiles). Grain yield in the SSNM treatment was used as reference in Figure 1 and yield in ER was 6.4 t ha^{-1} compared to 7.4 t ha^{-1} in LR (Figure 2). The indigenous nutrient supply was generally high and sufficient to support N limited yields of more than 5 t ha^{-1} while P and K were sufficient to support yields of 6 t ha^{-1} and above (Wang et al., 2001; Dobermann et al., 2003b).

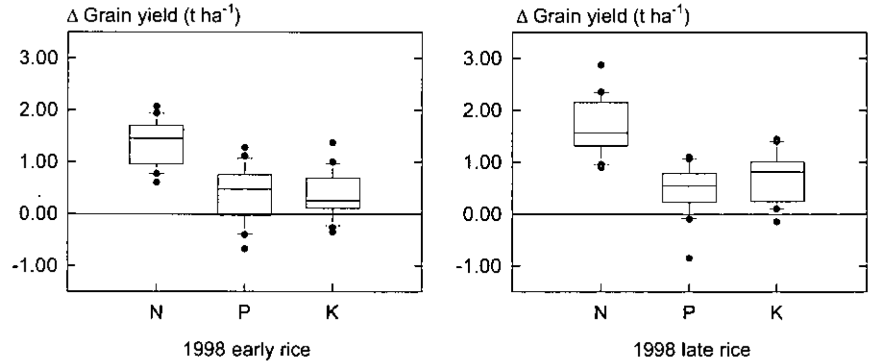


Figure 1. Differences in grain yield between SSNM and the N, P and K omission plots in on-farm experiments at Jinhua, Zhejiang Province, 1998 (n = 21).

With SSNM, the yield increase over the –F plot in 1999 was comparable to the previous year and yield was significantly higher than in FFP in all four seasons in 1998-1999 (Fig. 2). This was mainly attributed to an improved congruence of N application with N demand (Wang et al., 2001). The SSNM concept evolved with time and yield increases over SSNM in the second year were achieved with significantly less fertilizer N, P and K (Fig. 2). The yield response to fertilizer P and K application in farmers' fields was small unless the N management was improved with SSNM. The average profit increase with SSNM was 88 US$ ha^{-1} $crop^{-1}$ (Wang et al., 2001).

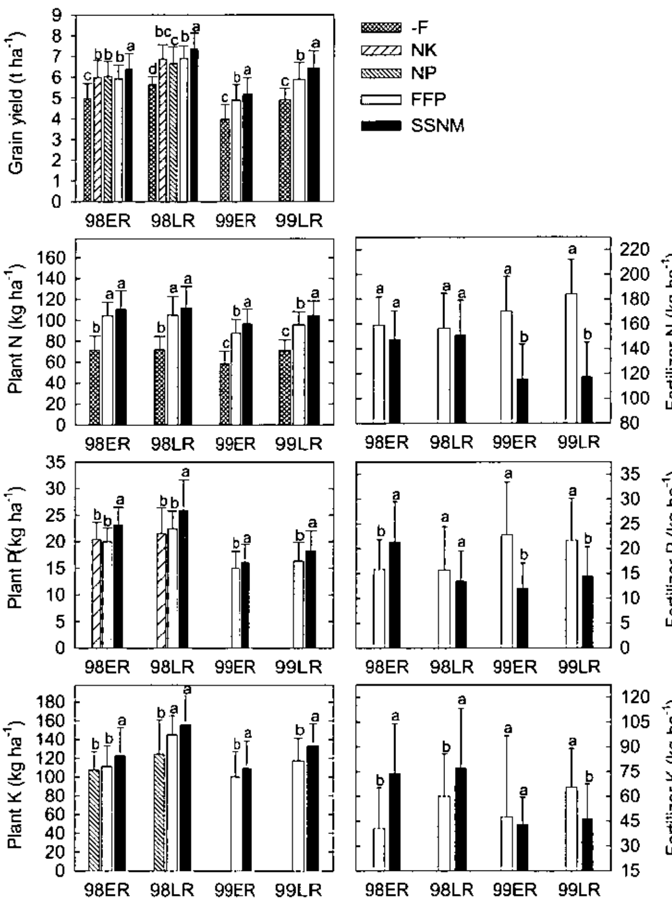


Figure 2. Grain yield, nutrient uptake and fertilizer rates of N, P and K in treatments with farmers' fertilizer practice (FFP) and site-specific nutrient management (SSNM) in Jinhua, Zhejiang Province, China, 1998-1999. Additional treatments included fertilizer omission plots without N, P and K application (-F) in 1998-1999 and without P (+NK) and K application (+NP) in 1998. ER = early rice; LR = late rice. Bars = mean; error bars = standard deviation. Means with the same letter within a season are not significantly different at $P<0.05$ (LSD).

Nutrient requirements

There are indications that the nutrient accumulation of N, P and K in above-ground plant dry matter was generally not limiting yields in SSNM and FFP. The internal efficiencies (grain yield per unit plant nutrient) shown in Figure 3 were mostly on or below the optimal nutrient accumulation (YN, YP and YK) as generated by the QUEFTS model. The model assumes a linear increase in grain yield if nutrients are taken up in balanced amounts of 14.7 kg N, 2.6 kg P and 14.5 kg K per 1000 kg of grain until yield targets reach about 70-80% of the yield potential (Ymax). The boundary lines depicted in Figure 3 represent the maximum dilution (YD) and accumulation (YA) of the nutrients N, P and K in the above-ground DM while YN, YP and YK represents the optimum nutrient uptake requirement to achieve a certain grain yield target without that other nutrients are limiting (Witt et al 1999). The nutrient accumulation in early, inbred rice was theoretically sufficient to support even higher yields in both SSNM and FFP, as most data points were close to the borderline of maximum nutrient accumulation. This indicates that constraints other than nutrients might have been limiting yield. For example, internal nutrient efficiencies will be low, if the conversion of nutrient uptake into grain yield is limited due to less favorable weather conditions during grain filling. In late, hybrid rice, nutrient accumulation was generally adequate to support the yields achieved in both SSNM and FFP except for a few cases of N limitation in SSNM where maximum plant N dilution was reached.

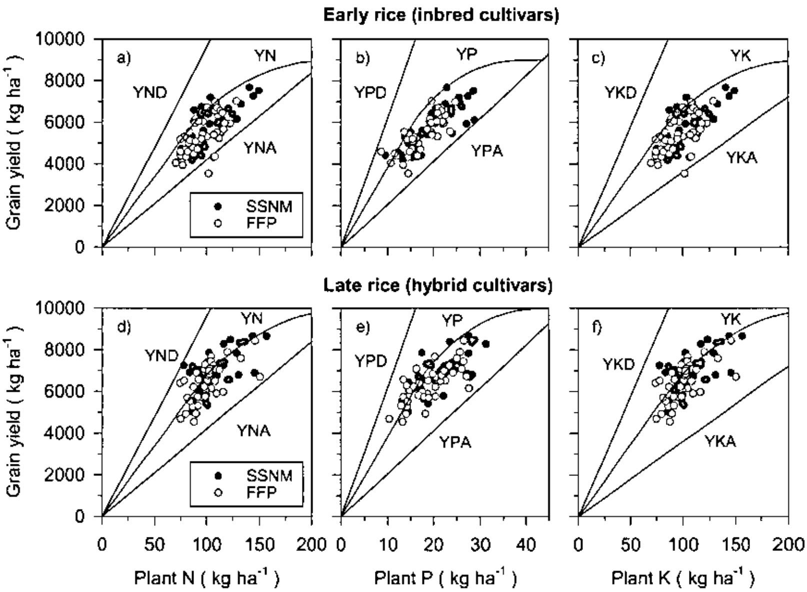


Figure 3. Internal nutrient efficiencies (kg grain yield kg^{-1} plant nutrient) at maturity of rice in treatments with farmers' fertilizer practice (FFP) and site-specific nutrient management (SSNM) in Jinhua, Zhejiang Province, China, 1998-1999 (21 farms x 4 crops).

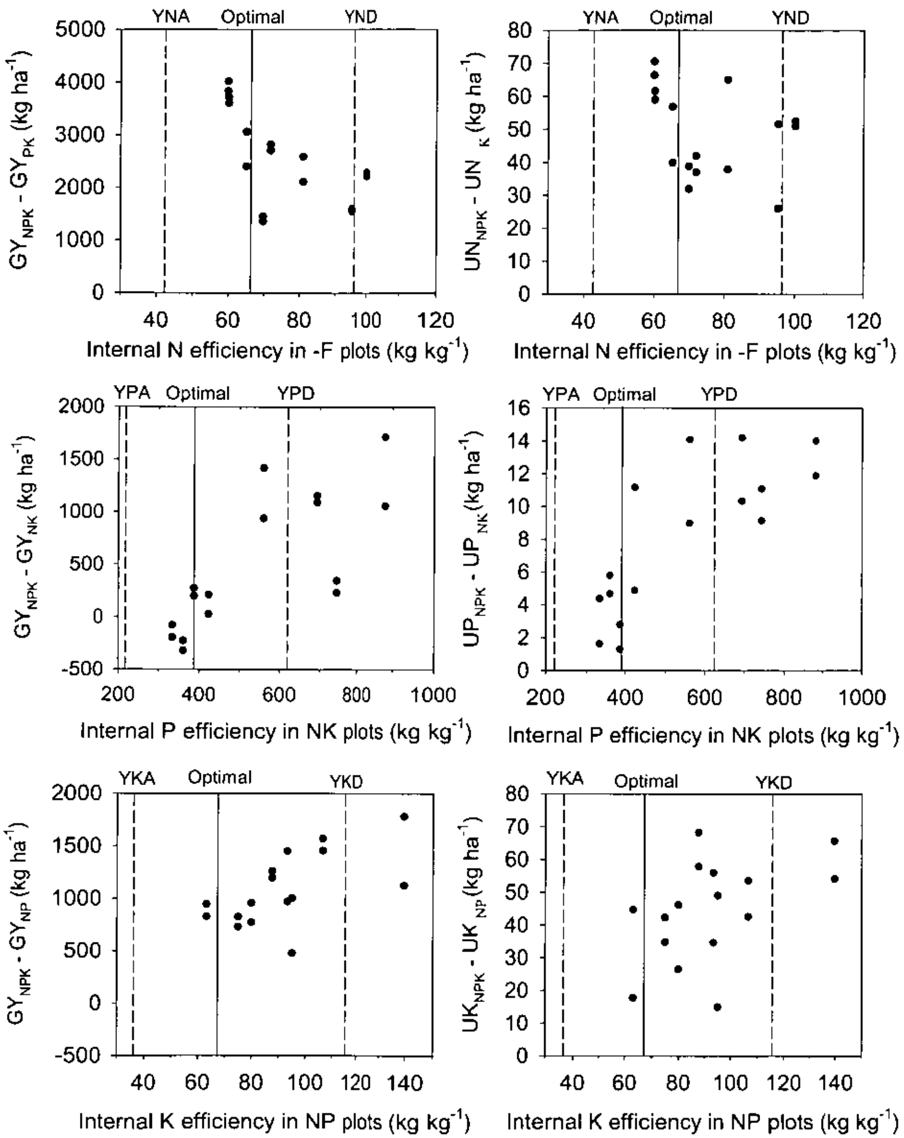


Figure 4. The increase in grain yield (left) and corresponding nutrient uptake (right) due to fertilizer N, P and K application over the respective omission plot (PK, NK, NP) in relation to the internal NP and K efficiency in the omission plots, long-term experiment, Jinhua, 1998-1999.

In conclusion, internal nutrient efficiencies seemed to be a poor indicator of nutrient limitation because yield increases with SSNM were associated with significant increases of plant nutrient uptake of N (+8%), P (+13%) and K (+10%) as shown in Figure 2. Thus, the yield advantage with SSNM appeared to be related to greater nutrient uptake without that internal nutrient efficiencies changed much. However, internal nutrient efficiencies of crops grown in nutrient omission plots may be a useful indicator of P and K limitations. The relationship between yield and nutrient uptake increases due to fertilization and internal nutrient efficiencies in omission plots is depicted in Figure 4. Yield and nutrient uptake responses to fertilizer P and K application were generally low when internal efficiencies in omission plots were near optimal levels. Yield responses to fertilizer P and K application increased when P and K uptake were close to the borderline of nutrient dilution (YPD, YKD). This relationship does not seem to hold for N, as substantial yield responses to fertilizer N application were even observed when internal N efficiencies were close to optimal levels in –F plots. A larger data set would be required to better evaluate these relationships.

Nitrogen efficiencies

Average yield increases of 0.45 t ha^{-1} with SSNM were achieved despite a reduction in fertilizer N rates by 21% compared to FFP (133 vs. 167 kg ha^{-1}). Thus, the agronomic N efficiency (kg grain yield per kg fertilizer N) in SSNM was on average about 80% higher (11.4 vs. 6.3 kg kg^{-1}) compared to FFP (Figure 5).

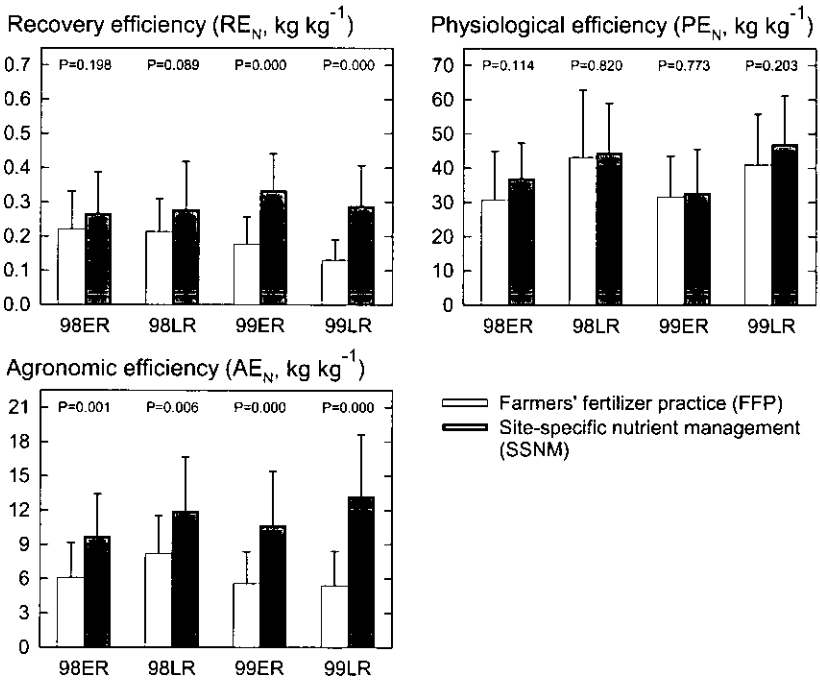


Figure 5. Recovery efficiency (increase in plant N per kg fertilizer N applied), physiological efficiency (increase in grain yield per unit increase in plant N), and agronomic efficiency (increase in grain yield per unit fertilizer N applied) in treatments with farmers' fertilizer practice (FFP) and site-specific nutrient management (SSNM) in Jinhua, Zhejiang Province, China, 1998-1999 (21 farms). ER = early rice; LR = late rice.

In other words, more grain was produced per unit fertilizer N applied. This corresponded to an average increase in fertilizer recovery efficiency from 19 to 29% with SSNM, which was mainly due to a better congruence of N supply with plant demand (Wang et al., 2001). The physiological N efficiency (kg grain yield increase per increase in plant N) remained largely unchanged with SSNM just like the internal efficiency was not much affected (Figure 5). While the physiological N use efficiencies in the on-farm experiments at Jinhua were comparable to those of other sites (Dobermann et al., 2002), average recovery efficiencies (29%) and agronomic efficiencies (11.4 kg kg^{-1}) were generally low in SSNM treatments compared with the 40-50% REN and 20-25 kg kg^{-1} AEN that can be reached with good crop and nutrient management. The SSNM strategy employed in 1998-1999 included relatively large early season applications of fertilizer N, which reduces N efficiencies but stimulates tillering before farmers practice a mid-season drainage prior to panicle initiation. With increasing experience, however, N management was further fine tuned in 2000 and 2001, resulting in increased N efficiencies of 30-40% for REN and 15-18 kg kg^{-1} for AEN (RTOP unpublished). However, fertilizer N requirements in the rice systems of Jinhua may still be closer to 60 kg fertilizer N per ton grain yield increase, which is substantially larger than the 40-50 kg per ton recommended under optimal conditions (Witt et al., 2002a).

Nutrient balances

The nutrient balances for the on-farm experiments in 1998-1999 given in Table 1 showed a net P removal with grain and straw in SSNM (-5 kg ha^{-1} $crop^{-1}$) while P supply and removal were well balanced in FFP (+1 kg P $ha^{-1}crop^{-1}$). This was mainly due to an increase in P removal with grain and straw due to higher yields in SSNM (see Figure 2), while fertilizer P rates were at the same time reduced by an average of 4 kg ha^{-1} $crop^{-1}$ compared to FFP (15 vs. 19 kg P ha^{-1} $crop^{-1}$ (see Figure 2)).

Table 1. Nutrient balances for P and K in treatments with site-specific nutrient management (SSNM) and farmers' fertilizer practice (FFP) in 21 farmers' fields in Zhejiang Province, China, (1998-99). ER = early rice; LR = late rice.

		Year and season				Mean of all
		1998 ER	1998 LR	1999 ER	1999 LR	four crops
P balance	SSNM	-1	-12	-3	-3	-5
(kg ha^{-1} $crop^{-1}$)	FFP	-4	-6	9	6	1
	Δ[a]	3	-6	-12	-9	-6
	P>|T|	0.312	0.066	0.000	0.001	0.000
K balance	SSNM	-12	-31	-31	-47	-30
(kg ha^{-1} $crop^{-1}$)	FFP	-35	-37	-20	-17	-27
	Δ[a]	23	6	-11	-30	-3
	P>|T|	0.038	0.646	0.374	0.000	0.575

[a] Δ = SSNM – FFP. P>|T| - probability of a significant mean difference between SSNM and FFP.

In 1999, fertilizer P rates were even 9 kg P ha^{-1} $crop^{-1}$ smaller with SSNM (13 vs. 22 kg P ha^{-1} $crop^{-1}$). Although fertilizer P rates were insufficient to fully balance P removal with grain and straw in SSNM, there was good evidence from internal P use efficiencies and increased P uptake that smaller P rates were sufficient to support the tar-

geted yield in SSNM. Thus, farmers fertilizer P rates could probably be slightly reduced without yield penalty unless long-term data indicated a decrease in indigenous soil P supply at smaller fertilizer P rates. Fertilizer K balances were negative in both SSNM and FFP -30 vs. -27 kg K ha^{-1} $crop^{-1}$ (Table 1), despite relatively high K rates of 60 and 54 kg K ha^{-1} $crop^{-1}$, respectively (see Figure 2). Like P, optimal internal K efficiencies (Figure 5) and increased K uptake with SSNM (see Figure 2) indicated that fertilizer K supply was sufficient to reach the targeted yield levels. However, given the negative K balance with SSNM, fertilizer K rates of about 60 kg K ha^{-1} $crop^{-1}$ seemed appropriate and further fertilizer K reduction may not be advisable to avoid long-term negative effects on soil indigenous K supply.
To compare the magnitude of the P and K balances, we suggest to adjust the balances by their relative requirement by the crop, i.e. K removal needs to be divided by the factor of 5.6 based on the ratio of plant P to plant K requirement of 1: 5.6 (Witt et al., 1999). This would mean for the nutrient balances given in Table 1 that the SSNM treatment removed about the same relative amount of P and K. Thus, the nutrient removal of -5 kg P ha^{-1} $crop^{-1}$ with SSNM is as severe as the removal of -30 kg K ha^{-1} $crop^{-1}$. It is difficult, however, to estimate the risk of nutrient depletion from nutrient balances without estimates of long-term changes in indigenous nutrient supplies. This has been considered in the SSNM approach, because the concept of maintenance rates in fertilizer P and K management was developed, using a simple nutrient balance model for irrigated rice (Witt et al 2002a; Witt and Dobermann 2003). It may therefore not be necessary to estimate nutrient balances on a routine basis.

Changes in indigenous nutrient supplies

There was little change in soil indigenous N supply measured during four cropping seasons in a long-term experiment in Jinhua (Figure 6). There is strong evidence that indigenous nutrient supplies in irrigated rice change little with time despite substantial seasonal variation (Dobermann et al., 2003b).

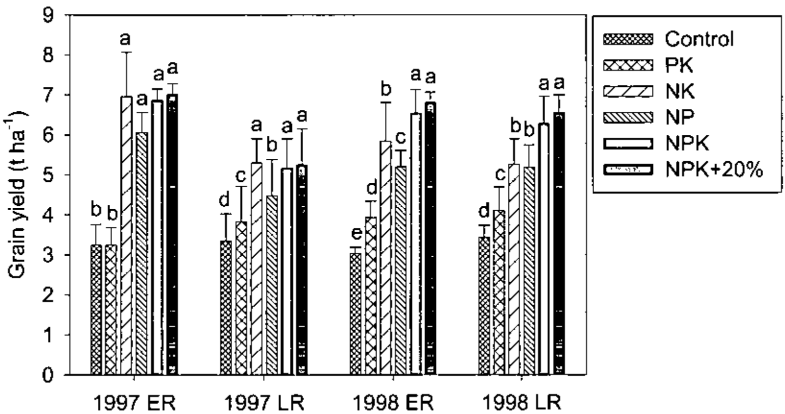


Figure 6. Grain yield as affected by N, P and K inputs in the long-term fertility experiment at the Agricultural Research Station in Jinhua, 1997-1998. Means with the same letter within a season are not significantly different at P<0.05 (DMRT).

More important for the development of adequate SSNM recommendations are medium- or long-term changes in indigenous P and K supplies. Yield differences between -P (NK plots), -K (NP plots) and plots with full fertilizer N, P and K application were insignificant in the first season in Jinhua (Figure 6). Starting with the LR 1997, however, a significant yield response to fertilizer P and K application evolved with time, indicating that maintenance applications of fertilizer P and K rates are clearly required to prevent a degradation of soil indigenous P and K supplies, even if a yield response was not observed in the first season. In 1998 LR, the yield response to fertilizer P and K application was about 1 t ha^{-1}. There was no effect on yield when additional 20% fertilizer N, P and K were applied.

Instead of using a single long-term experiment, multiple on-farm omission plots distributed in a larger area may be more representative to estimate long-term changes in indigenous P and K supplies. If a yield response was not observed in the first one or two seasons, the location of the omission plots could be fixed to estimate whether a nutrient response would develop within a few seasons without fertilizer application. Such stationary long-term omission plots would have a different purpose than the temporary omission plots used to develop fertilizer P and K recommendations as recently suggested for the simplified SSNM approach (Witt et al., 2002a; Dobermann et al., 2003c).

Conclusions

Plant based performance indicators were successfully used to develop, evaluate and refine a novel site-specific nutrient management strategy in Jinhua, Zhejiang Province. Results indicate that a range of parameters would be necessary to fully evaluate and fine-tune nutrient management strategies. Several nutrient efficiency parameters were required to fully isolate the causes of yield increases with SSNM compared to the farmers' fertilizer practice, including internal nutrient efficiencies, recovery efficiencies of applied fertilizer N, physiological N use efficiencies and agronomic N use efficiencies. These allowed to separate out effects whether yield increases were due to increased nutrient uptake, recovery of applied fertilizer N or the efficiency with which nutrient uptake is translated into grain yield. The most relevant parameter for extension purposes is probably the agronomic efficiency (grain yield increase per unit fertilizer N applied), since only grain yield measurements would be required in plots with and without N fertilizer application. Omission plots can be used to both relate fertilizer requirements to yield increases and visually demonstrate nutrient limitations to farmers. Nutrient balances might give some indications whether nutrient management strategies would bear the risk of nutrient depletion with time. This would be of particular interest where yield responses to fertilizer P and K application are less clear and maintenance applications are to be recommended. However, final conclusions on whether negative nutrient balances can be sustained for longer periods without yield penalties can only be drawn from long-term experiments. The intensity of declining soil indigenous P and K supply without fertilizer application could be estimated from single, replicated on-station or multiple on-farm experiments with omission plots at fixed locations. If yield responses occur within few cropping seasons, maintenance applications of fertilizer P and K should be recommended, even if an immediate yield response is not expected. The presented data strongly suggest that several cropping seasons of on-farm trails are required to develop meaningful and economically sensible fertilizer recommendations.

Acknowledgments

We wish to thank Ms. M.A. Adviento (IRRI) for her help with the soil and plant analysis and Mr. G.C. Simbahan (IRRI) for help with data management and statistical analysis. We acknowledge contributions made by scientists involved in this research, Professor C. Huang and Dr. Y. He of Zhejiang University and Mr. X Ding and Mr. J. Wu of Agricultural Bureau of Jinhua. The International Fertilizer Industry Association (IFA), the Potash and Phosphate Institute Canada (PPIC) and the International Potash Institute (IPI) provided funding for the research project.

References

Balasubramanian V, Morales AC, Cruz RT, Abdulrachman S. 1999. On-farm adaptation of knowledge-intensive nitrogen management technologies for rice systems. Nutr.Cycl.Agroecosyst. 53:59-69.

Cassman KG, Peng S, Olk DC, Ladha JK, Reichardt W, Dobermann A, Singh U. 1998. Opportunities for increased nitrogen use efficiency from improved resource management in irrigated rice systems. Field Crops Res. 56:7-39.

Dobermann A, Fairhurst T. 2000. Rice: Nutrient disorders and nutrient management. Singapore and Los Baños: Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute (IRRI). p 1-191.

Dobermann A, Simbahan GC, Moya PF, Witt C, Dawe D. 2003a. Methodology for socioeconomic and agronomic on-farm research in the RTDP project. In: Dobermann A, Witt C, Dawe D, editors. Increasing the productivity of intensive rice systems through site-specific nutrient management. New Delhi (India) and Los Baños (Philippines): Science Publishers and International Rice Research Institute (IRRI) (In press).

Dobermann A, White PF. 1999. Strategies for nutrient management in irrigated and rainfed lowland rice systems. Nutr. Cycl. Agroecosyst. 53:1-18.

Dobermann A, Witt C, Abdulrachman S, Gines HC, Nagarajan R, Son TT, Tan PS, Wang GH, Chien NV, Thoa VTK, Phung CV, Stalin P, Muthukrishnan P, Ravi V, Babu M, Simbahan GC, Adviento MA. 2003b. Soil fertility and indigenous nutrient supply in irrigated rice domains of Asia. Agron.J. (in press)

Dobermann A, Witt C, Abdulrachman S, Gines HC, Nagarajan R, Son TT, Tan PS, Wang GH, Chien NV, Thoa VTK, Phung CV, Stalin P, Muthukrishnan P, Ravi V, Babu M, Simbahan GC, Adviento MA, Bartolome V. 2003c. Estimating indigenous nutrient supplies for site-specific nutrient management in irrigated rice. Agron.J. (in press)

Dobermann A, Witt C, Dawe D. editors. 2003d. Increasing the productivity of intensive rice systems through site-specific nutrient management. New Delhi, India and Makati City, Philippines: Science Publishers and International Rice Research Institute (IRRI) (In press).

Dobermann A, Witt C, Dawe D, Abdulrachman S, Gines HC, Nagarajan R, Satawathananont S, Son TT, Tan CS, Wang GH, Chien NV, Thoa VTK, Phung CV, Stalin P, Muthukrishnan P, Ravi V, Babu M, Chatuporn S, Sookthongsa J, Sun Q, Fu R, Simbahan GC, Adviento MAA. 2002. Site-specific nutrient management for intensive rice cropping systems in Asia. Field Crops Res. 74:37-66.

Janssen BH, Guiking FCT, van der Eijk D, Smaling EMA, Wolf J, van Reuler H. 1990. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). Geoderma. 46:299-318.

ten Berge HFM, Shi Q, Zheng Z, Rao KS, Riethoven JJM, Zhuong X. 1997. Numerical optimization of nitrogen application to rice. Part II. Field evaluations. Field Crops Res. 51:43-54.

Wang GH, Dobermann A, Witt C, Sun QZ, Fu RX. 2001. Performance of site-specific nutrient management for irrigated rice in southeast China. Agron.J. 93:869-878.

Witt C. 2003. Principles of site-specific phosphorus and potassium management in irrigated rice. Paper presented at the workshop on P and K recommendation for Rice, Solo, Indonesia, 2-3 October 2002. AIAT Central Java: Solo, Indonesia. p 1-11.

Witt C, Balasubramanian V, Dobermann A, Buresh RJ. 2002a. Nutrient management. In: Fairhurst T, Witt C, editors. Rice: a practical guide for nutrient management. Singapore and Los Baños: Potash and Phosphate Institute & Potash and Phosphate Institute of Canada and International Rice Research Institute. p 1-45.

Witt C, Buresh RJ, Balasubramanian V, Dawe D, Dobermann A. 2002b. Improving nutrient management strategies for delivery in irrigated rice in Asia. Better Crops Int. 16-2:10-17.

Witt C , Dobermann A. 2003. A decision support system for site-specific nutrient management. In: Dobermann A, Witt C, Dawe D, editors. Increasing productivity of intensive rice systems through site-specific nutrient management. New Delhi, India and Makati City, Philippines: Science Publishers and International Rice Research Institute (IRRI) (In press).

Witt C, Dobermann A, Abdulrachman S, Gines HC, Guanghuo W, Nagarajan R, Satawathananont S, Tran Thuc Son, Pham Sy Tan, Le Van Tiem, Simbahan GC, Olk DC. 1999. Internal nutrient efficiencies in irrigated lowland rice of tropical and subtropical Asia. Field Crops Res. 63:113-138.

Yang W-H, Peng S, Sanico AL, Buresh RJ, Witt C. 2003. Estimation of leaf nitrogen status using leaf color charts in rice. Agron.J. 95:212-217.

Zheng Z, Yan L, Wang ZQ. 1997. Simulation of potential production and studies on optimum quantitative population indices of hybrid rice. J.Zhejiang Agric. University. 23:59-64.

"Cascade" Experiment on fertilizer efficiency and nutrient balance

Xi Zhenbang

Soil and Fertilizers Institute of Shanghai Academy of Agricultural Science 201106

Abstract

A crop response experiment with 4 treatments (CK: no-fertilization, OM: organic manure, MF: mineral fertilizer and OF: organic manure + mineral fertilizer) was carried out under a three-crop-per-year rotation system for three years in a row. The experiment was designed in a cascade pattern. At the beginning of each crop, a new treatment was laid out adjacent to the original treatment plot to ensure the treatments would develop continuously in a cascade pattern. The initial results show that under different fertilization treatments both crop yield as well as the N, P and K uptake declined with time. The decline was most pronounced in CK (no-fertilization). Meanwhile, the nutrient recovery rate showed an upward trend with time, especially those nutrients supplied by organic manure. For the first crop, the N recovery from applied fertilizer was 28.9% in treatment MF and 11.7% in treatment OM. The cumulative N recovery of four crops rose to 36.2% in treatment MF and 26.9% in treatment OM, showing that the cumulating nutrient efficiency of organic manure is high. A comparison of the nutrient consumption was also conducted between the three-cropping-per-year and the two-cropping-per-year rotation system.

Introduction

Response to nutrient application, independent on source either from organic manure or mineral fertilizer, is often influenced by the residual effects of the management to the preceding crop. This not only applies to observed yield differences but also to assessed nutrient use efficiencies. It may be assumed that a comparison of different fertilizer treatments over several years shows increasingly cumulative effects and it may be difficult to interpret the observation. This applies particularly to the question of nutrient efficiency calculations based on annual rates of fertilizers applied . To separate immediate and cumulative response to nutrient application, but also in order to assess the utilization of nutrients from either organic manure or mineral fertilizer, a specific trial layout was necessary. Therefore, during the period from 1979 to 1981, a continuous fixed location fertilizer efficiency experiment was designed in a cascade pattern. The selected locations were situated on three typical paddy soils in the suburbs of Shanghai and the tested crops were early rice, late rice and barley in a three-crop rotation system. The experiment lasted three years, involving eight crops. Plant samples and corresponding soil samples were collected for analysis. In this paper the results obtained during the cultivation of the first four crops are presented.

Materials and methods

Tested soils

The basic conditions of the seven experimental sites on three different paddy soils are shown in Table 1.

Table 1. Physical and chemical properties of the experimental soils

Location	pH	Clay <0.001 (g kg^{-1})	O.M. (g kg^{-1})	N Total (g kg^{-1})	N Readily available (mg kg^{-1})	P_2O_5 Total (g kg^{-1})	P_2O_5 Readily available (mg kg^{-1})	K_2O Total (g kg^{-1})	K_2O Readily available (mg kg^{-1})
Qingzini	7.2	166	38.0	2.15	115	1.70	23	23.7	153
	6.7	243	36.6	2.28	127	1.27	18	21.1	150
	7.3	174	31.5	2.07	114	1.60	27	27.5	135
Mean	7.1	194	35.4	2.17	119	1.52	23	24.1	146
Huang-	7.3	200	16.2	1.02	50	1.52	12	21.4	189
touni	6.7	185	31.5	1.95	109	1.86	54	22.7	184
Mean	7.0	193	23.9	1.49	80	1.69	33	22.2	187
Gouganni	7.1	127	15.1	0.99	54	1.97	89	25.3	107
	7.3	123	11.4	0.77	42	1.89	30	22.4	91
Mean	7.2	125	13.3	0.88	48	1.93	60	23.9	99
SD		$\pm$42	$\pm$11.1	$\pm$0.6	$\pm$37	$\pm$0.3	$\pm$27	$\pm$2.3	$\pm$37

Note: Readily available N determined by 1.2 mol l^{-1} NaOH method; readily available P by Olsen method and readily available K by 1 mol l^{-1} NH_4AC method.

Treatments in the experiment

The experiment consisted of following four treatments:

1) CK: No fertilizers of any type;
2) OM: 22.5t ha^{-1} pig manure $crop^{-1}$, containing 98 kg N, 32.5 kg P_2O_5 and 158 kg K_2O;
3) MF: 150 kg ha^{-1} N $crop^{-1}$ (ammonium bicarbonate), 24 kg ha^{-1} P_2O_5 (single superphosphate) and no K;
4) OF: OM + MF.

Experimental design

The trial fields of all sites had a size of 0.2 ha and each field was divided into 8 zones and each zone consisted of 3 plots with 33 m^2 in size (Figure 1). The treatments started in the first season with early rice in zone one, including CK, OM or MF whereas the remaining 7 zones (21 plots) were treated with OF to ensure that the plots reserved for the later seasons have all the same basal soil nutrient status. While the experiment continued throughout the years, the number of plots under treatment OF were reduced.

Season	Crop	experimental zones								
		1	2	3	4	5	6	7	8	
		CK_1	OF	OF	OF	OF	OF	OF	OF	
1	Early rice	OM_1	OF	OF	OF	OF	OF	OF	OF	
		MF_1	OF	OF	OF	OF	OF	OF	OF	
		CK_2	CK_1	OF	OF	OF	OF	OF	OF	
2	Late rice	OM_2	OM_1	OF	OF	OF	OF	OF	OF	
		MF_2	MF_1	OF	OF	OF	OF	OF	OF	
		CK_3	CK_2	CK_1	OF	OF	OF	OF	OF	
3	Barley	OM_3	OM_2	OM_1	OF	OF	OF	OF	OF	
		MF_3	MF_2	MF_1	OF	OF	OF	OF	OF	
		CK_4	CK_3	CK_2	CK_1	OF	OF	OF	OF	
4	Early rice	OM_4	OM_3	OM_2	OM_1	OF	OF	OF	OF	
		MF_4	MF_3	MF_2	MF_1	OF	OF	OF	OF	
		CK_5	CK_4	CK_3	CK_2	CK_1	OF	OF	OF	
5	Late rice	OM_5	OM_4	OM_3	OM_2	OM_1	OF	OF	OF	
		MF_5	MF_4	MF_3	MF_2	MF_1	OF	OF	OF	
		CK_6	CK_5	CK_4	CK_3	CK_2	CK_1	OF	OF	
6	Barley	OM_6	OM_5	OM_4	OM_3	OM_2	OM_1	OF	OF	
		MF_6	MF_5	MF_4	MF_3	MF_2	MF_1	OF	OF	
		CK_7	CK_6	CK_5	CK_4	CK_3	CK_2	CK_1	OF	
7	Early rice	OM_7	OM_6	OM_5	OM_4	OM_3	OM_2	OM_1	OF	
		MF_7	MF_6	MF_5	MF_4	MF_3	MF_2	MF_1	OF	
		CK_8	CK_7	CK_6	CK_5	CK_4	CK_3	CK_2	CK_1	OF
8	Late rice	OM_8	OM_7	OM_6	OM_5	OM_4	OM_3	OM_2	OM_1	OF
		MF_8	MF_7	MF_6	MF_5	MF_4	MF_3	MF_2	MF_1	OF

Figure 1. Experimental layout based on the Cascade design

When the second crop was planted, the 3 plots in zone two were assigned to treatment CK, OM and MF. The 3 plots in zone one remained unchanged. The remaining 18 plots in the remaining 6 zones received treatment OF. This arrangement continued until the eighth crop was planted. The eighth zone was split into 6 subplots, 1 for each treatment (CK, OM and MF) and the other 3 treatments for treatment OF. By that time, 7 crops had been grown successively on zone one under the treatment CK, OM and MF. The aim of the design was to achieve the mean values of a multi-point stationary experiment under large-scale field production conditions. Then by using the differential technique, the evolution trend of continuous effect, residual effects, recovery rate of fertilizers and soil productivity were analysed. As the number of treatment replications of the experiment rose in synchrony with the number of crops, the whole experiment developed in a cascade pattern.

Field management and sampling

The crops used in the experiment were local cultivars and managed according to the local traditional practice except for fertilization. In each plot, a sampling patch of 1 m^2 was installed for collecting samples of soils and plants during the growing period. Samples from organic manure for each crop were collected and immediately analyzed. The nutrient contents in organic manure, soils and plants were determined by conventional methods.

Results and Discussion

Based on the mean values of the first four crops on the 7 sites of the experiment, crop yield, fertilizer efficiency, after-effects of fertilizers, soil productivity and nutrient balances are presented and discussed.

Crop yield

The crop yield of the CK can be used to determine the indigenous nutrient supply at the beginning of the experiment. The yield increment of OM and MF to CK reflects the nutrient application effect. It shows that the inherent soil fertility was rather high. However, the total yield of the whole rotation in CK was only 73% of the yield in OF, reaching a total of 16.4 t ha^{-1} yr^{-1} (Table 2).

Table 2. Crop yields of different treatments

Treatment	Yield (t ha^{-1})				Total Yield
	Early rice	Late rice	Barley	Total	(%)
CK	5.26	4.61	2.13	12.0	73
OM	5.52	4.85	2.75	13.1	80
MF	6.58	5.77	3.26	15.6	95
OF	6.61	5.92	3.84	16.4	100

In Table 2, fertilizer efficiency is determined based on the total production of the three crops per year. The production in CK reflects the inherent soil productivity, being about 73% of the fertilized plots in this experiment. The efficiency of organic manure and mineral fertilizers was 7% and 22%, respectively, while the combined fertilizer efficiency of organic manure plus mineral fertilizers was 27%. The grain production in treatment OF was 5% greater than that in treatment MF, what can be attributed to the effect of organic manure. The comparison of early rice with barley shows that early rice where the yield in the control (CK) was 80% of that of treatment OF could benefit more from the inherent soil fertility than barley where the yield in treatment CK was only 55%. The poor productivity of barley in this treatment may be attributed to the low mean temperature below 20°C during the growing period. Low temperature reduces obviously the plant's access to inherently available nutrients in the soil.

The observation of successive yield responses in different fertilization treatments revealed that the yield response of barley dropped most dramatically from OF to CK and much less in early rice. Whereas in early rice an additional yield increase of 15-20% through mineral fertilization (MF) compared to organic manure (OM) was observed, the yield increment in barley in the same comparison was much less (10% increase). This indicates that in a typical upland crop like wheat stronger yield response to organic manure was observed than in irrigated rice (Table 3).

Table 3. Yields of crops and relative yields (OF = 100) of early rice and barley under continuous treatments

S*	Early rice						Barley					
	CK		OM		MF		CK		OM		MF	
	(t ha^{-1})	(%**)	(t ha^{-1})	(%*)	(t ha^{-1})	(%)	(t ha^{-1})	(%)	(t ha^{-1})	(%)	(t ha^{-1})	(%)
1	3.78	65	4.28	74	5.44	94	2.13	55	2.75	72	3.26	85
2	3.56	61	4.23	73	5.51	95	1.79	47	2.30	60	3.13	82
3	3.36	58	4.08	70	5.36	92	1.64	43	2.24	58	3.02	79
4	3.23	55	4.02	69	4.99	86						

*: Number of season,

**: The yield in treatment OF taken as 100% was 3.84 t ha^{-1} for barley and 5.82 t ha^{-1} for early rice.

As the yields in CK declined with the number of crops grown, the yield gap between CK and OF widened. After 3 consecutive crops, the yield in CK was only 50% of that in OF, indicating that the third crop's yield had to rely to 50 % on fertilizers. The yield in MF, though being reduced compared to that in OF, was much larger than that in OM. Thus, it is clearly indicated that a systematic consecutive fertilization (mineral fertilizers and organic manure) is needed to raise crop yield and to build up and maintain soil fertility. Furthermore, mineral fertilizer, just like organic manure, caused after-effects, showing that the succeeding crop benefited from previous nutrient application to the preceding crop (Table 4). The variation of crop response of the 4 consecutive crops to fertilization in different treatments was increasing with the duration of cropping on the same plot. In CK, the relative yield dropped from 79% to 55%, the fastest among the four treatments. In OM, the relative yield decreased from 83% to 69% or 10 points. The comparison of the relative yields in OM with those in CK showed that crop response rose from 4% in the first crop to 14% in the fourth crop, reflecting a quite significant residual effect. In MF, the relative yield declined from 98% to 86% at a rate much less than that in CK. The relative yield of the fourth crop in MF was 86% or 31% larger than that of the fourth crop in CK and 12% larger than the difference between the treatments in relative yield of the first crop. Obviously, the difference of 12% can be taken as residual effect of the consecutive application of mineral fertilizers which is reflected in the yield.

Table 4. Crop responses in consecutive cropping under different fertilization treatments (%)

Treatment	Early rice (1st crop) Rel. yield	Late rice (2nd crop) Rel. yield	Barley (3rd crop) Rel. yield	Early rice (4th crop) Rel. yield
CK	79	64	43	55
OM	83	70	58	69
MF	98	92	79	86
OF	100	100	100	100

Note: Rel. yield is the yield in % of OF which has been set 100.

The difference between OF and MF in relative yield which is small for the first crop of early rice can be considered as the contribution of organic manure applied to the same crop. The relative yield in OF minus that in OM can be regarded as the contribution of the mineral fertilizer applied to the same crop. The contribution of mineral fertilizer has been calculated as 17% for the first crop of early rice. When the experiment went on to the third crop of barley, the yield contribution of organic manure increased to about 21% and that of mineral fertilizers to 42%. Consequently, in order to evaluate the effect of mineral fertilizers on crop yield, it is necessary to determine both the yield increment of the current crop (grain increased kg^{-1} nutrients) and the after-effects by analysing the yield increments of the succeeding crops to obtain an idea about the fertilizer efficiency over years.

Nutrient uptake

Fertilizer efficiency of the different treatments was also determined by using the crop nutrient uptake. In CK, the uptake of N reached 60%, that of P 71% and that of K 68% in comparison to OF (set as 100%). The nutrient uptake by the third crop in CK decreased to 35% for N, 39% for P and 38% for K compared to OF. That means if no fertilizer was applied to three consecutive crops, depending on the nutrient, the soil could only supply between 35- 38% of the requirements of the crop (Table 5).
One of the main causes for reduced nutrient uptake, especially that of K which has been faster than the reduction in crop yield, is that with less reduction in biomass production, the nutrient content in the dry matter became diluted. There were clear differences in the nutrient concentrations between plant organs. In the grains, the K content

dropped only slightly whereas it dropped drastically in the straw by about 25%. This shows that the plant gives priority to K supply of the grains. There, the reduced nutrient uptake may lead to a decrease in the protein content as well as K and other minerals which will reduce the nutritional value of the product. Consequently, improving fertilization raises both yield and nutrient uptake of the crop, thus bringing more nutrients into the cycle of the biosphere that includes both man and animal.

Table 5. Nutrient uptake by crops as affected by fertilization

Crop	Treatment	N		P		K	
		(kg ha^{-1})	(%)	(kg ha^{-1})	(%)	(kg ha^{-1})	(%)
Early rice	CK	78.8	60	18.8	71	119	68
(1^{st} crop)	OM	87.0	66	20.3	77	131	75
	MF	131.0	99	25.4	97	179	102
	OF	132.0	100	26.3	100	175	100
Late rice	CK	47.2	49	11.4	61	44.2	47
(2^{nd} crop)	OM	52.9	55	11.7	62	54.7	58
	MF	90.0	94	18.5	98	84.8	87
	OF	96.0	100	18.8	100	94.5	100
Barley	CK	24.8	35	6.53	39	23.3	38
(3^{rd} crop)	OM	35.2	50	11.6	69	35.3	58
	MF	60.1	85	11.6	69	45.1	74
	OF	70.3	100	16.7	100	61.1	100

Nutrient recovery rate

The proportion of the nutrients taken up by the crop against the nutrients in the fertilizers applied is defined as nutrient recovery rate or utilization rate. In field experiments, the differential technique is used for calculation. The mean nutrient recovery rate observed in this experiment was similar to what is generally reported for the whole country. In treatment MF, the N and P recovery rate was 28.9% $\pm$ 1.1% and 8.8% $\pm$ 0.53%, respectively. In Treatment OM the N, P and K recovery rate was 11.7% $\pm$ 3.4%, 9.6% $\pm$ 1.5% and 11.5% $\pm$ 1.6%, respectively.

If the recovery rate of mineral N and organic N was determined separately, the recovery rate of the former was significantly higher than that of the latter. The N recovery from mineral fertilizer remained the same in the succeeding crops. In contrast, the recovery rate of organic N improved with the number of crops from 8.6% in the first crop to 16% in the fourth, which is probably associated with the rapid decrease in the supply of readily available N in the plough layer in treatment OM (Table 6).

Depending on the nutrient source (OM or MF), nutrients which were not removed by the crop or lost, i.e. by leaching or volatilisation, remain in the soil and can be utilized by the succeeding crops to a different extent. Obviously, independent of the form (in solution, adsorbed or organic), these residual nutrients can be regarded as residual effect of the fertilizers applied. Since every crop and every year fertilizers are applied,

Table 6. Recovery rate of N in fertilizers as affected by organic manure and mineral fertilizer application, depending on number of crop in the rotation

No. of crop in the rotation	N recovery rate (%)	
	Organic manure (OM)	Mineral fertilizers (MF)
1	8.6	27.5
2	9.3	30.1
3	13.0	29.4
4	16.0	28.6
Mean	11.7$\pm$3.4	28.9$\pm$1.1

the residual effect is determined by the observed cumulative yield increase. Therefore, after consecutive systematic fertilization of the crops grown in the same field, there will still be an upward trend in yields compared to the control, once fertilization is omitted in the year of recording. The long-term residual effect of N can be directly determined by ^{15}N. However, in this experiment, the differential method has been employed to calculate the residual effects of nitrogen (Table 7).

Table 7. N recovery rate of organic manure in comparison to mineral fertilizer determined by the differential technique.

Fertilizers	N recovery rate in different crop (%)				
	1st crop RR	2nd crop RR	3rd crop RR	4th crop RR	Cumulative (1st-4th crop)
Mineral fertilizer	28.9	5.9	0.9	0.5	36.2
Organic manure	11.7	7.9	5.7	1.6	26.9

Note: RR = relative recovery rate.

Table 7 shows that in the 1st crop, nitrogen recovery from mineral fertilizer was higher than from organic manure. In the following years, recovery of N from organic manure was always greater. Nevertheless, the cumulative recovery (1st-4th crop) with 36.2 % in the mineral fertilizer treatment (MF) was greater than in the organic manure treatment (OM) with only 26.9% of the applied amounts.

Soil nutrient balance

Since the 1960's when the cropping system of "three-crops-per-year" was introduced to the suburbs of Shanghai, the balance of soil nutrients became a major concern in crop production of this region. According to the reported research project and the data of previous field experiments, the net depletion of soil nutrients soared, although the nutrient consumption per unit of output (grain) for each crop remained nearly the same

(Table 8). Using the data in Table 8, the total nutrient uptake of each crop was calculated, depending on crop yield (Table 9). The "three-crop-per-year" system produced a total of 13 t ha^{-1} of grain, removing about 253 kg N, 56 kg P_2O_5 and 291 kg K_2O per hectare as much as 53 % more N, 55 % more P_2O_5 and 58 % more K_2O from the soil than the "two-crops-per-year system".

Table 8. Nutrient uptake per unit of crop product as affected by the intensity of the cropping system.

System	Crop	No. of samples	Nutrient uptake (kg 1000 kg^{-1})		
			N	P_2O_5	K_2O
3-crop-per-year	Early rice	14	21.6	0.389	2.44
	Late rice	12	17.3	0.337	2.12
	Barley	22	24.5	0.490	1.49
2-crop-per-year	Single rice	36	18.5	0.390	2.48
	Wheat	6	26.1	0.420	1.30

Note: Data cited from experiments conducted in 1974 –1979.

With 20 kg grain per kg of nutrients in the "three-crops-per-year" system and 22 kg grain per kg of nutrients in the "two-crops-per-year", the former had a 10 % smaller nutrient demand per unit of output. However, due to the larger yields, the more intensive "three-crops-per-year" system caused a stronger strain on soil nutrients.

Table 9. Crop yield and nutrient uptake in fertilized plots as affected by the intensity of the cropping system

System	Crop	Yield ($t\ ha^{-1}$)	Nutrient uptake (kg ha^{-1})		
			N	P_2O_5	K_2O
3-crop-per-year	Early rice	5.4	117	21	132
	Late rice	4.8	83	16	102
	Barley	2.8	69	14	42
	Total	13.0	293	56	291
2-crop-per-year	Single rice	5.7	105	22	141
	Wheat	3.3	86	14	43
	Total	9.0	191	36	184

Note: the yield of single crops in non-fertilized plots was 4.46 t ha^{-1} for rice and 0.906 t ha^{-1} for wheat.

On the other hand, with the rise in nutrient uptake under the "three-crops-per-year" system, the depletion of nutrients also increased. This is indicated by the nutrient removals of unfertilized fields of both crop rotations, showing that removal of all nutrients together was 73 % or 63 %, 106 % and 76 % (N, P_2O_5 and K_2O) larger in the "three-crops-per-year" system (Table 10).

The nutrients taken up by the crop accounts for a large proportion of the readily available nutrients stored in the soil. Under the system of "three-crops-per-year", 88%, 53% and 65% of the available pool of N, P and K were removed from the soil. This is much more than in the "two-crops-per-year" system (Table 11). The proportion of the nutrient removed from the total nutrient stored in the soil was the highest for N, being 4.8% under the former and 2.9% under the latter cropping system. Taking into account that only approximately 5% of N are mineralised annually, the values of 4.8% and 2.9% would be very high. Therefore, in order to sustain the yields under the "three-crops-per-year system, it is essential to apply large amounts of fertilizers and manure and systematically to build up soil fertility.

Table 10. Annual nutrient removal from the soil in non-fertilized fields as affected by the intensity of the cropping system

System	Crop	Nutrient removal (kg ha^{-1})		
		N	P_2O_5	K_2O
3-crop-per-year	Early rice	78.8	18.8	119.0
	Late rice	60.9	15.3	66.0
	Barley	33.5	9.5	30.5
	Total	173.0	43.6	216.0
2-crop-per-year	Single rice	82.5	17.4	111.0
	Wheat	23.6	3.8	11.8
	Total	106.0	21.2	123.0

Table 11. Effect of intensity of cropping system on the depletion of soil nutrients

		N		P		K	
		Total	Available	Total	Available	Total	Available
NSL*	(kg ha^{-1})	3600	196	3803	82	52.7×10^3	327
		Removal by 3-crops-per-year					
	(kg ha^{-1})	173		43.6		212	
	(%)	4.8**	88***	1.1	53	0.4	65
		Removal by 2-crops-per-year					
	(kg ha^{-1})	106		21.2		123	
	(%)	2.9	54	0.6	26	0.2	38

* NSL = nutrients in the surface soil layer (17 cm), **% of total, ***% of available.

Conclusions

1) The experimental soil has an initially high indigenous fertility being able to produce approx. 73% of the yield of fertilized plots.
2) Nutrient use efficiency was greater in mineral fertilizer than in organic manure whereas the combination of both showed the greatest efficiency with 27%.
3) Crops responded differently to the treatment, showing that rice was obviously better in acquiring of soil nutrients than barley which depended more on applied inputs by either mineral or organically bound nutrients.
4) With the duration of the experiment, the yield gap between fertilized and unfertilized crops widened.
5) Consecutive nutrient omission led to an expected significant decline in nutrient uptake, which after 3-4 crops stabilized at around 35-38% of the N uptake of a fertilized plot.
6) Nutrient recovery rate of the whole crop rotation was between 12% and 30% for N, 3% and 9% for P and 12% for K (from the organic manure).
7) There were clear differences in the nutrient recovery between organic manure and mineral fertilizer with the latter being 2-3 times larger.
8) Recovery rate of N from organic manure increased with the number of crops whereas that of mineral N remained the same.
9) Soil nutrient balance was affected by intensity of cropping, being more negative in the 3-crops-per-year rotation than in the 2-crops-per-year rotation, leading to a dramatic depletion of the available nutrient pools in the soil.

Crop response to fertilizer application and nutrient balance in a fluvio-aquic soil in Henan

Qin Shengwu, Gu Yichu and Zhu Zhaoliang

Institute of Soil Science, Chinese Academy of Sciences, 210008

Abstract

A long-term (1989-1999) stationary field experiment has been conducted on crop response to several major types of fertilizers. Furthermore, the effect of applying different fertilizer combinations on soil nutrient supply capability of a yellow fluvio-aquic soil in the Henan Province was studied. Results indicate that the yield-increasing potential of fertilization of yellow fluvio-aquic soil is large, but currently the response of crops grown in poor fluvio-aquic soils to the application of single N or single P is rather limited. As soon as both nutrients are applied in combination, crop response is highly significant. In the so-called "gold-gilded land", crop cultivation in fluvio-aquic soils for 10 successive years without any application of K fertilizers or organic manure did not affect the yield of wheat and maize to any significant extend, thanks to the K-rich clay soil below the plough layer. However, the readily available and slowly available K in the plough layer depleted rapidly. The apparent cumulative mean recovery rate (58.5%) for N and P of the 10 years is much greater than the 48.1% obtained from a single crop experiment. Under the current cultivation pattern and yield level, most fluvio-aquic soils have a positive N and P as well as organic matter balance, but show a negative balance for K.

Introduction

Fluvio-aquic soils constitute a large proportion of Henan's soils and are regarded as important crop production base in the province. The soils are generally regarded as rich, especially with regard to K reserves so that in the past no or only limited response to K application was observed. With the intensification of crop production and the long-term omission of potassium, the situation in the nutrient supply power of the soil should have undergone dramatic changes within the past decade. It is therefore the purpose of this experiment to study yield response to various nutrients and the nutrient supply capability of the yellow fluvio-aquic soils in the Huang-Huai-Hai Plain under current crop management and fertilization practices. Furthermore, development trends as caused by different fertilization patterns are studied, depending on the form and content of the major nutrients in soils and how they vary over time after long-term organic manure and mineral fertilizer applications. Finally, trends regarding soil fertility and economic returns from fertilization were assessed. The preliminary results obtained during 10 years of experimentation are reported in the following.

Experimental design and methodological approach

Design of the experiment

The experimental site is situated within the Fengqiu Agro-ecological System Experiment Station, Chinese Academy of Sciences in Henan Province. The soil for the experiment is a light loam yellow fluvio-aquic soil (Lianghetu) with a clay layer at a depth between 40 and 60 cm. The local farmers call the soil "Gold-gilded land". During the three years preceding the experiment, the land had been cultivated without any fertilization to achieve proper trial conditions. In the fall of 1989, the experiment was formally started, when the soil was rather poor in soil fertility. Analysis of the soil for nutrients had been conducted right before the start of the experiment with results shown in Table 1.

Table 1. Soil nutrient contents at the beginning of the experiment

O.M. ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Total P ($g\ kg^{-1}$)	Total K ($g\ kg^{-1}$)	R.A. N ($mg\ kg^{-1}$)	R.A. P ($mg\ kg^{-1}$)	R.A. K ($mg\ kg^{-1}$)	S.A. K ($mg\ kg^{-1}$)	pH
5.83	0.445	0.50	18.6	9.51	1.93	78.8	558.0	8.65

Note: O.M. stands for organic manure, R.A. for readily available and S.A. for slowly available

The experiment consisted of seven treatments with four replicates. The plot size for each treatment was 47.5 m^2. The entire experiment was divided into four blocks arranged at random.

The seven treatments of the experiment were: 1) CK (no fertilization); 2) NK; 3) PK; 4) NPK; 6) O.M.; and 7)1/2 O.M. + 1/2 NPK. The fertilizers used in the experiment were urea for N, single superphosphate for P and potassium sulphate for K. Their application rates are shown in Table 2. Organic manure (O.M.) was mainly composed of fragmented wheat straw, 4,500 kg ha^{-1} and a certain amount of ground soybean cakes or cottonseed cakes added to raise N content in the organic manure.

Table 2. Fertilization rates applied to the trial field

Crop	Time of dressing	N fertilizer (N kg ha^{-1})	P fertilizer (P_2O_5 kg ha^{-1})	K fertilizer (K_2O kg ha^{-1})
Wheat	Basal	90	75	150
	Side dressing	60	0	0
Maize	Basal	60	60	150
	Side dressing	90	0	0

The shortage of P and K in the organic manure was made up with P and K fertilizers. The application rate in the experiment was only moderate in comparison to the fertilizer rates used by local farmers.

The cropping system was a "two-crops-per-year" rotation system of "wheat –maize" with the varieties extensively grown in the region. After the harvest of maize in the fall of each year, samples for laboratory analysis were taken from the plough layer, and every five years samples were taken from the soil layer at a depth of 20 ~ 40 cm. Samples of plants for laboratory analysis were also collected after each crop was harvested.

Results and Discussion

Crop yield response to combined N and P fertilizer application to a fluvio-aquic soil

As the fluvio-aquic soil is deficient in both N and P, the mean yield of wheat over ten years in the CK is only 603 kg ha^{-1}, even with irrigation, yields only reached about 12% of those in treatment NP. If only one nutrient was applied no matter whether N or P, there was hardly any effect and yields were not increased compared to CK. Rational nutrient combination of N and P raised yields of wheat and maize in the same year to a rather high level, even if the application rate was only moderate in comparison to local practice. Continued balanced fertilization of N and P was able to maintain high crop yield successively. In the experiment, the mean yield of wheat in the NP treatment has reached 5,118 kg ha^{-1} and the yield of maize 7,328 kg ha^{-1} (Table 3), indicating that the yield-increasing potential of fluvio-aquic soil is great if it is properly fertilized. The returns from fertilization of the fluvio-aquic soil are also significant, showing that one kg of fertilizer (N or P_2O_5) increased maize grain yields by 20.07 kg and those of wheat by 31.58 kg. Wheat was supplied with 225 kg ha^{-1} N and P_2O_5 and maize with 210 kg ha^{-1} N and the same amount of P_2O_5.

Table 3. Treatments mean yield (kg ha^{-1})

Crop	Year	Treatment						
		CK	NK	PK	NP	NPK	O.M	1/2O.M+ 1/2NPK
Wheat	1990-1999	603	651	1166	5118	5120	3623	4937
Maize	1990-1999	696	747	1352	7328	7409	5863	7329

Variation of soil K during the 10 years and response to K fertilizers of crops grown in fluvio-aquic soil

According to soil analysis (Table 1), the initial content of readily available K in the tested soil with 78.8 mg kg^{-1} was rather on the low side. Nevertheless, during the studied 10 years, the application of 150 kg ha^{-1} K_2O (potassium sulphate) did not lead to any significant crop response for both crops, wheat and maize. The only exception was 1997 when maize responded significantly to K application (Table 3 and Fig. 1). Analysis of the plant samples also revealed that the application of K fertilizers did not significantly increase the K content in the grains and straw of wheat and the grains of maize. Only in the stalks of maize, the K content was significantly higher than that in treatments without K.

This observation of the general insignificant response to K of especially wheat may be explained by the fact that the tested soil had a clay layer at the depth of 40 ~ 60 cm, functioning as a rich K pool. Under the current cultivation conditions with a medium target yield, the soil can basically meet the K demand of the crops with no K or organic manure applied for 10 years. A calculation showed that in treatment NP (no K applied) the aerial parts of the crop have cumulatively removed a total of 1,684 kg ha^{-1} K from the soil, thus causing a rapid drop in soil K content in the topsoil. The decline began with readily available K in the plough layer and halted after 3 years at the critical level of approx. 60 mg kg^{-1}. Then the soil K content lingered around the critical level for the remaining 7 years. The content of slowly available K did not change much within the first 5 years and then started to drop rapidly from 558 mg kg^{-1} to 461 mg kg^{-1} in the 10th year (Table 4).

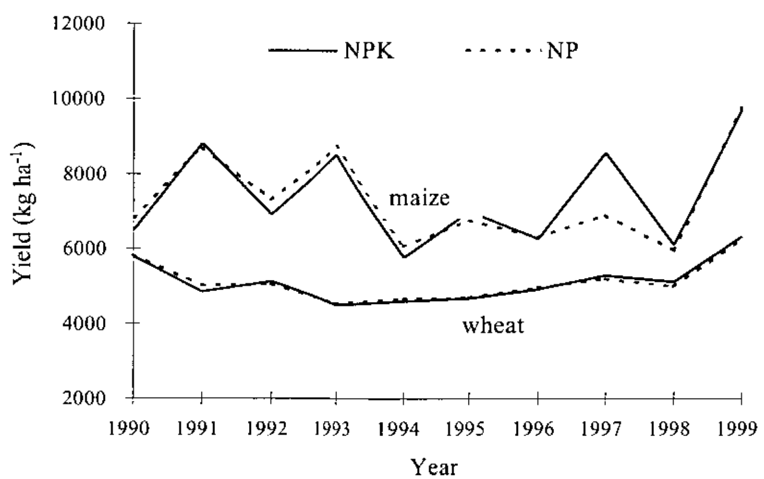


Figure 1. Effect of K fertilization on crop yield over ten years of experimentation

With the depletion of the K pools in the soil, in the fifth year of the experiment (1993) during the pre-winter phase of wheat, a significant difference was observed in seedlings between the treatments NP and NPK. The difference became however unnoticeable when the crop came into the shooting phase in the following spring (April 1994). During the five years that followed, the content of soil K in treatment NP decreased further.

Table 4. K uptake by crops and variation of soil K content in different treatments

Treatment	K rate (kg K_2O ha^{-1})	Annual K removal (kg K_2O ha^{-1})	1989		1994		1999	
			R.A. K	S.A. K	R.A. K	S.A.K	R.A. K	S.A. K
NP	0	168	78.8	558.0	59.5	558.9	57.1	460.9
NPK	249	226	78.8	558.0	119.7	641.1	136.7	560.7

The seedlings of wheat and maize were significantly poorer in growth than those in treatment NPK, especially during drought years. With the plants growing taller, their root system developed and stretched into the deep K-rich soil layer, taking up readily available K which was then replenished by release from the slowly available pool. The clay layer at a depth of 40 ~ 60 cm, containing much higher K than the surface layer of the sandy loam can therefore serve as a K source that is available to plants in their late growth stage. These are reasons why the K deficiency symptoms disappeared in the late growth stage of the crop in treatment NP, and there was no big difference between treatment NP and treatment NPK in grain yield.

The experiment also showed that soil K supply is significantly related to the soil moisture regime. In normal years, during the wheat and maize growing periods, the soil moisture regime is often favourable and does not affect K supply to the plants very much. In 1997, drought occurred during the maize growing period. The soil moisture supply was reduced. In that year, the maize performance in treatment NP was significantly poorer than that in treatment NPK throughout the whole growing period from seeding to harvesting. The grain yield was 19.4% less. Nevertheless, this phenomenon appeared only once during the whole duration of the experiment of 10 years.

Although the application of K fertilizers to fluvio-aquic soil did not have any significant yield response in cereals (except in fields of sandy topsoil), the soil K content of fluvio-aquic soil has dropped drastically in the recent 20 years. According to stationary monitoring of different soil types in five prefectures (cities) of Henan Province and the stationary investigation of the 10,000 mu (666.7 ha) experiment zone of the Fengqiu Agro-ecological Experiment Station of the Chinese Academy of Sciences, readily available K dropped at a rate of 10 - 15% every 3 - 5 years and 25 - 30% every 10 years.

With the increase in NP application rate and the resultant increase in crop yield, it is quite common to have one hectare of farmland to produce over 15 tons of grain (two crops per year). As a result, 225 kg K_2O ha^{-1} are removed annually in the harvested crop from the soil. The local farmers, however, seldom apply K fertilizers. According to the 1998 statistics, on average only 44.55 kg K_2O ha^{-1} were applied in Henan Province. It is even worse in Fengqiu where only 13.65 kg K_2O ha^{-1} were applied. The replenishment of soil K relies mainly on organic manure and straw returned to the field. Statistics show that about 50% of the K recycled in the cropping system comes from either organic manure or the straw returned to the field.

Comparison of the apparent cumulative mean recovery rate of N in fertilizers with that in the year the fertilizers were applied

Research findings of many research institutions showed that in calcareous fluvio-aquic soils derived from loess, the N recovery rate in the same year is very low. With wheat and maize the N recovery rate is only 34 - 45%, even if the fertilizers are applied properly. The main route of N loss is denitrification. The N recovery rate with rice is much lower, only 17 - 28% when the fertilizers are applied conventionally. The main route of N loss in irrigated rice is ammonia volatilization.

In the late 1980's, the Institute of Soil Science, Chinese Academy of Sciences conducted a micro-plot field experiment with ^{15}N tracing technique in the Fengqiu Agro-ecological Experiment Station. Results showed that on average only 42.1% of the ^{15}N fertilizer applied to the crop was recovered by wheat plants and 32.6% by maize plants.

The plants absorbed N not only from the fertilizers applied to the crop during their growing period but also to a large degree from the N stored in the soil. The latter is mostly residual N from previous application of mineral fertilizers and organic manure. So, the N recovery rate obtained from the long-term stationary experiment (the apparent cumulative mean recovery rate) is much higher than the recovery rate obtained in a single crop experiment. The apparent cumulative mean recovery rate of fertilizer N of upland fluvio-aquic soil was 57.8% in wheat, 59.2% in maize (Table 5). The data show that in the long run the final apparent cumulative mean recovery rate was much greater than the recovery rate of the fertilizer N applied to the crop in an ordinary field experiment. This can serve as a relatively reliable scientific basis for the calculation of the farmland N balance that has long been treated with mineral N fertilizers.

Table 5. Ten years' apparent cumulative mean recovery rate of fertilizer N

Crop	Fertilizer N applied ($kg\ ha^{-1}$)*		N removed from the soil ($kg\ ha^{-1}$)**		Apparent N recovery rate (%)***	Recovery rate by ^{15}N tracing technique (%)
	NPK	PK	NPK	PK		
Wheat	1500	0	1077	210	57.8	< 42.1
Maize	1500	0	1171	283	59.2	< 32.6

Note: * and ** are both cumulative values of the 10 years and *** is apparent cumulative mean recovery rate.

Accumulation, transformation and apparent cumulative mean recovery rate of fertilizer P from calcareous fluvio-aquic soils

In a calcareous fluvio-aquic soil of the Huang-Huai-Hai Plain, besides the amount of P removed by the crop, a large proportion of the fertilizer P applied was transformed from soluble Ca_2-P into slowly available Ca_8-P whereas a small fraction remained as

Al-P and Fe-P in the soil. The slowly available proportion of P is likely to have a residual effect to the succeeding crops. In this long-term experiment, after P fertilizers were applied to the first 10 crops during the first 5 years, the soluble P and slowly available P significantly accumulated, while the content of fixed P, Ca_{10}-P did not change much (Figure 2). After 10 years of continued P fertilizer application, a large proportion of the applied P has accumulated in the soil in the form of readily available and slowly available P, rather than being transformed into apatite or other unavailable forms.

A number of experiments carried out all over China, whether in the field or in the pot and partly using radioactive isotopes showed that the P fertilizer recovery rate of the crop to which it is applied is roughly 10 - 25%. In the early 1980's, an experiment conducted by the P Research Team of the Institute of Soil Science, Chinese Academy of Sciences in Fengqiu revealed that the apparent recovery rate of single superphosphate in wheat was 15.9% and in maize it was 11.4%. On the other hand, the experiment carried out by the Chinese Academy of Agricultural Sciences in North China showed that the P fertilizer recovery rate was 18%.

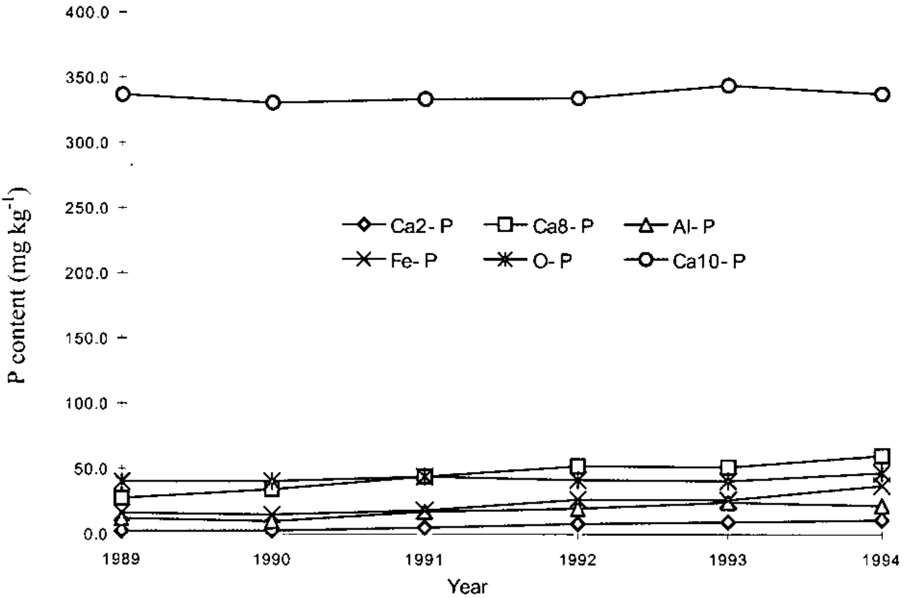


Figure 2. Changes of P forms in the soil of the PK treatment

In this experiment, the apparent cumulative mean recovery rate of P fertilizer (single superphosphate) was relatively high, being about 35.8% for wheat, 63.5% for maize and 48.1% on average, which is much higher than the results obtained in the single P fertilizer test (Table 6).Apparent cumulative recovery rate of P fertilizer refers to the percentage of the total fertilizer P absorbed consecutively by a series of crops against the amount of fertilizer P applied. In this long-term experiment, however, the P fertilizer was applied according to common practice, i.e. a certain amount of P fertilizer was applied to every crop and every crop was harvested. Thus, we eventually get the mean P recovery rate of the 20 crops in 10 years. In order to distinguish this from the above-mentioned apparent cumulative recovery rate, this is called the apparent cumulative mean recovery rate.

Table 6. Apparent cumulative mean recovery rate of fertilizer P in 10 years

Crop	Fertilizer P applied (kg ha^{-1})*		P removed from the soil (kg ha^{-1})*		Apparent P recovery rate (%)**	Recovery rate in single crop experiment (%)
	NPK	NK	NPK	NK		
Wheat	327.3	0	132.8	15.8	35.8	15.9
Maize	261.8	0	192.2	26.0	63.5	11.4

Note: * cumulative values of the 10 years and ** is the apparent cumulative mean recovery rate.

The apparent cumulative mean recovery rate of P fertilizer obtained in this experiment was 48.1%, which means that under the current cultivation conditions in the Huang-Huai-Hai Plain any P fertilizer applied to the field 50% will be at least absorbed and utilized by the crops. This can be used as a reliable basis for evaluating soil P balance in the region, and at the same time P recovery calculations can serve as a reliable parameter for rational application of P fertilizers. Continued P application over years has raised soil P nutrient levels in the soils in certain regions to such an extent that fresh P application to a crop does not lead to yield response to P anymore.

Developmental trends in the nutrient contents of fluvio-aquic soils under different combinations of fertilizer application

Combined N and P fertilization

In treatment NP of this experiment, mineral N and P fertilizers were applied to every crop every year (see Table 2) at rates which were 35% and 80% larger than the absorption by the plants. The used rates were defined as medium, whereas the yield response to the application can be classified as medium to high based on the observations in similar experiments.

Since the tested soil originally had a poor fertility, which was further depleted by cropping without any fertilizer application for three years prior to the experiment, the inherent nutrient availability of the soil was very poor (see Table 1). Due to the treatments during the 10 years of cultivation, the total soil N content rose significantly from 0.445 g kg^{-1} to 0.534 g kg^{-1} in the first 3 years, and then lingered around that level in the following seven years. In contrast to that, the available N fraction showed a continuous increase until the final year without indicating a particular pattern between years (Table 7).

The content of total P reflected a regular pattern. In the first year, readily available P jumped from 1.93 mg kg^{-1} to 3.06 mg kg^{-1} and then stabilized around this level. It increased only by 1.4 mg kg^{-1} within 9 years.

Table 7. Changes in the soil nutrient contents of plough layers of the treatments during ten years (1989-1999).

Year	Treatment	Total N (g kg^{-1})	Total P (g kg^{-1})	Total K (g kg^{-1})	r.a. N (mg kg^{-1})	r.a. P (mg kg^{-1})	r.a. K (mg kg^{-1})	s.a. K (mg kg^{-1})	O.M. (g kg^{-1})
1989	Original	0.445	0.495	18.6	9.51	1.93	78.8	558.0	5.91
1994	CK	0.459	0.486	19.3	6.81	1.23	67.7	601.9	5.93
	NK	0.480	0.492	19.2	31.4	1.31	222.1	681.7	6.04
	PK	0.520	0.576	19.3	7.02	10.3	207.7	648.5	6.37
	NP	0.534	0.544	18.9	6.93	2.90	59.5	558.9	7.38
	NPK	0.582	0.547	19.2	7.66	3.17	119.7	641.1	7.45
	O.M.	0.740	0.544	19.2	8.87	6.21	126.5	638.6	11.6
	1/2O.M.+ 1/2NPK	0.634	0.534	19.4	8.42	3.81	116.0	626.1	9.41
1999	CK	0.420	0.492	19.5	13.2	0.909	68.4	462.9	5.99
	NK	0.433	0.496	20.1	33.5	1.05	299.7	568.3	6.44
	PK	0.464	0.677	20.5	12.1	17.1	254.9	610.1	7.26
	NP	0.531	0.616	19.4	17.2	4.46	57.1	460.9	8.18
	NPK	0.553	0.610	18.9	17.2	4.54	136.7	560.7	8.19
	O.M.	0.813	0.583	19.6	20.7	6.87	147.6	569.1	12.2
	1/2 O.M. +1/2 NPK	0.639	0.597	20.0	17.9	6.75	141.1	574.8	10.0

Note: Original = nutrient contents determined prior to the experiment, r.a. stands for readily available, s.a. for slowly available and O.M. for organic matter.

As treatment NP did not receive any K, neither in the form of fertilizer nor through organic manure, the fertilizer management in the experiment put a heavy strain on the K reserves of the soil, because during the ten years the crops removed a total of 1,680 kg ha^{-1} K, about 168 kg ha^{-1} per year from the soil. However, as the soil has a large total K pool, no significant changes in this parameter was observed. The content of readily available K, however, dropped from 78.8 mg kg^{-1} to 61.2 mg kg^{-1}, almost to the critical value (60 mg kg^{-1}) during the first three years. And in the seven following years, the content fluctuated around the critical value instead of dropping further. Slowly available K did not change much during the first five years and then dropped from 558.0 mg kg^{-1} to 460.9 mg kg^{-1} during the last five years. It seems to be clear that during the first five years the K absorbed by the crops was mainly readily available K and during the following five years the K taken up by the crops mainly derived from the slowly available K pool in the soil.

As in treatment NP, the two fertilizers were applied in combination, the crops grew normally and produced a fairly high yield. As a large amount of crop residues remained in the soil, soil organic matter rose slowly with a distinct pattern from 5. 91 g kg^{-1} to 8.18 g kg^{-1}.

NPK combined fertilization

In treatment NPK, the changes in soil N, P and organic matter were similar to those in treatment NP (see Table 7). Since this treatment received 150 kg ha^{-1} K_2O in form of K fertilizers which was 10% higher than K removed by the crop, the content of readily available K soared from 78.8 mg kg^{-1} to 196.7 mg kg^{-1} within ten years.

Application of organic manure only

Treatment O.M. was designed to simulate a fertilization pattern of applying only organic manure. In order to keep abreast with other treatments, a small amount of P and K fertilizers were applied to make up the P and K shortage in the organic manure.

As organic manure is not suitable for side dressing due to its slow release of nutrients, the manure was applied as basal dressing to meet the requirement of the crops during the vegetative period. Mineral fertilizer was applied in a split application divided into basal and side dressing. This may explain that the efficiency of the organic manure is slightly lower than if an equal amount of nutrients in the form of mineral fertilizers was applied. The 10 years of experiment showed that the yield of wheat and maize in treatment O.M reached only 70% and 80% of that in treatment NPK (see Table 3).

However, with regard to soil nutrient accumulation, O.M. was superior to treatment NPK, especially in terms of soil organic matter content, which increased steadily during the ten years from 5.91 g kg^{-1} to 12.2 g kg^{-1}. In NPK, however, soil organic matter rose only from 5.91 g kg^{-1} to 8.19 g kg^{-1}, equivalent to 38%.

Furthermore, soil physical properties developed more favourably in treatment O.M. than in the other treatments with mineral fertilizers only. This is reflected by reduced bulk density, improved soil porosity, larger water-holding capacity, better water permeability and enhanced soil aggregation in the O.M. plots.

Experience, however, shows that availability of organic manure is limited and it is virtually not feasible to advocate the road of so-called "organic farming" which would depend solely on organic manure. Only by making full use of organic manure, excluding any resources of organic manure that may pollute the environment (contaminated material) and utilizing organic manure in combination with mineral fertilizers, a sustainable agriculture can develop.

Organic manure applied in combination with mineral fertilizers

In the experiment, treatment 1/2 O.M. + 1/2 NPK was arranged to simulate the local fertilization practice of farmers, relying on mineral fertilizers as main nutrient sources for N and P supplemented by organic manure. In recent years, however, this practice has dramatically changed and local farmers reduced the application of organic manure, which currently contributes far less than 1/2 of the total nutrient input.

Crop response in treatment 1/2 O.M. + 1/2 NPK was greater than the mean of those in the treatments O.M. and NPK, which is attributed to the interaction between organic manure and mineral fertilizers. The results of the experiment showed that the yield increase attributed to the interaction between organic manure and mineral fertilizer was 12.9% in wheat and 10.4% in maize (Table 8).

Table 8. Yield increase attributed to the combined effect of organic manure and mineral fertilizers

Crop	I 1/2 O.M+1/2NPK	II 1/2 O.M	III 1/2NPK
	----------kg ha^{-1} ----------		
Wheat	4937	1812	2560
Maize	7329	2932	3705

The effect of treatment 1/2 O.M. + 1/2 NPK on accumulation of soil nutrients was reduced compared to that of treatment O.M. alone but much larger than that in treatment NPK (see Table 7).
Combined application of N and P coupled with organic manure as supplement is the major fertilization pattern in agricultural production in North China. This pattern, however, supplies only a small amount of K, far below the amounts required to compensate for the K removed in the harvested crop. As a result, a serious K deficit appears in the K balance.

Conclusion

1) In the Huang-Huai-Hai Plain, the potential of fertilization to increase crop yield on fluvio-aquic soil is great and yield response to a combined N and P application is significant. This is explained by the fact that the soil is low in fertility and has a poor ability to conserve nutrients. Therefore, crop yields usually drop to very low levels, once fertilization with these two nutrients is discontinued.
2) The loamy fluvio-aquic soil with its rich K pool and the existence of a clay layer underneath the plough layer is able to ensure a good crop yield for 10 years without applying organic manure or K fertilizers. But the content of readily available K in the plough layer dropped from 78.8 mg kg^{-1} to 61.2 mg kg^{-1} during the first three years. Slowly available K decreased by nearly 100 mg kg^{-1} during the 10 years.
3) The long-term experiment showed that the apparent cumulative mean recovery rate of fertilizer N determined by ^{15}N dilution technique was 58.5%, much larger compared to 32 - 42% if only one cropping year is considered. The apparent cumulative mean recovery rate of P fertilizer was 48.1%, more than twice as much as the 10 - 25%, usually found for P fertilizers in the crop to which it has been applied.
4) Under the current fertilization pattern based on N and P fertilizers with organic manure as supplement, soil nutrients of fluvio-aquic soils are not balanced. Generally, N and P nutrients and organic matter are slightly accumulating whereas K seriously depletes over the years. Therefore, increased emphasis needs to be placed on the K supply as a standard practice in the nutrient management of fluvio-aquic soils.

Nutrient balance of a rice-rice rotation in paddy fields on a red earth soil of Jiangxi

Lai Qingwang, Li Chagou, Lai Tao, Huang Qinghai and Yu Jinxiang

Jiangxi Province Red Soil Research Institute 331717

Abstract

The effect of fertilization on yield, nutrient balance and nutrient recovery was studied in a long-term rice-rice-green manure rotation on a paddy soil derived from red earth, over a period of 18 years (1981-1998). The treatments consisted of a control (CK), N_1, P_1, K_1, N_1P_1, N_1K_1, P_1K_1, $N_1P_1K_1$, $N_1P_1K_1$+ O.M. (including organic manure) and $N_2P_2K_2$. Results show drastic differences in the cumulative yields being in the order N1P1K1+ O.M. > $N_2P_2K_2$ > $N_1P_1K_1$ > N_1P_1 > N_1K_1 > N_1 > P_1K_1 > P_1 > K_1 > CK. With the exception of two treatments, $N_1P_1K_1$+ O.M. and $N_2P_2K_2$, yields continuously declined from the first until the last year of experimentation. Largest yield declines were observed in K_1 and smallest in the N_1 treatment. The nutrient budgets calculated as the total input over 18 years minus the total output (grains and straw) showed that nutrient balances varied greatly between the nutrients and treatments involved. Negative balances for N occurred in those treatments without N application in the order P_1K_1 > P_1 > K_1 > CK. Strongly positive balances were especially observed in $N_1P_1K_1$+ O.M. and $N_2P_2K_2$, which in the former treatment reached almost 3.5 tonnes of N per hectare over 18 years or 194 kg N ha^{-1} yr^{-1}. For P, similar trends were observed and a P depletion of the soil between 870 and 994 kg P_2O_5 ha^{-1} or 48 and 55 kg P_2O_5 ha^{-1} yr^{-1} was recorded in plots without P application. P accumulation as indicated by a positive P balance was smallest with an amount of 303 kg ha^{-1} in the $N_1P_1K_1$ treatment and exceeded 1.5 t ha^{-1} in $N_2P_2K_2$ over the whole study period. Negative balances for potassium occurred in all treatments without K but also in N_1K_1, P_1K_1 and $N_1P_1K_1$, showing that the application of K in these treatments was not sufficient to balance the removals by grain and straw. The most severe K depletion of the soil of up to 2.3 t ha^{-1} was observed in P_1, followed by CK and N_1P_1 at the amount of 1.9 and 1.8 t ha^{-1}. Nutrient recovery efficiency varied dramatically between nutrients and treatments. Cumulative recovery (36 crops) was in the order K >> N > P, following the fertilization practice, it was largest in the balanced (NPK treatments) and smallest in the unbalanced treatments (N_1; P_1, K_1, etc.). Soil chemical analysis at the beginning and at the end of the study period indicate a general decline in soil fertility parameters with the exception in $N_1P_1K_1$ + O.M. and $N_2P_2K_2$, where soil fertility levels could be maintained. P application at the rates applied, generally led to an increase in Olsen P in the soils.

Introduction

Rice-rice-green manure are the typical crop rotations on a paddy soils developed from red earth in the sub-humid to humid subtropical region of the Jiangxi Province. The increasing demand for mineral fertilizers to sustain the production of two to three crops per year has resulted in an increased demand for improved fertilizer recommendations. For this purpose a long-term experiment was set up to study various treatments with different nutrient rates from mineral fertilizer, including one treatment with organic manure. Main focus is laid on studying annual grain yields and cumulative nutrient balances over a period of 18 years or 36 crops. Furthermore, the aim of the study is to record changes in the soil nutrient status over time as affected by the fertilizer management.

Materials and methods

The study was carried out in the experimental field of the Red Soil Research Institute in Jiangxi. Prior to the experiment, the field had been cultivated by a rice-rice-green manure rotation, with an average rice yield of 9000 kg ha^{-1} yr^{-1}. The paddy soil derived from a quaternary red clay which had a profile described as A-P-W_1-W_2. The experiment consisted of 10 treatments with CK (Control without fertilization); N_1, P_1, K_1; N_1P_1; N_1K_1; P_1K_1; $N_1P_1K_1$; $N_2P_2K_2$; $N_1P_1K_1$ + O.M. The fertilizer application rates were N_1 = 90 kg N ha^{-1}, P_1 = 45 kg P_2O_5 ha^{-1} and K_1 = 75 kg K_2O ha^{-1}; N_2 = 180 kg N ha^{-1}, P_2 = 90 kg P_2O_5 ha^{-1} and K_2 = 150 kg K_2O ha^{-1}. The Organic manure (O.M.) in $N_1P_1K_1$ + O.M. consisted of 22,500 kg ha^{-1} (milk vetch for early rice and pig dung for late rice). The plot size for each treatment was 46.67 m^2 and each treatment had three replications, randomly arranged. The experiment began in 1981 with early rice under a rotation system of rice-rice-winter fallow. The varieties of early and late rice were changed every five years. Soil and plant samples were taken for analysis of readily available nutrients every year or every crop during the period from 1981 to 1990 and once every two years during the period from 1991 to 1998. Soil samples were taken after the late rice was harvested, and nutrient analysis was conducted using conventional methods.

Results and discussion

Variation of rice yield under long-term fertilization

The cumulative rice yield of the 36 crops in 18 years varied from treatment to treatment, following the order of $N_1P_1K_1$ + O.M. > $N_2P_2K_2$ > $N_1P_1K_1$ > N_1P_1 > N_1K_1 > N_1 > P_1K_1 > P_1 > K_1 > CK. This shows a trend that the combination of organic manure with mineral fertilizers in a long-term cultivation is superior to mineral NPK only, as shown by the differences between $N_1P_1K_1$ + O.M. and $N_1P_1K_1$.and $N_2P_2K_2$. (Figure 1). Comparing the yields of the first year of the experiment (1981) and those of the final year (1998), the different treatments can be analysed with regard to their long-term yield trends, giving an indication about their sustainability. It is interesting to note that in all treatments the rice yields declined after 36 crops were continuously grown in rotation on the same field. The only exceptions were the treatments $N_2P_2K_2$ and $N_1P_1K_1$+ O.M. with yield increases of 9.4% and 10.5% over the 18 years (Figure 2).

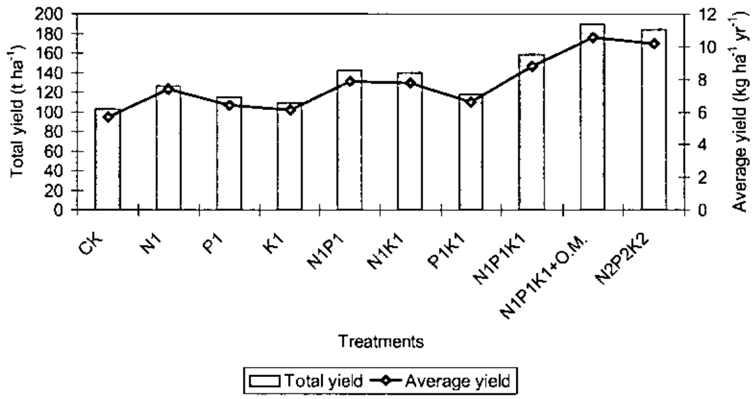


Figure 1. Cumulative rice yields (t ha^{-1}) over 18 years (36 crops) and annual average yields (2 rice crops) in a long-term experiment as affected by nutrient application

The yield declines in the other treatments were substantial and reached levels between –0.1% in N_1P_1 and –21.5% in K_1. This shows that sustained high yields can only be achieved by a balanced supply of nutrients. Larger yields in $N_1P_1K_1$+O.M. compared to $N_2P_2K_2$ may be attributed to a better supply of nutrients, possibly others than NPK, since the supply of Ca, Mg and sulphur on the red earth soils may have also become yield limiting factors after 18 years of intensive cultivation.

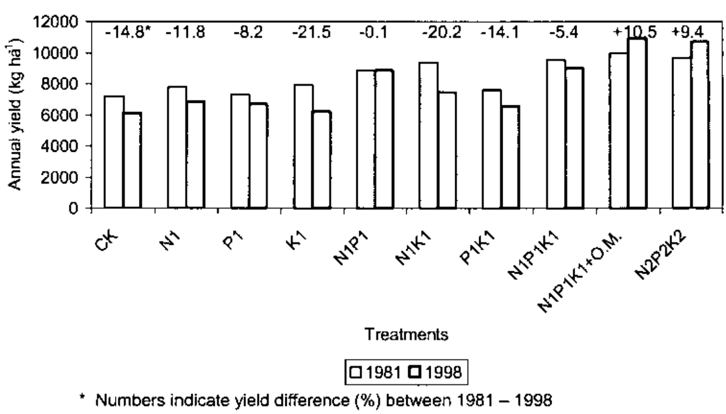


Figure 2. Comparison of yields during the first cropping season (1981) and the final crop (1998) and proportional yield decline (%) after 36 harvests

Nutrient balances and nutrient recovery

A nutrient budget for each treatment was calculated by the nutrient input minus the nutrient output. For technical reasons, only the input by fertilizers was taken into account and no estimate for nutrients supplied by rainfall and irrigation water was made. Nutrient output was calculated on the basis of removed biomass and nutrients contained in the grains and straw. The nutrients left in the field in form of crop stubbles and roots were not taken into account. Nutrient recovery efficiency (RE) was calculated by deducting the nutrient uptake of a non-fertilized plot (indigenous soil nutrient supply) from the uptake of a fertilized plot, than dividing it by the amount applied, according to the formula:

$$RE(\%) = [(NU_{fert.} - NU_{unfert.}) / N_{applied}] \times 100, \qquad (1)$$

where NU_{fert} is the nutrient uptake of the fertilized plot, NU_{unfert} the nutrient uptake in the unfertilized plot and $N_{applied}$ the nutrient applied.

Nitrogen

The nitrogen balance was negative for all treatments without N application (CK, P_1, K_1, P_1K_1) at amounts accumulating to approximately 1.5 t ha^{-1} on average over the whole study period. The nitrogen in these treatments can be regarded as the indigenous supply from the soil (Table 1). In all the treatments receiving nitrogen, the cumulative N balance was positive between 655 kg N ha^{-1} (equal to 36 kg N ha^{-1} yr^{-1}) in $N_1P_1K_1$ and 3458 N ha^{-1} (equal to 192 kg N ha^{-1} yr^{-1}) in $N_1P_1K_1$+O.M. From this it is evident that the latter treatment led to a dramatic over-supply of nitrogen whereas the former with the smallest positive N balance, however, was clearly inferior with regard to yields (see Figure 2). Using the figures of average uptake of those plots which didn't receive any nitrogen from mineral fertilizer (mean of CK, P_1, K_1, P_1K_1 in Table 1) as indigenous nitrogen supply from the soil, the recovery efficiency was calculated according to above shown equation 1.

Table 1. Cumulative nutrient budget of a rice-rice rotation (36 crops) calculated based on the total inputs and outputs (crop removal) as affected by different fertilization treatments (kg ha^{-1})

Treat-ment	Input			Output			Balance		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
CK				1405.6	796.5	1920.8	-1405.6	-796.5	-1920.8
N_1	3330			2173.5	967.2	1495.4	1156.5	-967.2	-1495.4
P_1		1665		1591.8	1034.1	2256.9	-1591.8	630.9	-2256.9
K_1			2775	1506.4	873.0	2662.5	-1506.4	-873.0	112.5
N_1P_1	3330	1665		2302.6	1201.2	1813.5	1027.4	463.8	-1813.5
N_1K_1	3330		2775	2197.8	994.6	3424.2	1132.2	-994.6	-649.2
P_1K_1		1665	2775	1630.0	1094.6	2910.6	-1630.0	570.4	-135.6
$N_1P_1K_1$	3330	1665	2775	2674.6	1361.6	3685.4	655.4	303.4	-910.4
$N_2P_2K_2$	6660	3330	5550	3542.4	1826.1	5202.0	3117.6	1503.9	348.0
$N_1P_1K_1$ +OM.	6660	3330	5550	3201.9	1877.1	4883.0	3458.1	1452.9	667.0

The results show that cumulative recovery efficiency (including 36 crops) of applied nitrogen varied depending on treatment between 19% in N_1 and 34.3% in $N_1P_1K_1$ (Table 2). These values indicate an extremely poor recovery of applied nitrogen over the years. Though balanced nutrition ($N_1P_1K_1$) almost doubled the recovery efficiency of nitrogen, the results emphasize the importance of increased efforts to overcome the poor utilization of nitrogen which is a major reason for detrimental effects of agriculture on the environment.

Phosphorus

As could be expected, the plots without P application revealed a dramatic depletion of P from the indigenous soil reserves which was between -796 and -995 kg ha^{-1} (44-55 kg ha^{-1} yr^{-1}). The nutrients N and K were promoting the uptake of P by the plants and hence triggering the P depletion of the soil as it is evident from the order of the negative balance: $N_1K_1 > N_1 > K_1 >$ CK (see Table 1). With a total input of P_2O_5 of 1665 kg ha^{-1} in P_1 and 3,330 kg in P_2, an output of between 1034-1361 kg ha^{-1} in P_1 and more than 1877 in P_2, the balance shows a surplus in phosphorus which cumulated to 303-631 kg ha^{-1} in the P_1 and up to 1504 kg ha^{-1} in P_2. The surplus was in the order $N_2P_2K_2 > N_1P_1K_1$ +O.M. and $P_1 > P_1K_1 > N_1P_1 > N_1P_1K_1$. The cumulative P recovery efficiency with values between 7.6% and 29.1% (Table 2) was relatively poor and clearly improved with the level of balanced fertilization, being largest in $N_1P_1K_1$+ O.M.

Table 2. Cumulative nutrient application (18 years) and recovery efficiency (%) for applied mineral nutrients depending on treatment

Treatment	Nutrient application (kg ha^{-1})			Nutrient recovery (%)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
CK				-	-	-
N1	3330			19.2	-	-
P1		1665		-	7.6	-
K1			2775	-	-	28.5
N1P1	3330	1665		23.1	17.6	-
N1K1	3330		2775	20.0	-	55.9
P1K1		1665	2775	-	11.2	37.4
N1P1K1	3330	1665	2775	34.3	27.2	65.3
N2P2K2	6660	3330	5550	30.2	27.6	60.0
N1P1K1+O.M.	6660	3330	5550	25.1	29.1	54.3
Average				25.3	20.1	50.2

Potassium

K deficiency of paddy soils derived from red soil is getting increasingly a major yield limiting factor for rice. This is due to a still widespread perception that rice does not need much potash for average yields caused by relatively small removals if straw is returned to the field after harvest. However, the practice of returning straw to the field lost in importance due to alternative uses of the straw in recent years. The experiment was therefore undertaken to study the K uptake and removal as affected by the K supply. The plots without K application (CK, N_1, P_1, N_1P_1) show a dramatic negative balance of K and reflect to a certain extent the situation in many farmers' fields. Surprisingly, the K deficit was most severe with 2.26 t ha^{-1} (equal to 126 kg ha^{-1} yr^{-1}) and 1.9 t ha^{-1} (equal to 106 kg ha^{-1} yr^{-1}) in the P_1 and the CK plots, not in the N_1P_1 or N_1 plots as could be expected from the fact that N is usually stronger fuelling growth and hence triggering to a greater extent the K removal from the soil than P. It is important to note that even if K was applied, certain treatments still showed a negative balance for K of up to 910 kg K_2O ha^{-1} (equal to 51 kg K_2O ha^{-1} yr^{-1}) in $N_1P_1K_1$. The order of K depletion was hence: P1 > CK > N_1P_1 > N_1 > $N_1P_1K_1$ > N_1K_1 > P_1K_1 (Table 1). Positive balances were only observed in three treatments, K_1 < $N_2P_2K_2$ < $N_1P_1K_1$+O.M. These latter ranged from 112 kg K_2O ha^{-1} to 667 kg K_2O ha^{-1} (equal to 6 and 37 kg K_2O ha^{-1} yr^{-1}). Recovery efficiency of K with 28.5% - 65.3% was generally larger than for N and P (Table 2). Poorest K recovery was observed in K_1 due to the lack of N and P, needed to fuel the biomass production and hence the uptake of K. Largest K recovery was found in the $N_1P_1K_1$ treatment.

Changes in soil fertility parameters during the long-term experiment

Looking at the nutrient balances and the distinct variation between the treatments (see Table 1), it was of particular interest to study how this would affect the nutritional status of the soil. Therefore, results of soil analyses at the beginning of the experiment (1981) and after 18 years (1998) are compared in Table 3 (total nutrients) and Table 4 (readily available nutrients).

Table 3. Changes in soil fertility parameters during the long-term experiment

Treatment	pH		Organic C		Total N		Total P		Total K	
	1981	1998	1981	1998	1981	1998	1981	1998	1981	1998
			($g\ kg^{-1}$)							
CK	6.2	5.7	16.1	16.0	1.35	1.43	1.09	0.94	10.7	12.3
N_1	6.2	5.6	16.5	17.9	1.50	1.66	1.10	0.84	11.0	12.8
P_1	6.5	6.0	16.4	17.2	1.45	1.40	1.13	1.45	11.0	13.2
K_1	6.6	5.7	15.2	17.5	1.44	1.57	1.04	0.86	11.7	12.2
N_1P_1	6.3	5.7	16.6	17.7	1.48	1.89	1.17	2.05	10.7	12.3
N_1K_1	6.6	5.3	16.1	17.2	1.57	1.69	1.04	0.97	11.0	12.5
P_1K_1	--	5.3	--	16.7	--	1.69	--	1.54	--	12.7
$N_1P_1K_1$	6.6	5.6	17.0	17.5	1.64	1.64	1.19	1.52	11.0	12.5
$N_2P_2K_2$	6.3	6.1	17.3	18.5	1.64	1.70	1.18	2.52	11.1	12.7
$N_1P_1K_1$ +OM	6.4	6.0	17.7	21.0	1.52	2.01	1.28	3.28	11.6	12.5
Mean	6.41	5.7	16.5	17.7	1.51	1.67	1.14	1.60	11.1	12.6

During the study period, pH declined in all treatments and smallest values were recorded in P_1K_1 and N_1K_1 whereas in $N_2P_2K_2$ the decline in pH was less pronounced compared to the other treatments. Mean organic C contents increased which, however, was mainly due to treatment $N_1P_1K_1$+ O.M. which showed a distinct increase. Slightly less organic C accumulated in $N_2P_2K_2$, confirming that better mineral nutrient supply, hence larger yields, also cause an improvement of the soil organic matter status due to larger amounts of plant residues (stubbles, roots, etc.) at harvest. Total N slightly increased on average surprisingly even in the CK plots. Largest increases were again found in $N_1P_1K_1$+ O.M. In contrast, the hydrolyzable (readily available) fraction (Table 4) declined on average of all treatments and could only be maintained in $N_1P_1K_1$+ O.M.

Table 4. Changes available nutrients in the soil during the long-term experiment

Treatment	Hydrolyzable N			Olsen P (P_2O_5)			Readily avail. K_2O		
	----------mg kg^{-1}----------								
	1981	1998	Δ	1981	1998	Δ	1981	1998	Δ
CK	154.9	140.8	-14.1	5.9	5.1	-0.8	49.0	42.9	-6.1
N_1	176.6	180.3	3.7	7.6	9.6	2.0	60.6	48.3	-12.3
P_1	156.0	147.4	-8.6	8.0	29.4	21.4	41.0	48.3	7.3
K_1	166.9	135.5	-31.4	4.0	8.3	4.3	49.2	49.5	0.3
N_1P_1	180.8	160.6	-20.2	4.8	58.2	53.4	51.5	47.1	-4.4
N_1K_1	192.5	148.7	-43.8	3.9	9.5	5.6	56.5	79.2	22.7
P_1K_1	--	147.3	--	--	34.1	--	--	49.5	--
$N_1P_1K_1$	190.3	155.3	-35.0	11.3	35.1	23.8	63.4	51.7	-11.7
$N_2P_2K_2$	196.6	158.7	-37.9	10.5	62.5	52.0	58.4	50.0	-8.4
$N_1P_1K_1$+OM	185.6	190.2	4.6	7.6	84.1	76.5	68.0	70.8	2.8
Mean	177.8	156.5	-21.3	7.1	33.6	26.5	55.3	53.7	-1.6

For phosphorus, significant changes during the study period occurred in both P fractions, showing that total P declined in the treatments without P application whereas Olson P slightly increased. The application of P caused a significant increase, particularly in Olsen P and the order based on treatments was $N_1P_1K_1$+ O.M. > $N_2P_2K_2$ > N_1P_1 > $N_1P_1K_1$ > P_1 (Table 4). This shows that P accumulation in soil not necessarily reflects the poor recovery efficiency of P as could be expected for treatment P_1 (Table 2). The total amount of P applied and the recycling of larger amounts of organic matter in the residues or by organic manure may have played a more important role. On average off all treatments, total K slightly increased during the duration of the experiment, however, no clear trends with regard to treatments could be observed. This is different for the readily available K fraction, which shows that in most treatments available K contents declined, even at K_2 (180 kg K_2O ha^{-1} yr^{-1}). Only in one treatment (P_1K_1), an increase in soil K could be observed. This may be explained by inefficient uptake due to lack of nitrogen. The application rates in general were not suited to maintain the K supply status of the continuous rice crop rotation in the long run. Therefore, it is essential to increase K rates in a balanced fertilization scheme and to reduce K losses through leaching which may be a major source of poor recovery as it could be observed especially in the K_1 treatment.

Conclusions

1) The long-term field experiment revealed a detailed insight in the nutrient demand and nutrient balances over a longer time span.
2) Cumulative yields varied dramatically and were largest in $N_1P_1K_1$+ O.M. whereas the control or the application of one nutrient only led to significant yield depressions.
3) In all treatments, with the exception of $N_1P_1K_1$+ O.M. and $N_2P_2K_2$, yields declined from the first year to the last year of experimentation with largest declines when no N and P was supplied.
4) Cumulative nutrient balances were negative for all the omitted nutrients and were most severe in treatments where the two other nutrients were adequately applied.
5) Nutrient recovery efficiency was greatest for K followed by N and P, being less than half than that of K, indicating good conversion of applied K into biomass.
6) There was a poor nutrient use efficiency of both N and P, especially in the one-sided fertilized treatments.
7) Relatively poor N and P recovery in the best treatments of around 30% for both nutrients indicate the need for a further improved nutrient management with regard to both quantity and timing.

Residual effects of mineral fertilizers and organic manure and their impact on soil nutrients in a long-term experiment

Sun Gengyin

Soil and Fertilizers Institute, Jiangsu Province Academy of Agricultural Science 210014

Abstract

A long-term field experiment was carried out on desalinised fluvio-aquic soil in Jiangsu to study the effect of a combination of organic manure (M0, M1) on yield as well as the residual effect to the succeeding crop. The mineral fertilizer treatments consisted of C (control), PK, NK, NP and NPK. The results reveal significant differences between yields without and with organic manure and best exploitation of the yield potential of wheat and maize grown in rotation was found in M1 + NPK. In the average of seven years, NPK application more than tripled wheat yields in M0 whereas they only doubled in M1, though the yield level was much higher in M1 than in M0. This is due to the yield increasing effect of organic manure in the control treatment in M0. For maize, a similar observation was made and largest yields were found in the combination M1 and NPK. Omission of one nutrient always led to a yield decline which was most dramatic for N and P whereas the latter was particularly limiting the yield of wheat when no organic manure was applied (M0). Residual effects followed the order NP > NPK > NK > C in M0 and NK > NP > NPK > C > PK in M1. Soil analysis after 7 years revealed drastic differences between both M0 and M1 and between the different mineral fertilizer treatments. Though there were also differences in the total N and O.M. contents, the long-term fertilization practice mainly influenced the readily available nutrients. Extreme depletion for P was observed in the combination M0-C, M0-NK whereas in M0-NPK, M0-NP and M0-PK a slight enrichment of soil P could be observed. In the combination M1, the P accumulation was PK > NP > NPK > C > NK. Readily available K was clearly in the deficiency range for the combination M0-C, M0-NP and M0-NPK. Only M0-PK and M0-NK showed K availability at the lower range of adequate supply. In the M1 treatment, with the exception of M1-PK, all soils showed low to extremely low K availability. This clearly indicates the insufficient K supply despite organic manure application over the years.

Introduction

An anticipation of the yield response to fertilization has to include the direct effect on the crop the fertilizer is applied to and the residual effects from fertilizers to the succeeding crops. Most methods currently used for making fertilizer recommendation, however, do not take into account the residual effect of the applied nutrients. To quantify residual effects of mineral fertilizers and organic manure under different rotation systems could assist in providing an improved basis for fertilizer recommendation. In certain countries, nitrogen fertilizer recommendation is based on the determination of residual NO_3-N in the soil. However, this method has not yet been widely adopted in the practice of Chinese agriculture.

A long-term fertilizer experiment was therefore carried out in the Experiment Zone for Comprehensive Management of Saline-alkalytic Fluvio-aquic soils in Wangji, Suining County, Jiangsu Province, to study the direct and the residual effect of fertilizer application on yield and soil parameter in more detail.

Materials and methods

The trial soil was originally salinized-alkalized fluvio-aquic soil. After years of intensive management, the soil has been desalinized and may be described as sandy loam in texture and moderate to low in soil fertility. The groundwater table was recorded at 1 - 3 m, fluctuating in the range between 0.5 - 1.5 m. The chemical properties are dominated by HCO_3^-,-Na^+-Mg^{++} or HCO_3^--Cl^--Na^+-Mg^{++}.

The experiment was initiated in October 1986 and has been going on for 13 years. It was designed as a split plot with organic manure as main plots: 1) without organic manure (M0) and 2) with organic manure (M1), 37.5 t ha^{-1} farmyard manure, containing 186 kg N, 140 kg P_2O_5 and 232 kg K_2O applied in this treatment. The subplots consisted of: 1) no mineral fertilizers (C), 2) with P and K fertilizers (PK), 3) with N and K fertilizers (NK), 4) with N and P fertilizers (NP) and 5) with N, P and K fertilizers (NPK). The rotation system adopted for the experiment was wheat-maize with two crops per year. The fertilizer application rate was 210 kg N, 112.5 kg P_2O_5 and 112.5 kg K_2O per hectare for wheat and 165 kg N, 75 kg P_2O_5 and 75 kg K_2O per hectare for maize. From fall 1991 onwards, the N application rate has been changed to 187.5 kg N ha^{-1}. For N urea, for P single super phosphate and for K potassium sulphate were used. Organic manure, P and K fertilizers were all applied as basal application. Three-quarters of the N fertilizer for wheat and two-thirds of the N fertilizer for maize were basal applied whereas the rest was side-dressed. The cultivar of wheat was Xuzhou-211 and the cultivar of maize Yedan-2. The plots for the treatments were 13.3 m^2 each and arranged at random. Each treatment had three replicates. Beginning with wheat in the autumn of 1993, fertilization was discontinued in all treatments for the observation of residual effects resulting from fertilization to the preceding crop. And in the autumn of 1994 fertilization was resumed.

Results and discussion

Crop yield, depending on residual effects of long-term fertilization

Mean yields (1987-1993) and residual effects of mineral fertilizers and organic manure on crop yield and yield increase are shown in Table 1. The yield depending on residual effects in treatment M1 is equal to 40% - 55.6% of the mean yield of the preceding 7 years, whereas in treatment M0 only amounts to 25.8% - 52.1%. Obviously, the difference can be attributed to the beneficial effect of organic manure. The calculation shows that the yield in treatment M1-C is 2,744 kg larger than in treatment M0-C, on average 5.23 kg t^{-1}. The comparison between the crops shows that residual effects in maize were greater than in wheat, which is probably due to higher soil temperatures during the maize growing season, speeding up soil nutrient mineralization and facilitating nutrient uptake by the crop. The difference in residual effects between sub-plots were in a decreasing order: NP > NPK > PK > NK > C when no organic manure (M0) was applied and NK > NP > NPK > C > PK when organic manure was applied (M1). No matter whether organic manure was applied or not, the residual effects in treatment NPK rank second and third which is quite consistent with the crop growth (Table 3 and Table 4). Further studies have to be done exploring the causal effects.

Table 1. Residual effects of different fertilization treatments

Treat-ment		Mean yield (1987-1993)			Yield depending on residual effect (1994)			Yield increase rate (%)			1994/7 years*
		Wheat	Maize	Total	Wheat	Maize	Total	Wheat	Maize	Total	
M0	C	1476	2609	4085	870	396	1266	100	100	100	31.0
	PK	1546	2703	4429	833	698	1531	95.8	176.3	120.9	36.0
	NK	1463	3273	4736	663	762	1425	76.2	192.4	112.6	30.1
	NP	3941	5541	9482	2751	2193	4944	316.2	553.8	390.5	52.1
	NPK	4896	7250	12146	1901	1235	3136	218.5	311.9	247.7	25.8
M1	C	2860	5710	8570	1568	2442	4010	180.2	616.9	316.8	46.8
	PK	2877	5642	8519	1371	2045	3416	157.6	516.4	269.8	40.1
	NK	4605	8258	12863	3225	3920	7145	370.7	989.9	564.4	55.6
	NP	4657	8297	12954	3405	3392	6797	391.4	856.6	536.9	52.5
	NPK	5055	8610	13665	3135	3080	6215	360.3	777.8	490.9	45.5

Note: *: "1994/ 7 years" means the percentage of the yield, depending on residual effect in 1994, against the mean yield of the preceding 7 years.

Yield increment attributed to residual effects of applying N, P and K fertilizers for a number of years prior to nutrient omission

The yield increment attributed to residual effects of applying N, P and K fertilizers for 7 years was calculated by the difference method (Table 2). It is evident that in treatment M0 the residual effects of P fertilizer are the greatest followed by that of N. The residual effects of K are negligible and the equal that of C. According to Table 1, the yield increment in treatment NPK was 1031 kg for wheat and 839 for maize in the M0 main plot. The comparison between M0 and M1 both at the level C (control) shows that the effect of organic manure alone had an residual effect of 698 kg for wheat and 2046 for maize.

Table 2. Yield increment attributed to residual effects of long-term application of mineral fertilizers

Item*	Wheat			Maize			Total yield		
	N	P	K	N	P	K	N	P	K
Yield (M0) (kg ha^{-1})	1068	1238	-850	537	473	-958	1605	1711	-1808
Total input (kg ha^{-1})	2625	573	1090	2625	573	1090	2625	573	1090
Increment (kg kg^{-1})	0.41	2.16	-0.78	0.21	0.83	-0.88	0.61	2.99	-1.66

*: Yield (M0) = Yield, depending on residual effect in treatment M0; Total input = The total input of fertilizers and Increment (kg kg^{-1}) = Yield increment attributed to residual effect (kg kg^{-1} nutrients).

Effect of residual effects on crop properties

After long-term fertilization over 7 years, fertilizer application was discontinued for one year, growing two crops without being fertilized. Both crops, wheat and maize, grew better in treatment M1 than in treatment M0 (Table 3).

Table 3. Residual effects of treatments on the plant properties of wheat

Treatment		Plant height (cm)	Ear length (cm)	Spikelet	Grains/ear	Thousand-grain weight (g)
M0	C	38.1	2.4	6.1	4.3	33.9
	PK	37.3	2.5	4.5	3.2	36.5
	NK	35.4	2.4	4.1	3.3	30.6
	NP	58.0	4.8	9.0	11.1	39.4
	NPK	41.3	3.1	4.7	7.0	40.6
M1	C	46.5	4.2	7.0	9.8	39.9
	PK	43.5	3.9	6.4	8.0	37.9
	NK	65.5	6.1	12.0	19.5	40.8
	NP	66.0	6.4	13.4	13.3	39.9
	NPK	52.4	4.7	8.7	14.4	41.3

In treatment M0, the residual effects on plant properties of the first crop (wheat) was variable in the sub-plots. Looking at plant height, ear length, number of spikelets and grains per ear, the sub-plots were in the order of NP > NPK > PK > NK and in thousand-grain weight NPK > NP > PK > NK. In treatment M1 the order was NK, NP > NPK > PK. PK had the lowest thousand-grain weight and the other treatments were similar. The residual effects on plant properties of the second crop (maize) was quite similar to wheat. Without organic manure (M0), ear length and grains per ear, the sub-plots were in the order of NP > NPK > PK > NK and in thousand-grain weight NP and NPK > PK and NK. NP and NPK were close to each other but much greater than PK and NK. In treatment M1, the order was NK > NP > NPK in terms of ear length and grains per ear and NK > NPK > NP > PK with regard to thousand grain weight. The crop response in plant properties was consistent with that in yield.

Effect of crop cultivation after long-term fertilization on soil nutrients

Soil tests, after 7 and the first year of discontinued fertilization, when the first crop (wheat) was harvested, revealed that readily available K dropped most significantly followed by organic matter content. The drop of total N was not significant. After the second crop (maize), total N contents decreased in all treatments. Readily available P generally increased in treatment M0, reflecting the release of adsorbed P from the soil. A decline in readily available P was observed in PK and in all the treatments in M1, which may be due to a faster release of P when organic manure was applied.. There were clear differences in readily available K in the control (C) between M0 and M1, showing larger K contents when organic manure was applied. In both M0 and M1 the previous application of K maintained the available K contents in the PK and NK treatments at higher level but not in the NPK treatments. This may be explained by an accumulation of K due to reduced K uptake caused by lack of N (PK treatment) or P (NK treatment). In the second crop (maize) residual effects on available K clearly declined but were apparent in PK and NK only.

Table 4. Effect of crop cultivation after long-term fertilization on soil nutrients

Treatment		After wheat (1993)					After maize (1994)				
		O.M. g kg^{-1}	Total N g kg^{-1}	Al. N mg kg^{-1}	r.a. P mg kg^{-1}	r.a. K mg kg^{-1}	O.M. g kg^{-1}	Total N g kg^{-1}	Al. N mg kg^{-1}	r.a. P mg kg^{-1}	r.a. K mg kg^{-1}
	C	7.6	0.64	46.7	1.9	44.8	7.3	0.54	41.0		37.1
	PK	8.5	0.68	50.8	40.0	105.3	8.3	0.54	53.2	22.0	53.9
M0	NK	8.2	0.71	52.5	2.9	116.9	8.9	0.59	68.4	5.0	54.3
	NP	10.7	0.80	115.5	14.0	49.2	9.9	1.37	73.0	20.1	40.1
	NPK	10.5	0.84	121.1	9.5	55.6	10.1	0.67	76.9	27.0	33.5
	C	14.7	1.05	80.3	15.5	58.7	11.9	0.84	100.4	5.9	33.4
	PK	15.5	1.06	82.3	73.6	109.5	15.4	0.85	99.0	38.4	58.3
M	NK	14.8	1.09	87.2	13.3	74.6	14.7	1.00	93.6	4.7	40.2
	NP	15.5	1.13	91.2	42.3	49.0	12.9	0.84	62.5	16.2	31.9
	NPK	14.4	1.05	94.3	38.5	53.4	16.5	1.11	106.5	17.6	38.5

Note: O.M. = organic matter; Al. N = alkalytic N (1.0 M NaOH incubation at 40 °C for 24 h, reflecting the available N pool); r.a.= readily available

Conclusion

1) The yield response to residual effects of long-term fertilization was great. With organic manure (M1), the yield amounted to 48% of the average yield of the preceding 7 years whereas it accounted for 53% when no organic manure was applied (M0).

2) Without organic manure (M0), it was the nutrient P which revealed the most significant residual effects followed by N and K fertilizer. For K, only small residual effects were observed. This indicates that the application rate of 187.5 kg ha^{-1} is just enough to keep K in balance.
3) After long-term combined NPK application similar residual effects with regard to agronomic efficiency (0.44 kg nutrient kg^{-1} yield) in M0 (no organic manure) and 0.45 kg kg^{-1} in M1 (organic manure) were observed.
4) Residual effects on yield parameters (plant height, ear length, number of spikelets and grains per ear) were in the order of M1 > M0 and NP, NK > NPK. Further study needs to be done to explore the reason.
5) After long-term fertilization, discontinuation of fertilization for one year (two crops) did not have much effect on soil organic matter. Total N dropped in all treatments and readily available K decreased drastically.

Soil K status and crop response of wheat to K application in the wheat production area of Southern Shanxi

Liu Yinzhong, Zhang Ouzhu, He Yuzhu, Li Zheng and Qiao Hongjin

Shanxi Province Soil and Fertilizers Work Station 030001

Abstract

The rise in multiple cropping index and crop yield increase in Shanxi fuelled by increase in mineral N and P consumption, insufficient return of K through organic manure has caused that the loess derived fluvio-aquic soils and drab soils as major soil types in the wheat production areas in South Shanxi experienced a dramatic decline in K availability in recent years. The degree of the reduction varies according to soil, agricultural ecosystem and soil fertility and followed the order of fluvio-aquic soil > drab soil; basin > hills > tableland > mountain; and low fertility > high fertility > medium fertility soils. Crop response to K is closely related to the status of soil K, showing great response of wheat where the readily available K was ≤ 80 mg kg^{-1}. A value of 100 mg K kg^{-1} was found to be the critical value for K response under general production conditions. Under certain conditions, however, yield response to K application was significant, even if the readily available K reached 120 - 130 mg K kg^{-1}, highlighting the strong influence of site conditions (soil, climate) on the critical soil K threshold levels. Combined application of organic manure together with N and P fertilizers, 75 - 225 kg ha^{-1} K_2O increased wheat yields by 7.8 - 15.5% or 2.2 - 4.2 kg grain kg^{-1} K_2O. Crop response to K was greater in soils with high fertility and smaller in soil with low fertility. Including the current price relationships between grain and fertilizer, an optimal K application rate for wheat of 135 ~ 180 kg ha^{-1} was worked out.

Introduction

Potassium is one of the nutrients that is needed for crop growth at largest amounts. In recent years, with an enhanced development of the agricultural production, the application rates of mineral N and P fertilizers were rising year by year and partly substituted the application of organic manure. This caused that potassium was only to a lesser extent recycled to the field, leading to a steady decline in soil K reserves and a significant crop response to mineral K application. Experiments and surveys were carried out to quantify the change in soil K and crop response to K application in the wheat production area in South Shanxi. The study here analyses the changes in readily available K, depending on agro-ecosystem and tries to link changes in soil fertility to yield and yield parameters of wheat: In the end, an attempt is undertaken to develop an appropriate fertilizer recommendation for wheat in various important agro-ecological regions in Shanxi.

Changes in soil K in the wheat production area in South Shanxi

Changes in readily available K in different soil types

The survey carried out in 1997, covering 519 sites in Linfen and Yuncheng revealed that in recent years readily available K in soils of fields cultivated with wheat showed a distinct downward trend. The extent to which this decline occurred differs from soil to soil. It dropped faster in fluvio-aquic soil than in drab soil. In comparison to 1983, readily available K of fluvio-aquic soils dropped by 39.7mg kg^{-1} (average) at a rate of 2.8 mg kg^{-1} per year while in cinnamon soils it decreased by 21.8 mg kg^{-1} at a rate of 1.6 mg kg^{-1} yr^{-1}. Among the fluvio-aquic soils, the severity in decline followed the order: salinized fluvio-aquic soil > fluvio-aquic soil > de-fluvio-aquic soil. Among the drab soils, the sequence was cinnamon-like soil > fluvio-aquic cinnamon soil > calcareous cinnamon soil > cinnamon soil (Table 1).

Table 1. Contents of readily available K of different soil types (1983 and 1997)

Soil	Number of samples	1983 (mg kg^{-1})	1997 (mg kg^{-1})	Balance (mg kg^{-1})	(%)
Cinnamon	39	190	186	-4	-2.1
Calcareous cinnamon	158	173	150	-23	13.2
Cinnamon-like soil	137	167	132	-35	26.5
Fluvio-aquic cinnamon	55	178	153	-25	14.0
Fluvio-aquic soil	95	155	127	-28	18.1
De-fluvio-aquic soil	24	207	186	-21	10.1
Salinized fluvio-aquic soil	11	221	151	-70	31.7

Changes in readily available K in soils of different agricultural ecosystems

Table 2 shows that readily available K in all the analysed soils showed a downward trend, which varied strongly in its extent among the different agricultural ecosystems. It dropped fastest in the basins, by 34 mg kg^{-1} (at a rate of 2.4 mg kg^{-1} yr^{-1}). The decline in readily available K followed the order of basin > hills > tableland > mountains.

Table 2. Contents of readily available K in soils of different agricultural ecosystems (1983 and 1997)

Ecosystem	Number of samples	1983 (mg kg^{-1})	1997 (mg kg^{-1})	Balance (mg kg^{-1})	(%)
Basin	220	174	140	-34	-19.5
Tableland	99	199	169	-30	-15.1
Hills	185	175	142	-33	-18.9
Mountain	15	121	114	-7	-5.8

Changes in readily available K in soils of different fertility

Within the same ecosystem, the decline in readily available K varied according to soil fertility status. For instance, from 1983 to 1997, readily available K in the tableland in Emeiling, Yuncheng, decreased on average by 30 mg kg^{-1} (at a rate of 2.1 mg kg^{-1} yr^{-1}). But in soils with low fertility, it dropped by 42 mg kg^{-1} (at a rate of 3.0 mg kg^{-1} yr^{-1}). The decrease in readily available K in soils with different soil fertility followed the order: soil low in fertility > soil high in fertility >soil moderate in fertility.

Table 3. Contents of readily available K in soils, differing in fertility (1983 and 1997)

Soil	Number of samples	1983 (mg kg^{-1})	1997 (mg kg^{-1})	Balance (mg kg^{-1})	(%)
High in fertility	6	216	176	-40	-18.5
Moderate in fertility	24	203	188	-15	-7.4
Low in fertility	32	194	152	-42	-21.6
Mean	62	199	169	-30	-15.1

Crop response of wheat to K application

Wheat is a K demanding crop and for normal growth, the plant needs to take up 2 - 4 kg of K_2O to produce 100 kg of grain. The N : P_2O_5 : K_2O ratio of crop's nutrient uptake is 1 : 0.34 : 1.11. During its growth, wheat has two peaks of K uptake between tillering and wintering and between booting and flowering stage. Hence response to K application may be expected when supply is poor during these stages.

Effect of K application on yield parameters of wheat

The results of the experiments carried out at more than 20 sites between 1995 and 1997 indicate that application of K fertilizers to wheat significantly increased the number of tillers, effective ears and grains per ear as well as the thousand-grain weight. In a combined application of organic manure together with mineral N and P, the application of 75 - 225 kg K_2O per hectare increased ears by 28.5 - 39×10^4 ears ha^{-1}, grains ear^{-1} between 0.11% and 25% for the smallest and largest K rate (K_5 and K_{15}), respectively. The thousand-grain weight increased only by 1.4% and 2.4% in K_5 and K_{10}, and only very marginally in K_{15} (Table 4).

Table 4. Effect of K application on wheat yield parameters

Treatment	Ears ha^{-1} ($\times10^4$)	Grains ear^{-1}	Thousand-grain weight (g)
CK	447.0	26.6	41.0
$N_{10}P_{10}$	520.5	29.7	41.8
$N_{10}P_{10}K_5$	549.0	29.9	42.4
$N_{10}P_{10}K_{10}$	526.5	32.3	42.8
$N_{10}P_{10}K_{15}$	559.5	37.2	42.0

Effect of K application on wheat yield

Using 150 kg of N and P_2O_5 ha^{-1}, the application of 75 - 225 kg K_2O per hectare increased the yield of wheat by 316.5 ~ 625.5 kg or by 7.8% - 15.5%. K efficiency was 2.16 - 4.22 kg kg^{-1} K_2O (Table 5). Crop response varied according to soil fertility. In soils where the yield of non-fertilized wheat exceeded 2,250 kg ha^{-1}, the application of K increased the yield by 379.5 - 532.5 kg or 8.6% - 16.6% which equals 2.37 - 5.06 kg kg^{-1} K_2O. In soils where the yield of non-fertilized wheat was less than 2250 kg ha^{-1}, the application of K increased the yield by 150 ~ 378 kg (5.5% ~ 13.6%) equivalent to 1.6 ~ 2 kg kg^{-1} K_2O (Table 6). It is obvious that the yield-increasing effect of K application is greater in fertile soils than in soils moderate or low in fertility.

Table 5. Crop response of wheat to K application

Treatment	Yield (kg ha^{-1})	Δ kg ha^{-1}	Δ %	Δ (kg kg^{-1}) K_2O
CK	2949	-	-	-
$N_{10}P_{10}$	4040	-	-	-
$N_{10}P_{10}K_5$	4356	316	7.8	4.22
$N_{10}P_{10}K_{10}$	4665	525	15.5	4.17
$N_{10}P_{10}K_{15}$	4526	486	12.0	2.16

Table 6. Crop response of wheat to K application, varying with soil fertility

Treatment	Yield in CK* <2250 kg ha^{-1}			Yield in CK > 2250 kg ha^{-1}		
	Yield kg ha^{-1}	Δ %	Δ kg kg^{-1} K_2O	Yield kg	Δ %	Δ kg kg^{-1} K_2O
CK	1880			3287		
$N_{10}P_{10}$	2777			4427		
$N_{10}P_{10}K_5$	2928	5.5	2.20	4806	8.6	5.06
$N_{10}P_{10}K_{10}$	3080	10.9	2.02	5165	16.6	4.92
$N_{10}P_{10}K_{15}$	3155	13.6	1.68	4959	12.0	2.37

*CK = control (without mineral fertilizer)

Effect of K application on wheat quality

According to the tests in Yuncheng, Yongji, Linfen, Quwo and Hongdong counties, K application increased crude protein and crude oil in wheat by 9.1% - 11.4% and 3.5% - 5.5%, respectively. Meanwhile, it also significantly increased the content of the valuable amino acids, e.g. serine, glucine, leucine and lysine in grains.

Effect of K application on stress-resistance of wheat

Application of K to wheat significantly improved the crop's stress-resistance. Observations showed that application of K fertilizers improved crops' resistance to drought. In 1996 – 1997, wheat seriously suffered from drought during its growing period. Only crops supplied with K maintained their yield. In Linyi County, the wheat crop in a 333.3 hectare K demonstration field grew healthily with dark green leaves and well filled grains. In comparison with fields without K application, K increased the thousand-grain weight by 1.2 g and yield by 600 kg ha^{-1} or 14.3%. The results of the experiment in Yuncheng showed that after K application, high-yielding wheat shortened the distance between the first node and the second by 1 - 2 cm and thickened the wall of the second section of the stalk by 54.6 μm. The mechanical tissue increased by 52 μm in thickness, thus strengthening the crop's tendency to lodge. Investigations of a number of experiments revealed that addition of K application to the basal N and P fertilizer application reduced incidence of sheath blight by 25% - 67%. The effect was more significant the greater the application of K.

Techniques for K application on wheat

Soil conditions and K application

Results of the multi-location field experiment showed that in wheat fields with soil, containing <100 mg kg^{-1} of readily available K, potassium application in addition to N and P fertilizers significantly or highly significantly increased yield. Consequently, 100 mg kg^{-1} readily available K can be regarded as the critical threshold value of soils under general production conditions. In some fields where the crop was sown late, despite the fact that readily available K in the soil ranged between 120 ~ 130 mg kg^{-1}, there was a clear yield response to K application. Therefore, the content of soil K at which K response is observed varies with crop yield and other ecological and technical factors.

K application rate

The decision how much K should be applied is closely associated with soil fertility and the soil's K supply capacity. The results of the experiment on K application rate conducted between 1995 and 1997 showed, under the current pricing system and agricultural production management, the optimal K_2O application rate for wheat is 135 - 180 kg K_2O ha^{-1}. The smaller amount is for soils with high fertility and the large amount for soils with low fertility (Table 7).

Table 7. Equation for calculating effect of K application on wheat and optimal application rate (kg K_2O ha^{-1})

Yield level (kg ha^{-1})	Equation	R	Optimal rate (kg ha^{-1})
> 2250	y=4410 +8.3x-0.0253x^2	0.9949	138
< 2250	y=2772+2.45x-0.0327 x^2	0.9956	184.2

Timing of K application

Wheat has a typical K nutrient uptake during the growing season with a peak, occurring between tillering and flowering stage. Therefore, K application at an early stage can cause the major yield response to K application. In Linfen City, the results of an experiment on K application at different wheat growth stages in fields with a moderate soil fertility indicate that K applied either in one application as basal dressing or split into 60% as basal and 40% as side-dressing at greening stage produced the best results. 100% used as side-dressing produced the smallest yield increase (Table 8).

Table 8. Effect of K application at different growth stages on wheat yield

Treatment	Pattern of K application	Range of yield (kg ha^{-1})	Mean yield (kg ha^{-1})	Δ kg ha^{-1}	Δ %
NP(CK)	None	4368 - 5552	5259		
NPK (B)	100% (B)	5180 - 6243	5825	566	10.8
NPK(B+S)	60% (B),40%(S)	4955 - 6087	5573	314	6.0
NPK (S)	100%(S)	4653 - 5708	5456	182	3.4

Note: (B) = basal and (S) = side dressing.

Placement of K

Studies on placement (results not shown) revealed that band application produced the best effect. Foliar application at booting and milking stages also led to a significant yield response.

Conclusion

1) Fluvio-aquic soils and drab soils are the major soil types in the wheat production areas in South Shanxi. Derived from loess, they usually contain 80 - 200 mg kg^{-1} readily available K. In recent years with the rise in multiple cropping index and crop yield increase caused by larger N and P application rates, concomitant reduction of organic manure application, an imbalance of NPK nutrient input ratios occurred. The surplus of N and P and the deficit of K accelerates the decline of readily available K. The degree of the reduction varies according to soil, agricultural eco-

system and soil fertility and followed the order of fluvio-aquic soil > drab soil; basin > hills > tableland > mountain; and low fertility > high fertility > medium fertility soils.

2) Crop response to K is closely related to the status of soil K. In wheat fields of South Shanxi with readily available K $\leq$ 80 mg kg^{-1}, crop response was high. The value of 100 mg kg^{-1} can be taken as the critical value for K response under general production conditions. In some individual wheat fields where the crop was sown late or the soil texture consisted of heavy clay, crop response to K application was significant, even if the readily available K reached 120 - 130 mg kg^{-1}. This indicates the strong influence of site conditions on the critical K value of a soil.
3) Crop response varies with soil fertility. On the basis of rational application of organic manure and N and P fertilizers, application of 75 - 225 kg ha^{-1} K_2O increased the yield by 7.8 - 15.5% equivalent to 2.16 - 4.22 kg kg^{-1} K_2O. Crop response was greater in soils with high fertility and smaller in soil with low fertility.
4) Under the current agricultural management and pricing (grain versus fertilizer) system, the optimal K application rate for wheat is 135 - 180 kg K_2O ha^{-1}. The smaller rate is for wheat fields high in soil fertility and the larger rate for wheat fields low in soil fertility. Best results were obtained when K fertilizers were applied as basal dressing and banded along the seeding rows.

Effects of K application to a long-term crop rotation of rice, wheat and oilseed rape on yields and soil fertility

He Caifu[1], Sun Xifa[1] and Qiu Gubin[2]

[1] Soil and Fertilizers Institute, Sichuan Province Academy of Agricultural Science 610066
[2] Leshan City Agricultural Research Institute, Sichuan Province, 614216

Abstract

A long-term field experiment in Hongnitian, Sichuan, on the application of potassium and organic manure was carried out with 23 crops of rice, wheat and oilseed rape grown in a crop rotation. The six treatments consisted of 1. CK (no fertilisation) 2. NP (120 kg N and 60 kg P_2O_5 ha^{-1}), 3. NPK (120 kg N and 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}), 4. OM (15 tons ha^{-1} pig dung), 5. OM + NP and 6. OM + NPK. Results showed that the yield was largest in the treatment NPK and OM + NPK. The yield differences between treatments with and without K increased with the duration of the experiment. On average of the whole rotation, yield differences due to K application were 37.4% and 11.7% for rice, 248.6% and 142.1% for wheat and 89.7% and 17.3% for oilseed rape, in the NPK and OM + NPK treatments, respectively. Crop response to K without organic manure (NPK) was larger than with organic manure (OM + NPK). Soils under long-term K application had a reduced bulk density, greater porosity and contained larger amounts of soil organic matter as well as larger N and P contents. The K : N ratios in plant tissues were used to determine whether K deficiency occurred for the respective crop. The results indicate that K deficiency for rice can be expected if the K : N ratio in the plant is <0.6. For wheat and oilseed rape, K deficiency can be expected at K : N ratios <0.5. The steady rise in N and P application rate and the declining recycling of K to the field through organic manure led to a nutrient imbalance and to a K deficit in the soil. As a result, crops began to show K deficiency symptoms and became more susceptible to plant diseases, thus greatly affecting the crops' yield and quality.

Introduction

With the introduction of high yielding crop rotations, relying increasingly on the supply of mineral nitrogen and phosphorus in the Sichuan Province, observations revealed that yields stagnated or even declined. In order to find out whether this is caused by an undersupply of potassium, which during this time was rarely applied as a standard fertilization, in 198, a long-term experiment on K application was laid out on a red earth in Jiufeng township, Leshan City. The experiment was designed to test the effect of potassium in a rotation of rice-wheat-rice-oilseed rape of 23 crops altogether. The objectives of this study were to monitor yield differences and to assess the effect of K application on soil mineral and physical conditions with and without the use of organic manure. Furthermore, plant tissue analysis was carried out with the aim of defining critical K : N ratios as a K deficiency indicator.

Materials and methods

The experimental soil was a red earth with a sandy loam texture derived from thick colluvial sandstone of the Jiaguan Group. Prior to the experiment, the soil of the plough layer had a pH of 6.6 and contained 15.6 g kg^{-1} organic matter, 0.7 g kg^{-1} total N, 0.66 g kg^{-1} total P, 15.5 g kg^{-1} total K and 79.1 mg kg^{-1} slowly available K. The contents of available nutrients in the soil were N = 78 mg kg^{-1}, P = 27.7 mg kg^{-1}, K = 21.2 mg kg^{-1}, Mg = 12.2 mg kg^{-1}, B = 2.0 mg kg^{-1}, Zn = 1.0, Mn = 0.13 mg kg^{-1} and Mo = 0.01 mg kg^{-1} Mo.

The plot size was 13.34 m^2 and the treatments were randomly arranged and four times replicated. To separate the fields from each other, a piece of cement board was buried 30 cm deep into the soil to prevent nutrient transfer from one plot to another. Ditches were also built between plots for irrigation and drainage. The crops used in the experiment were rice, wheat and oilseed rape cultivated in a rotation of rice - wheat - oilseed rape, according to the following sequence (crop No. in the rotation in brackets):

Year	Crop		Crop
1981:			Rice (1)
1982:	Wheat (2)	-	Rice (3)
1983:	Oilseed rape (4)	-	Rice (5)
1984.	Wheat (6)	-	Rice (7)
1985:	Oilseed rape (8)	-	Rice (9)
1986:	Wheat (10)	-	Rice (11)
1987:	Oilseed rape (12)	-	Rice (13)
1988:	Wheat (14)	-	Rice (15)
1989:	Oilseed rape (16)	-	Rice (17)
1990:	Wheat (18)	-	Rice (19)
1991:	Oilseed rape (20)	-	Rice (21)
1992:	Wheat (22)	-	Rice (23)

The fertilizer treatments consisted of the following 6 basic treatments and 2 additional treatments (7. and 8.) added during the course of the experiment:

1. CK (non-fertilized)
2. NP (120 kg N and 60 kg P_2O_5 ha^{-1})
3. NPK (120 kg N and 60 kg P_2O_5, 60 kg K_2O ha^{-1})
4. OM (15,000 kg ha^{-1} pig dung)
5. OM + NP
6. OM + NPK
7. NP + K (60 kg K_2O ha^{-1}, applied to crop (8) – (13))
8. OM + NP (60 kg K_2O ha^{-1} to crop (8) – (13))

The continued omission of K, especially in treatment 2. (NP) and 5. (OM + NP) led to a drastic depletion of the K reserves in the soil. Therefore, starting with oilseed rape (8) in 1985, two of four replicates of NP, OM + NP received 60 kg K_2O ha^{-1} for an entire rotation of six consecutive crops, ending with rice (13) in 1987. With this kind of arrangement the question should be answered whether fresh K applications to soils depleted for a certain period can fully overcome the yield gap that developed between the fertilized and non-fertilized plots. Furthermore, it was of interest whether similar crop productivity can be re-established by this measure. K supplementation was discontinued, starting from the 14th crop (wheat), to determine the residual effect of K application in wheat and the succeeding rice as 15th crop in the rotation.
Plant analysis was carried out at different stages during the vegetation period to determine the nutrient contents and to develop critical K : N ratios which could indicate the occurrence of K deficiency. For this purpose, whole plants were harvested at culm elongation and heading for rice, tillering, stem elongation and head emergence for wheat, rosette, booting and flowering stage for oil seed rape. Samples were analysed, using conventional methods.

Results and discussion

Effect of long-term nutrient application

The incremental yields of the crops due to K application with and without organic manure (OM) for the period 1981 – 1992 are shown for each crop individually in Figure 1-3. Yield increments compared to the NP control were significant in all crops in each year.

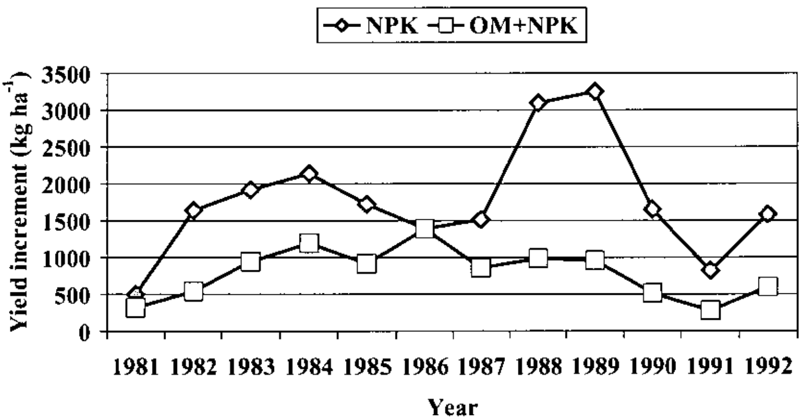


Figure 1. Incremental crop response of rice to K application in comparison to the NP treatment (NP or OM+NP)

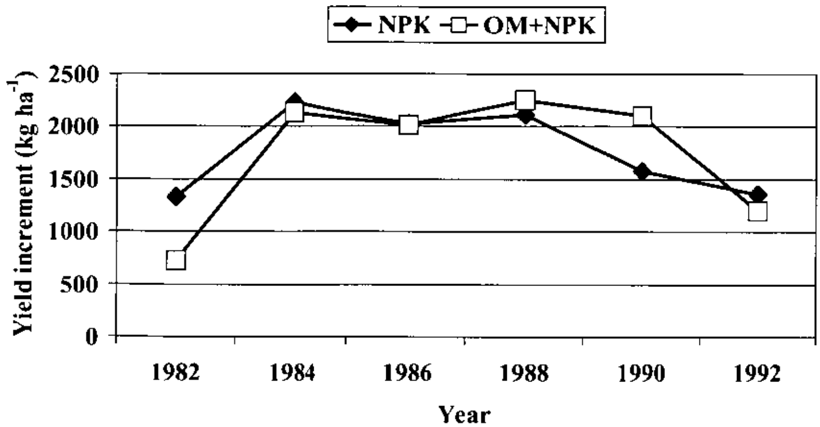


Figure 2. Incremental crop response of wheat to K application in comparison to the NP treatment (NP or OM+NP)

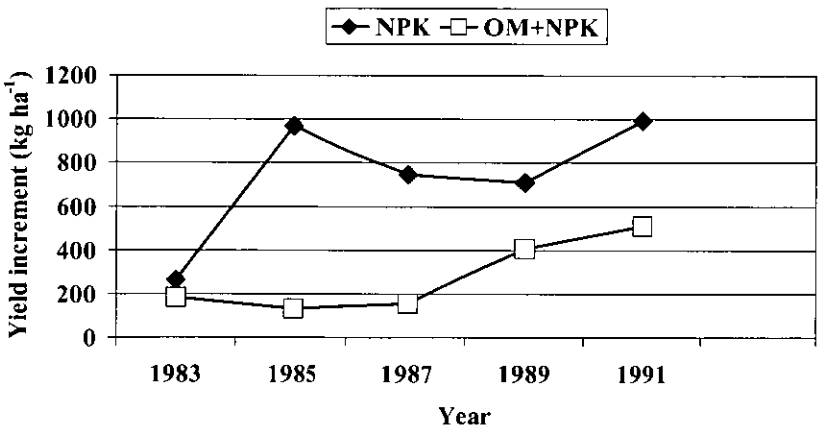


Figure 3. Incremental crop response of oilseed rape to K application in comparison to the NP treatment (NP or OM+NP)

With few exceptions (possibly due to variation of conditions from year to year), in all three crops, the average yield increments due to K were larger in the NPK than in the OM+NPK plots. This indicates that crops benefited from better K supply in the plots receiving manure as was also confirmed by the higher yield level in these plots.

The average yields of the three crops differed between the various treatments (Table 1). Rice yields were smallest in the NP treatment, indicating a slight depressive effect if only nitrogen and phosphorus were applied. Organic manure alone (OM) caused a yield increase over the control (CK) of 27.3% followed by OM + NP with 30.6%, NPK with 36.3% and OM + NPK with 45.8%. This observation shows that balanced application of mineral NPK alone out-yielded the organic matter treatments without mineral K. The largest yield increase by OM + NPK may be explained by the nutrient additions through the organic manure but also by the improvement of nutrient availability through its impact on other soil characteristics (see Tables 4 and 5). It is clearly evident that annual applications of 15 tons ha^{-1} of organic manure were not able to balance the K removals by the crops which have to be compensated by mineral K. The coefficients of variance (CV) show a strong variation of yields between the years, and it seems that NP produces the largest and OM the lowest CVs, indicating larger fluctuations in the most unbalanced compared to a rather balanced though insufficient nutrient application.

Compared to rice, maize showed much stronger response to K application. Whereas NP with 18% yield increase had a rather moderate effect, OM and OM + NP doubled the yields. Largest increases of more than 300 and 400% occurred when NPK and OM + NPK were applied. Extremely high CVs indicate strong variation between the yields and fluctuations were greatest in CK and NP. Smallest variations were observed in NPK and OM + NPK, indicating highest yield stability in these treatments.

Similar results were obtained in oilseed rape, where average yields in CK were very small and significantly increased by more than 75% in NP. OM alone further increased yields, but the difference to NP was not significant. Largest yield increases of more than 200% were found in the order OM + NPK > OM + NP > NPK. The coefficients of variance were highest in CK and NP as well as in OM + NP. Lowest CVs were found in OM and both NPK treatments. This indicates again poorest stability of the unbalanced and relatively high stability in those fertilisation systems which were most balanced.

Table 1. Crop response of rice, wheat and oilseed rape to long-term K application

Crop	Rice (n=12)			Wheat (n=6)			Oilseed rape (n=5)		
Treatment	Mean. yield kg ha^{-1}	CV %	Relative yield %	Mean yield kg ha^{-1}	CV %	Relative yield %	Mean yield kg ha^{-1}	CV %	Relative yield %
CK	5107	12.9	100	579	149.6	100	466	23.2	100
NP	5067	26.5	99.2	682	147.7	117.9	817	56.5	175.2
NPK	6961	12.7	136.3	2379	37.6	410.9	1551	12.3	332.5
O.M.	6499	7.7	127.3	1221	77.4	210.9	979	11.7	210.0
O.M.+NP	6670	13.7	130.6	1230	100.6	211.1	1603	24.6	343.7
O.M.+NPK	7449	11.3	145.8	2959	29.5	511.1	1881	12.9	403.2
L.S.D 5%	339			322			207		
L.S.D 1%	547			427			279		

Effect of K supplementation to crop 8-13 in the rotation

Continued cropping until the 7th crop led to a depletion in soil K, especially in the NP and OM + NP plots where severe K deficiency symptoms and significant yield reductions were observed. Therefore, these two treatments received a supplemental K application of 60 kg ha^{-1} K_2O per crop over an entire rotation from the 8th crop to the 13th crop which again was discontinued in the 14th (wheat) and 15th crop (rice).

Table 2 shows that the supplementation of 60 kg K_2O ha^{-1} to these two treatments increased the yield drastically. In both years of rapeseed cultivation, yields almost doubled in the NP+K treatment but had no effect in the OM+NP+K treatment. In both treatments which were supplemented with K, yields were inferior to those in the respective NPK or OM + NPK plots. This clearly indicates that yields after fresh application of K to depleted soils could not catch up with those in continuously fertilized plots.

Dramatic yield increases were also observed in rice, following the K supplementation and yields jumped by almost 30% in NP+K. In the OM+NP plots, yields increased by almost 20% after K was applied. Yields of the supplemented treatments could clearly catch up with those which until this point had received a continued supply (NPK, OM + NPK) of potash over the years.

In wheat, only one crop enjoyed the K supplement in 1986, when yields in both NP+K and OM + NP+K were about three times increased compared to NP and OM + NP. Wheat is hence the crop in the rotation with the strongest response to K supplementation after long-term depletion of potash reserves in the soil. Comparing the supplemented plots (NP+K, OM +NP+K) with those of continuously K supplied treatments (NPK, OM +NPK) reveals that the continued supplied crops showed slightly larger yields. Supplementation after depletion of K was hence inferior to continued K application.

Table 2. Effect of K supplementation on rice, wheat and oilseed rape

Crop	Year	NP	NP+K*	NPK	OM +NP	OM+NP +K*	OM +NPK	Crop order**
Oilseed	1985	717	1379	1686	1820	1820	1950	(8)
rape	1987	987	1622	1730	1877	1890	2033	(12)
	Mean	852	1500	1781	1848	1856	1992	
Rice	1985	4053	5784	5769	5406	6675	6323	(9)
	1986	5654	6801	6744	6053	7289	7434	(11)
	1987	5205	6413	6717	6512	7391	7370	(13)
	1988	4352	4955***	7545	7029	7098***	8052	(15)
	Mean	4816	5988	6694	6250	7113	7295	
Wheat	1986	905	2408	2477	875	2711	2885	(10)
Wheat	1988	179	371***	2390	384	837***	3014	(14)
	Mean	542	1390	2434	1259	3548	2950	

*60 kg K_2O ha^{-1} applied to former treatments NP and OM+NP to crop (8)-(13)

**in the rotation (see Materials and Methods)

***yields after re-omission of K application to crop (14) and (15)

After discontinuing the K supplementation to wheat (14), yields were still about double those of the respective NP and OM + NP crop. This indicates a strong residual effect of previous application of 360 kg K_2O ha^{-1} to six crops. However, looking at the overall yield level obtained in the same year, especially those observed in NPK and OM + NPK, reveals a dramatic yield loss by omitting K again. Yields in the NPK and OM + NPK plots were 6.4 and 3.6 times larger than in the respective supplemented crops after reintroducing K omission.

Similar effects were observed in rice, succeeding wheat in the rotation (15^{th} crop). Though yield differences were significantly increased in both NP+K and OM + NP+K with almost 14% and about 1% compared to NP and OM + NP, they were much less dramatic than in wheat. The NP+K treatment was clearly inferior to the NPK treatment, showing a less pronounced residual effect. In view of the overall yield level in the continued fertilized treatments, the two supplemented treatments were clearly inferior.

Both the example of wheat and rice show that even though significant residual effects of previous K application exist, the duration of this effect is very limited and yields compared to continued fertilized crops were clearly inferior. Therefore, it can be concluded that under the studied conditions it is important to continuously supply K for sustained large yields with little fluctuation between the years.

Effect of long-term nutrient application on K uptake by and the K : N ratios in the crops during growth

The K concentration in the plant tissue and the K : N ratios have been used for diagnosing the K status of the crops (Table 3). *Rice:* The analysis of rice during culm elongation and heading stages reveal poor K status of especially NP, CK and OM + NP. Only the two treatments with K application showed K concentrations in the sufficiency range. Caused by dilution during growth there was a further decline in K concentrations until heading stage. The K : N ratios showed the same trend and were extremely low in NP and OM + NP. Serious K deficiency was observed when rice showed K concentrations during culm elongation stage of <1%. So the plants suffered extremely from K deficiency in the following order NP > OM + NP > OM. The plants were retarded in growth and yields were strongly affected. When K : N ratios were below 0.4, plants generally suffered from K deficiency and this could be overcome once K : N was clearly above 0.5 so that the recommended ratio for rice is >0.5.

Wheat: Tissue K concentrations in wheat followed a similar pattern with greatest values at tillering followed by stem elongation and head emergence (Table 3). There were again significant differences between the treatments in the order CK < NP < OM + NP < OM < OM + NPK < NPK. This order changed with the age of the crop, when the dilution of K by growth due to a more intensive biomass production in NP and OM + NP caused a stronger K depletion of the plants compared to CK. This pattern persisted also throughout the head emergence stage. K : N ratios indicate the same trends and were extremely wide, below 0.2 in the NP plot at heading stage. Deficiency symptoms were already severe at K : N ratios of < 0.4 during stem elongation stage when K concentrations hardly reached 2.0% in all treatments with the exception of NPK. Stem elongation is still a phase in which corrective applications with potassium can reduce the occurrence of yield depression due to K deficiency. Therefore, it is recommended that during this period tissue samples are taken and K : N ratios determined which according to the trial observations should be above 0.5 to avoid K deficiency.

Oil seed rape: In this crop, plant tissue samples were collected at rosette, booting and flowering stage. Again the largest K concentrations in the plant tissue were observed at the youngest stage and declined with the age of the plants (Table 3). During all growth stages, there were significant differences in the K concentrations and the K : N ratios in the plant tissue between the treatments. Similar to wheat during the early growth, at rosette stage of the oilseed rape, the K concentrations and K : N ratios were smallest in CK followed by OM + NP < OM < NP. This changed dramatically with the increasing biomass production during growth. Based on the observations during the crop monitoring, the K : N ratios in the biomass of oilseed rape at booting should be > 0.5 to secure adequate K supply for large yields.

Table 3. K concentrations in plant tissues and K : N ratios as affected by fertilizer application and growth stage

Crop	Growth stage	Item	CK	NP	NPK	OM	OM +NP	OM +NPK	Mean
Rice	Culm elongation	K (%)	0.71	0.44	1.55	0.87	0.73	1.67	0.99
		K : N	0.45	0.17	0.55	0.52	0.26	0.57	0.42
	Heading	K (%)	0.31	0.19	0.69	0.47	0.33	1.05	0.51
		K : N	0.30	0.13	0.59	0.46	0.21	0.73	0.40
	Harvest	Yield (kg ha^{-1})	5619	5354	6749	6794	6051	7436	6334
Wheat	Tillering	K (%)	1.34	1.47	3.67	2.43	1.77	3.56	2.37
		K : N	0.27	0.41	0.66	0.48	0.29	0.62	0.46
	Stem elongation	K (%)	1.14	0.74	2.45	1.79	0.94	1.97	1.51
		K : N	0.36	0.16	0.51	0.49	0.19	0.43	0.36
	Head emergence	K (%)	0.51	0.40	0.89	0.71	0.49	0.79	0.63
		K : N	0.48	0.18	0.62	0.55	0.30	0.48	0.44
	Harvest	Yield (kg ha^{-1})	438	940	2478	1167	875	2885	1464
Oilseed rape	Rosette	K(%)	1.23	1.82	2.88	1.62	1.09	2.20	1.81
		K : N	0.43	0.12	0.54	0.51	0.19	0.40	0.37
	Booting	K(%)	1.20	0.67	1.63	2.39	1.09	2.05	1.51
		K : N	0.39	0.15	0.33	0.57	0.23	0.42	0.35
	Flowering	K(%)	1.34	0.61	1.44	2.15	1.05	2.06	1.44
		K : N	0.46	0.14	0.35	0.63	0.25	0.51	0.39
	Harvest	Yield (kg ha^{-1})	486	984	1730	1049	1877	2033	1360

Effect of long-term K application on soil fertility

In 1990, soil analysis for physical and chemical properties was carried out after harvest of rice (19^{th} crop). The results show that the un-fertilized control (CK) had a greater bulk density and smaller total porosity than the treatments O.M. and O.M.+NPK (Table 4). This improved porous system through fertilization was also evident from the larger proportion of the gas phase. It shows that particularly the application of organic manure breaks up the soil and improves aeration, thus raising the soil's ability of conserving water and nutrients. Though less pronounced, also the application of mineral fertilizers alone (NP, NPK) improved soil physical properties. This may be explained by larger amounts of roots and residues remaining on the field after harvest compared to the CK treatment.

Table 4. Effect of long-term nutrient application on soil physical parameters

Parameter	CK	NP	NPK	OM	OM + NP	OM + NPK
Bulk density (g cm^{-3})	1.36	1.36	1.31	1.28	1.27	1.26
Total porosity (%)	48.64	50.34	50.64	51.70	52.23	52.34
Gas phase proportion (%)	4.53	8.20	11.58	12.60	10.76	13.85
Liquid phase proportion (%)	43.28	44.32	44.35	45.60	42.33	46.27

Chemical soil analyses from the plough layers of different treatments were carried out at the time when the experiment was laid out in 1981 and after rice (19^{th} crop) in 1990. The results reveal the following:

1. Total nutrients: Total nitrogen in the soil decreased slightly by about -4.6% compared to 1981 in CK and NPK, remained unchanged in NP and increased by about +4.6% in OM and by about +17.4% in both OM + NP and OM + NPK. A very similar observation was made for total P, which slightly declined by -9.8% in CK, -2.8% in NPK, remained again unchanged in NP and increased by +7.0% in OM, +47.9% in OM + NP and 45.1% in OM + NPK. In contrast, all treatments showed a decline in total K which surprisingly was most severe in NPK and OM + NP with –13.3% compared to the initial level in 1981. The smallest decline of –9.8% in total K was observed in OM. Even OM + NPK revealed a strong decline in total K of -12.5% which indicates that despite largest K supply by both mineral and organic sources the nutrient balance for K was obviously negative in this system.
2. Organic matter: Soil organic matter contents declined by almost -9% in CK whereas they increased in all the fertilized treatments in the order NP (2.6%) < NPK (5.1%) < OM + NPK (14.7%) < OM (16%) < OM + NP (20.5%). This clearly shows the importance of organic manure in increasing soil organic matter. What becomes also evident is, however, that mineral fertilisation also substantially contributes to a

maintenance or even slight improvement of the SOM status under intensive crop rotation systems.

3. Available nutrients: The available nitrogen contents only declined in the CK (-2.6%) whereas they increased in all the other treatments in the order NPK (2.6%) < OM + NP (5.1%) < NP (7.7%) < OM and OM + NPK (both 21.8%). The available phosphorus contents, which were very high at the beginning of the trial, declined in all treatments in the order CK (-89.5%) > NPK (-76.9%) > OM (-75.4%) > NP (-67.5%) > OM + NPK (-58.8%) > OM + NP (-58.5%). The accumulated P in the soil due to previous P application prior to the experiment was therefore depleted to a very great extent in all treatments with the exception of those receiving organic manure. To maintain soil productivity, in the mid to long-term, therefore larger amounts of mineral P than the 60 kg P_2O_5 ha^{-1} in the experiment should be applied. A similar trend was observed in case of available K where the decline was most severe in NP (-47.2%) followed by OM + NP (-40.6%). The other treatments followed in the order OM (-32.5%) > CK (-23.1%) > NPK (-20.7%).

Table 5. Comparison between soil nutrient contents at the beginning of the experiment (1981) and after continued cultivation of 19 crops (1990) as affected by nutrient application

Parameter	Year 1981	Year 1990					
		CK	NP	NPK	OM	OM + NP	OM + NPK
Total N	0.086	0.082	0.086	0.082	0.09	0.101	0.101
Change (1981-1990)		-0.004	0	-0.004	0.004	0.015	0.015
Total P (P_2O_5)	0.071	0.064	0.071	0.069	0.076	0.105	0.103
Change (1981-1990)		-0.007	0	-0.002	0.005	0.034	0.032
Total K (K_2O)	1.570	1.391	1.397	1.361	1.416	1.361	1.373
Change (1981-1990)		-0.179	-0.173	-0.209	-0.154	-0.209	-0.197
Organic matter	1.56	1.42	1.60	1.64	1.81	1.88	1.79
Change (1981-1990)		-0.14	0.04	0.08	0.25	0.32	0.23
Available N	78.0	76.0	84.0	80.0	95.0	82.0	95.0
Change (1981-1990)		-2.0	6.0	2.0	17.0	4.0	17.0
Available P_2O_5	27.7	2.9	9.0	6.4	6.8	11.5	11.4
Change (1981-1990)		-24.8	-18.7	-21.3	-20.9	-16.2	-16.3
Available K_2O	21.2	16.3	11.2	16.8	14.3	12.6	17.1
Change (1981-1990)		-4.9	-10.0	-4.4	-6.9	-8.6	-4.1

In conclusion, based on the selected chemical parameters a general declining trend of soil fertility could be observed. This could partly be compensated or even reversed, e.g. for total organic matter content and nitrogen contents by the use of organic manure but not for the nutrient K. Mineral application could partly compensate for the losses in P and especially K fertility. However, employed application rates in the experiment were obviously too small to maintain adequate supply levels. Using the described soil fertility indicators, OM + NPK appeared as the most sustainable system in the experiment.

Conclusions

The yield-increasing effects of applying K in combination with NP and in particular with organic manure (OM + NP) on rice, wheat and oilseed rape was evident through the 12-year experiment, comprising 23 crops. The significance of yield differences to the treatments without K increased with the duration of the experiment. Supplementation of K to the cropping system after the 7th crop of continued cultivation without K showed that yields immediately recovered, but that yield levels clearly remained below those of continuously K supplied crops. Re-omission of K after supplementation caused that yields of succeeding wheat and rice crops dropped quickly again. Plant tissue analysis at various growth stages of the crops revealed that integrated analysis of N and K contents, including K : N ratios are valuable diagnostic tools. All three crops suffered serious K deficiency and lost much of their yield when the K : N ratios were < 0.2. K deficiency and concomitant yield losses already appeared when K : N ratios were < 0.4. At K : N ratios of > 0.5, normal crop growth can be expected and it was found that an adequate K : N ratio is > 0.6 for rice and > 0.5 for oilseed rape and wheat at the early growth stages. Using this assessment would allow a supplementation of K during the growth period if poor K status has been diagnosed. The development of soil physical and chemical parameters indicate a strong deterioration of the soil conditions if inadequate amounts of nutrients are applied. Even in the NPK treatments, the applied amounts of P and K were insufficient to compensate for removals and other losses from the soil. Maintenance or improvement of the soil fertility can only be achieved if nutrient removals are balanced with the application and organic manure is applied in combination with mineral fertilizers.

Chapter V

Nutrient management in perennial crops, cash crops and in special applications

Nutrient turnover and requirements in perennial crops using oil palm as an example

Rolf Härdter

Coordinator East/South East Asia, International Potash Institute,
c/o K+S KALI GmbH, Kassel, Germany

Introduction

Oil palm has become one of the most important vegetable oil producing crops in the world. Having its origin in the Guinea zone of West Africa, oil palm today is found in a narrow band of 10° north and south of the equator. The main producers of palm oil are the two SE Asian countries Malaysia and Indonesia. The reason for the great expansion of this crop in these two countries may be largely the favorable climate with an average rainfall of clearly above 1,600 mm per year. This is usually more than in the area of its origin. Oil palm moreover has shown to be the most suitable crop cultivated on former tropical rain forest land, where adverse soil conditions often restrict the successful cultivation of other, especially annual crops.

Though these advantages had been known for many decades, it was only during the 1980's when the expansion of this crop really took off. The success of oil palm, especially in SE Asia, may be largely because of the research carried out and implemented by the plantation industry. Today oil palm is probably one of the best studied crops due to its great economic importance to the oil palm cultivating countries. Therefore, the plantation industry is continuously challenged to further optimize the performance and productivity of oil palm.

This paper tries to share some of the knowledge accumulated about oil palm, especially in the field of crop nutrition, looking at the past achievements and at the challenges lying ahead. Being a perennial tree crop, the lessons learned in optimizing oil palm nutrition may also serve as examples for other long-term crops cultivated elsewhere under similar conditions. After adapting the experience and research results gained from cultivating oil palm, certain basic aspects may be used in other perennial crops, e.g. fruit trees, rubber and tea.

Oil palm in comparison with other oil crops

In the ecological region of the tropical rain forest belt, oil palm performs so well that it clearly out-yields other vegetable oil producing crops, e.g. soybean, oilseed rape seed, sunflower, etc. At times of diminishing rain forest and other natural resources as well as shrinking availability of agricultural land, this advantage over the traditional oil seeds receives an additional ecological dimension, i.e. much less land area is required compared with other crops (Figure 1).

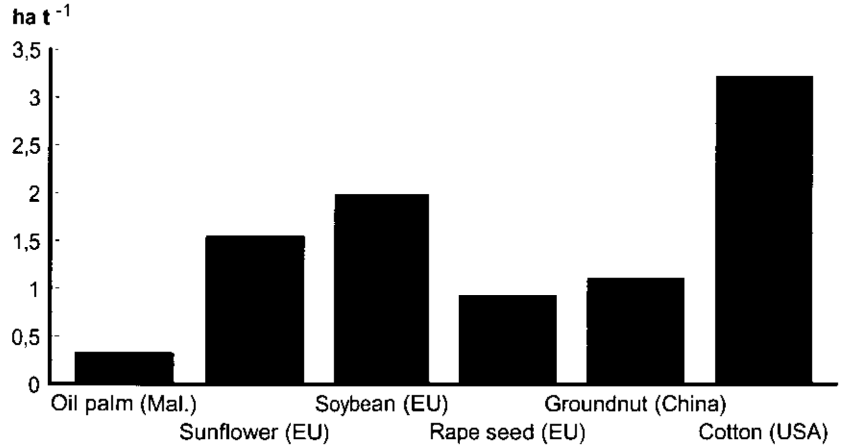


Figure 1. Land requirement of selected oil crops to produce one ton of vegetable oil (Source: Härdter et al., 1997)

Based on this productivity, oil palm appears to be more favorable in converting inputs into high value biomass. This becomes evident from an energy balance in which all inputs and outputs in joule equivalents were compared. A medium productive oil palm plantation is able to produce more than nine times the energy equivalents needed as inputs for its cultivation. This high ratio between output and input is unsurpassed by other vegetable oil crops as it is indicated in Figure 2.

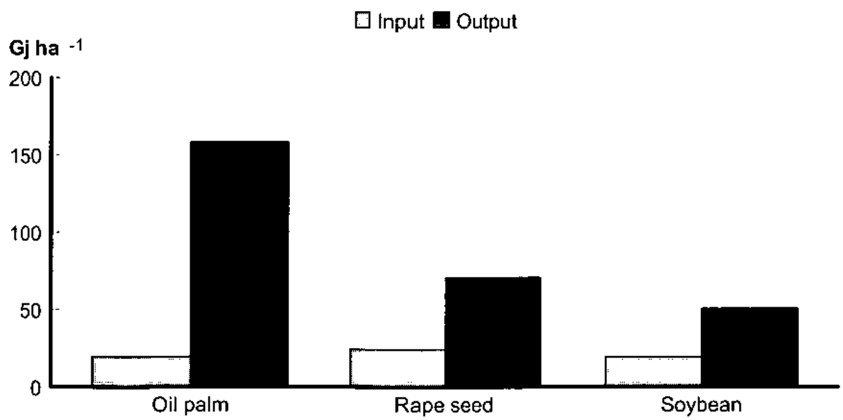


Figure 2. Output versus input ratios of selected vegetable oil producing crops (Source: Wood and Corley, 1991)

Owing to these advantages, countries with large populations, generally high demands for cooking oils and concomitant land shortages are very interested in introducing oil palm as main producer for cooking oil. However, it was only recently that the most populous two countries China and India have discovered oil palm. Whereas in India the growth rate of oil palm appears to get a certain momentum, China's expected expansion of oil palm seems to be rather unimportant (Figure 3).

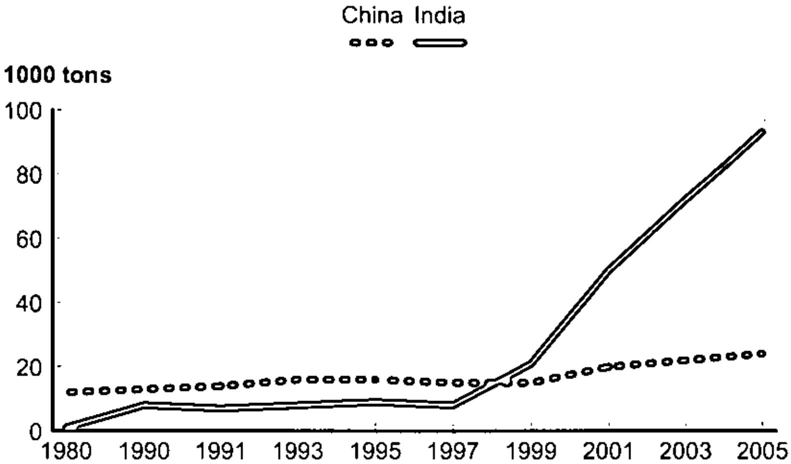


Figure 3. Palm oil production in the P.R. China and India (Source: Mielke, 1998)

The major reason for the slow development in China and the major reliance on other oil crops, especially oilseed rape, may be mainly explained by limited land availability and the marginal conditions found in its main growing area Hainan. The island is regarded as the only area of China, where due to climatic conditions, oil palm could be successfully cultivated.

Nutrient requirement and uptake by oil palm

The growth cycle of oil palm which lasts for about 25 years is characterized by different stages of which each has its specific requirement regarding nutrition. Three main stages can be distinguished: 1. Young immature (year 0 to 3), 2. Young mature (year 4 to 7) and 3. Mature (year 8 to 11) and 4. Old mature trees (> 12 years). The annual uptake of the various nutrients is shown in Figure 4, indicating the relatively small demand during the initial two years after planting and the dramatic increase in uptake during the following third year. From this figure, it is evident that maximum nutrient uptake is already reached from the third year onward and will be sustained until year 10 - 12. After 10 – 12 years, the annual nutrient uptake slows down slightly, especially when mutual shading of trees occurs as production limiting factor and is not properly handled by the agronomists. Figure 4 also shows that potassium is quantitatively the most important nutrient followed by nitrogen, magnesium and phosphorus. On the widespread nutrient deficient Ultisols and Oxisols, on which oil palm is usually grown, great emphasis should be placed on the initial supply of P. Therefore, oil palm receives between several hundred grams and one kilogram of rock phosphate into the planting hole.

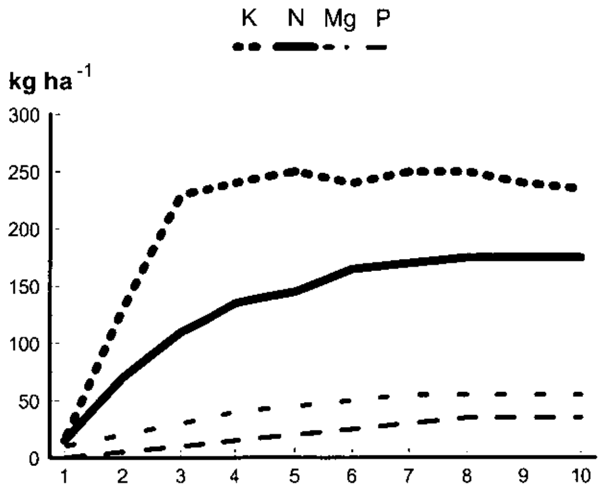


Figure 4. Annual uptake of N, P, K and Mg of oil palm as affected by age (Source: Ng, 1977)

Additional P is required to develop a decent leguminous cover crop, which is needed to reduce soil erosion (especially in the initial years) and also to provide symbiotically fixed nitrogen to the growing trees. Additional nitrogen supplied by mineral fertilizer is, however, required to satisfy the high demands of the palms. The same is applicable for potassium and magnesium which are almost exclusively supplied in the mineral form as potassium chloride (KCl) and Kieserite ($MgSO_4$). Because of their high water solubility, these two fertilizers have shown to be the most suitable for adequate and timely supply. In case large amounts are required, all nutrients with the exception of phosphorus are usually split into two and more splits per year to optimize uptake and to reduce losses by runoff and leaching.

Once taken up by the roots, the nutrients are redistributed within the palm to the growing tissues or serve as a reserve in trunks, fronds and roots as it is shown in Table 1.

Table 1. Nutrient removal, immobilization and recycling in mature oil palms (30 tons FFB ha^{-1}) (Source: Based on Ng and Tamboo, 1967)

	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)	Mg ($kg\ ha^{-1}$)
Removal with harvested fruit bunches	85	15	109	24
Immobilized in palm tissue	47	4	81	12
Nutrients recycled	91	13	119	33
Total uptake	223	32	309	69
Removal in % of total uptake	38	47	35	35

The figures clearly indicate that a large proportion of the nutrients taken up is needed for the formation of the trunk, fronds, etc. where they are partly stored as a reserve pool for the formation of fruit bunches and fruits. A large proportion of nutrients is also recycled by cut fronds during harvest. Therefore, the amounts of nutrients finally removed from the field in the harvested fresh fruit bunches (FFB) constitute only a relatively small proportion as it is shown in Figure 5.

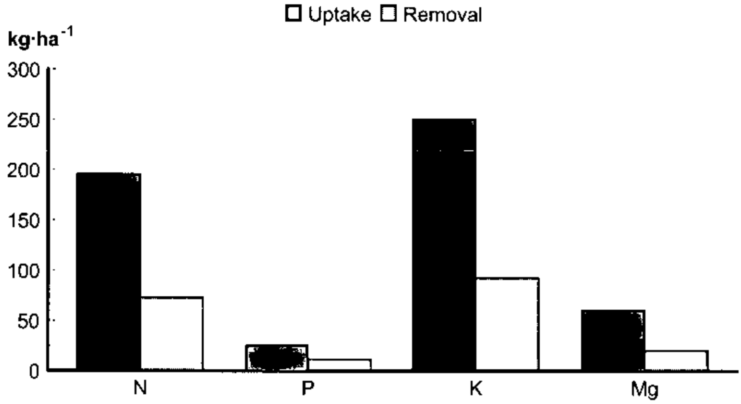


Figure 5. Annual uptake and removal of nutrients by one hectare of mature oil palm plantation, producing 25 tons of FFB (Source: Based on Ng and Tamboo, 1967)

The proportion of the total uptake which is removed varies between 35% for K and Mg and 47% for P. If only these amounts were considered in the fertilizer management of the plantations, a drastic under-supply of nutrients would be the result. The remaining proportion of the total nutrient uptake is required for the built-up of tree biomass, e.g. trunk and canopy. From these plant organs, a part of the nutrients can be mobilized and re-translocated to supply the new tissues and fruits. For an adequate and sufficient nutrient supply, the nutrients fixed in the tree biomass have to be considered as well as the large proportion of applied nutrients that is usually lost, mainly through leaching and surface runoff.

Nutrient losses and gains in palm oil plantations

If properly managed, the main nutrient losses from a stand of palms are those which are removed in the harvested crop. However, conditions that usually prevail in the humid tropics, e.g. high levels of rainfall, high rainfall intensities and partly sloping land with soils, having a poor water and nutrient retention capacity, make unproductive nutrient losses from the system through runoff and leaching unavoidable. The magnitude of these losses may vary drastically, depending on above mentioned environmental or site factors. Hence, the numbers given in Figure 6 and 7 may only serve as approximation and have to be determined for each location. To reduce these losses, good management practice is to plant leguminous cover crops which protect the land from runoff and erosion losses. Especially, critical stages are the period of establishing the plantation and the juvenile growth of the palms when trees provide only very limited shelter to the soil surface. The age of the trees has also a significant impact on nutrient losses through leaching as it is evident from Figure 7. In this trial, both the nutrients lost by leaching expressed as percentage of nutrients applied and the magnitude or range of losses were larger in the more mature palms. An observation that could be due to the reduced uptake, especially by the trees or by the cover crop.

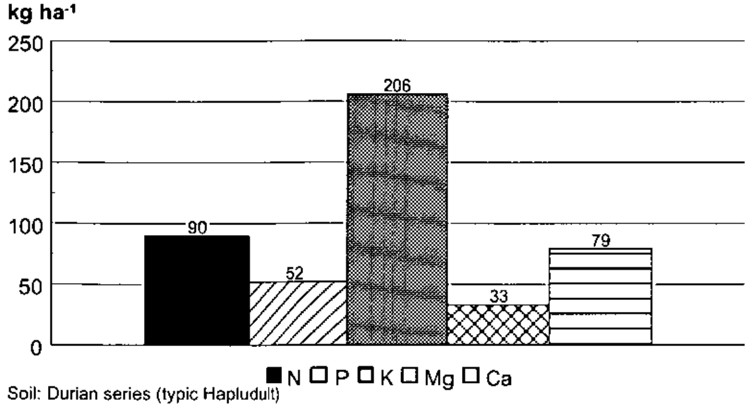


Figure 6. Nutrient losses by runoff in a mature oil palm plantation in Malaysia (Source: Maene et al., 1979)

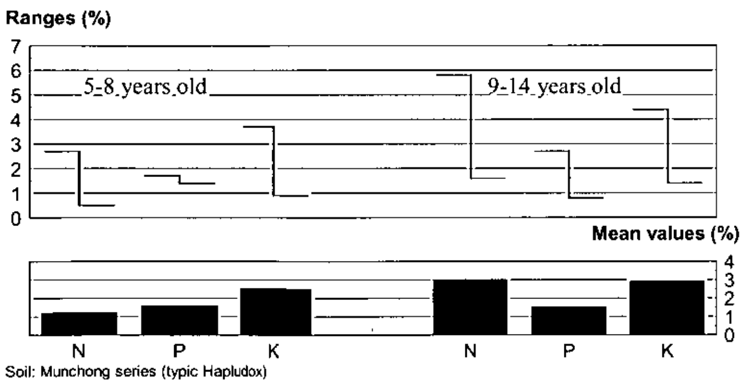


Figure 7. Nutrient leaching losses as affected by palm age (in % of applied nutrients) (Source: Foong, 1993)

In this experiment, the losses through leaching (clearly below 10%) were relatively small for all nutrients studied. In a similar experiment, in Nigeria, leaching losses were distinguished according to applied and native nutrients (Figure 8). The results indicate that in general, slightly more nutrients were leached out in the young planting than in the older or mature planting. However, it appeared that in the young planting the majority of the nutrients came from fertilizers whereas it was vice versa in the mature plantation. There, the losses of applied nutrients seemed to be drastically reduced compared to the so-called native nutrients. This, however, may be partly also losses of nutrients that had been previously applied or recycled with the fronds and roots of the trees and were mineralized in the soil. Besides magnesium that is heavily leached in the immature plantation, it is mainly nitrate that contributes to the nutrient losses in oil palm. The high mobility of these two nutrients in the soil profile makes them very prone to losses.

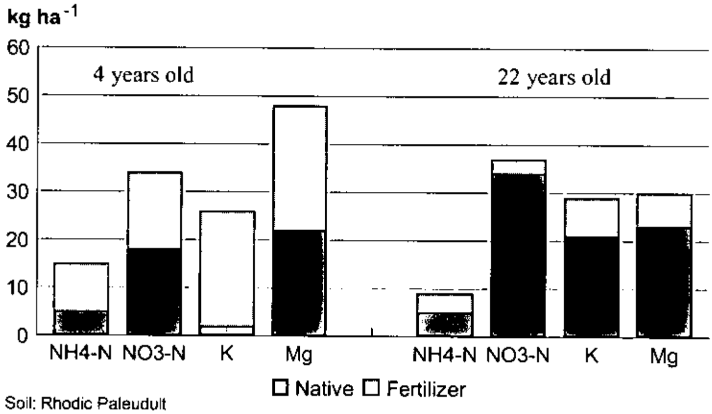


Figure 8. Leaching losses of native and applied nutrients in Central-South Nigeria as affected by palm age (Source: Omoti et al., 1983)

However, nitrogen, which is often applied in the form of urea, can also be lost by volatilization. Estimations of gaseous losses from urea show that up to 70% of the applied nitrogen may be lost in this way. Therefore, guidelines were developed to assess these losses better, depending on the conditions and hence to adapt fertilizer spreading accordingly to reduce volatilization (Table 2).

Table 2. Major environmental parameters for assessing potential volatilization losses from applied urea (Source: Ng et al., 1983)

Probability of NH_3 losses from urea	High	Moderate	Low
Clay & Silt (%)	< 35	35 – 65	> 65
Soil moisture (% WHC)	< 45	45 – 65	65 – 85
Soil surface	hard	firm to friable	friable
Site conditions	open	moderately shaded	well shaded
Radius of weeded circle (cm)	160	160 – 200	200 – 240
Days between application and rain	> 4	3 – 4	1 - 2

The examples indicate that the quantification of losses through the major pathways described above may need a site specific approach due to the large variation between locations and also between stands of different age and productivity. General figures provide only rough estimates of nutrient losses from oil palm plantations. In case these latter need to be evaluated according to their nutrient efficiency, more quantitative observations are required. These are crucial with respect to the economical and ecological impact of measures taken or for comparisons with other crops and/or cropping systems.

Nutrient cycling in oil palm plantations

Figure 9 shows a schematic picture of the fate of nutrients in an oil palm plantation. The amounts of nutrients that are recycled within the plantation depend to a great extend on the agronomic practices of the management. In general, for practical reasons and due to its convenience, fronds that are cut during harvesting of the fresh fruit bunches (FFB) are left on the field in the inter-rows. The nutrients fixed in this biomass are released during decomposition and mineralization to the soil and constitute an important nutrient pool for the supply to the palms (see also Table 1).

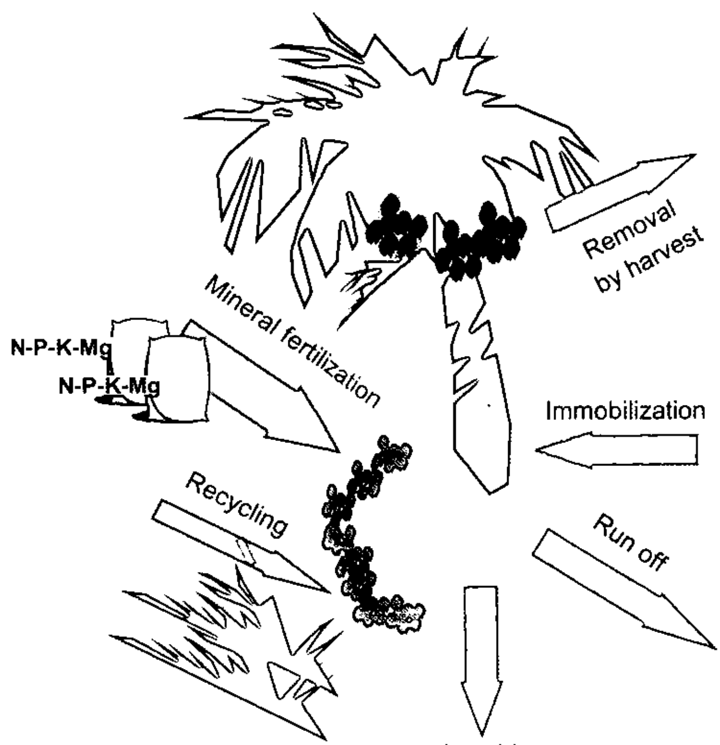


Figure 9. Schematic overview on the nutrient cycling in oil palms

The recycling of empty fruit bunches (EFB), though known for their nutritional high value, has not been fully accepted yet among planters due to relatively high transport and spreading costs. The common practice, where incinerating of EFB has not been banned for environmental reasons, is therefore still the use of bunch ash (BA). This by-product of the oil extraction process in the mill, however, is very alkaline with a pH of close to 12 and poses certain risks, especially when applied together with nitrogen fertilizers, increasing the losses by volatilization. Nevertheless, bunch ash potentially recycles slightly higher amounts of nutrients, especially K, within the plantation. On the other hand, the nitrogen contained in the empty bunches is virtually lost during incineration (Figure 10). In addition to being an important nutrient source, EFB mulching is a valuable tool for erosion control and improvement of nutrient uptake efficiency. It is therefore preferably used in the sloping areas where soil erosion poses a great problem and where topsoil losses prevail. Under such conditions, widespread occurring Mg deficiency can be corrected by a combined application of EFB and mineral magnesium fertilizer.

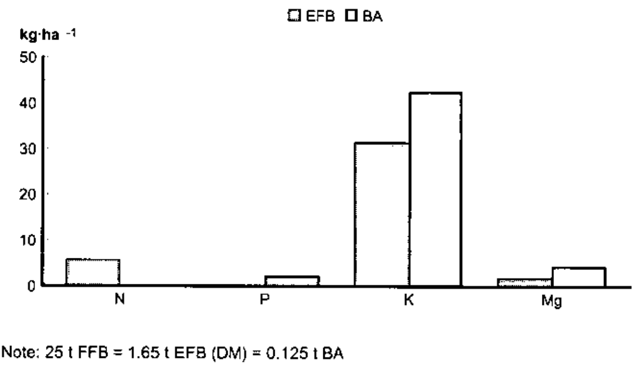


Figure 10. Amounts of nutrients recycled from empty fruit bunches (EFB) and bunch ash derived from 25 tons of FFB yield (Source: Based on Redshaw, 2003)

Another by-product of the oil extraction from the FFB is the palm oil mill effluent (POME). The use of this material which is relatively rich in nutrients, especially potassium and nitrogen, however, needs to be treated due to its high biological oxygen demand prior to its use for land application. The amount of nutrients that is returned with POME after it has been digested in ponds is shown in Figure 11. The use of this organic residue from the processing of the FFB is usually restricted to fields close to the palm oil mill from where it is transported through pipes or channels to the places of application.

In summary, integrating organic residues into the fertilization scheme of an oil palm plantation to supplement the application of mineral fertilizers appears to be sound in terms of environment and with regard to fertilizer economy. The feasibility of the use of all by-products as organic manure, however, depends on the infrastructure, labor availability and, especially, distance from the oil mill to the field. Nevertheless, even if all by-products from the mill were returned to the field, under the assumption that no losses occur during storage and transport, there would be a negative balance for the nutrient potassium of about 7 kg per ton of FFB or approximately 180 kg K ha^{-1} of a medium productive plantation with 25 tons FFB per hectare. So, mineral fertilization of considerable amounts is a prerequisite for supplying sufficient nutrients to the crop.

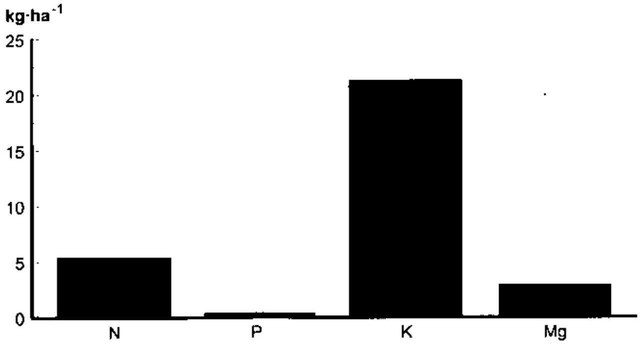


Figure 11. Amounts of nutrients that can be recycled to the field by palm oil mill effluent (POME) produced form the processing of 25 tons of FFB (Source: Based on Redshaw, 2003)

Nutrient management for higher efficiency

In order to remain competitive as vegetable oil producer, the palm oil industry faces a number of challenges, especially with respect to its productivity. The dramatic increase of palm oil production in the two major producing countries Malaysia and Indonesia during the last two decades has been mainly achieved by the expansion of the cropping area and not by an increase in yields, hence improvement of its productivity as it could be observed for other oil producing crops. With land suitable for the cultivation of this crop becoming increasingly limited, new approaches are introduced to improve the overall productivity of oil palm. One step into this direction is the introduction of higher yielding planting material obtained from tissue culture as it has been successfully demonstrated by Ng et al. (1999).

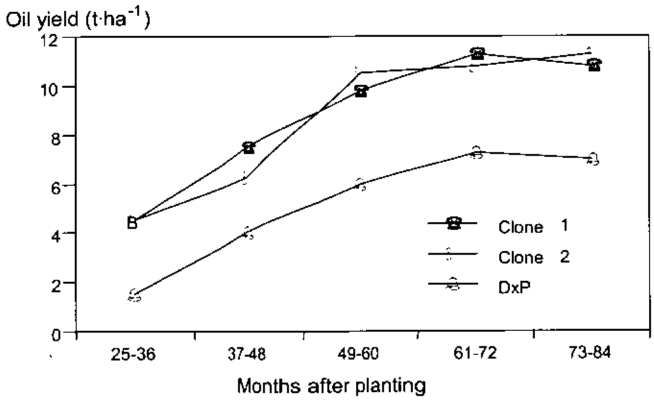


Figure 12. Comparison of FFB yields between traditional D×P and clonal oil palm produced from tissue culture (Source: Agrocom, 1998)

Despite certain setbacks the industry experienced in the early stages of this innovation in the 1970's and 1980's, there is increasing evidence that this technology is feasible under practical conditions. The yield performance of such improved planting material, clearly out-yielding the traditional palms from seeds, was obtained by crossings of *dura* and *pisifera* (D×P) palms. This opens a new scope for promoting a better realization of the high genetic potential of this plant species for vegetable oil production (Figure 12). Besides 30% larger yields and more, the new clonal planting material seems to offer additional advantages over D×P palms. Based on earlier findings by Woo et al. (1994), clonal oil palms appear to be also superior with regard to nutrient use efficiency (Table 3).

Table 3. Oil yield and calculated K efficiency of different planting material in the first six years after planting (Source: Woo et al., 1994)

Parameter (Cumulative)	Clonal palm	Seedling palm (DxP)
Oil yield (t ha^{-1})	32.3	19.4
K application (kg K_2O ha^{-1})	1865	1687
Oil production (kg oil kg^{-1} K_2O)	17.32	11.50
Efficiency (%)	151	100

Source: Woo et al., 1994

Despite an increased total K requirement of the higher yielding clonal palms, their demand for potash per unit of produced oil seems to be reduced, obviously due to a higher efficiency in converting inputs such as energy and nutrients into oil. Various observations indicate that there is a much greater uniformity in the plantation regarding performance, reducing the number of unproductive palms and furthermore, this planting material produces fresh fruit bunches with higher oil extraction rates in comparison to traditional D×P palms (Khaw et al., 1999).

Recently Prabowo et al. (2002) employed a non-destructive method to assess the recovery of applied nutrients to oil palm at five sites in North Sumatra. They found a great variation in the recovery efficiency (*RE*) between sites, nutrients and even nutrient sources (Table 5).

Table 5. Recovery of nutrients from mineral fertilizers in five fertilizer experiments in North Sumatra, Indonesia (Prabowo et al., 2002)

	Fertilizer recovery efficiency (%)				
Fertilizer increment	Trial 231	Trial 232	Trial 275	Trial 277	Trial 1403
N_1–N_0	24.0	18.8	36.0	23.7	26.7
P_1–P_2 (Trial 1403 P_2-P_1)	20.8	16.2	29.0	25.6	7.2
K_1-K_0	69.5	57.9	48.0	38.1	37.6
Mg_1-Mg_0	60.0	21.9	10.0	9.7	6.7

Preliminary results from one year of measurements indicate recovery efficiencies of 19.4% (N), 7.3% (P), 29.7% (K) and 10.6% (Mg). Large differences in *RE* were measured for different fertilizer sources of P and Mg fertilizer, and *RE* was much greater when these nutrients were supplied in soluble forms respectively as TSP and Kieserite. This became evident by smaller nutrient recovery when TSP and Kieserite in Trial 1403 were substituted by rock phosphate and dolomite. In almost all cases, *RE* was greater for each nutrient when other nutrients were supplied in non-limiting amounts. *RE* was smaller in Trial 231 where high rainfall resulted in large fertilizer nutrient losses in surface water runoff and eroded soil (Prabowo *et al* ., 2002). In Trial 231, *RE* was >100% for K where yield was less than 23 t ha^{-1}. This suggests that palms were able to use soil indigenous K more efficiently after K deficiency had been corrected.

Summary

Oil palm has become one of the most important vegetable oil producing crops in the world with a yield potential that, for the time being, is unsurpassed by other oil bearing crops. To realize this high potential, a generous nutrient supply is a prerequisite, in particular, in the climatic zone of the humid tropics where high rainfall levels combined with soils of poor fertility and low sorption capacity for nutrients prevail. In perennial crops exists a relative close nutrient cycle similar to forest ecosystems. However, due to large nutrient removals in the harvested crops as well as by natural, unproductive losses, the nutrient cycle is far from being closed, even if all the waste or by-products from oil extraction are returned to the field. Though these amounts of recycled nutrients may be considerable, mineral fertilizers and in particular potassium are needed to compensate for these losses to make the plantation system highly productive and sustainable. In the attempt to further improve the productivity of the oil palm, new approaches to higher yielding, more uniform plantations, i.e. with the introduction of clonal oil palm, offer a new perspective. Latest results on nutrient use efficiency studies in oil palm indicate large differences between nutrients and nutrient sources, suggesting there is an increased need to further fine-tune the nutrient management techniques to this important plantation crop.

References

Agrocom (1998). Towards 2000 with super bio-tech oil palm. Bulletin No. 3. Agrocom Enterprises Sdn. Bhd. Ipoh, Malaysia, pp. 10.

Foong, S.F. (1993). Potential evapo-transpiration, potential yield and leaching losses of oil palm. In: Y. Basiron, J. Sukaimi, K.C. Chang, S.C. Cheah, I.E. Henson, N. Kamaruddin, K. Paranjothy, N. Rajanaidu and M.D. Tayeb (Eds). 1991 PORIM Int. Oil Palm Conf. Progress, Prospects and Challenges Towards the 21st Century, PORIM, Kuala Lumpur, 105-119.

Härdter, R., Woo, Y.C and Ooi S.H. (1997). Intensive plantation cropping, a source of sustainable food and energy production in the tropical rain forest areas in Southeast Asia. Forest Eco. and Management 91, 93-102.

Khaw, C.H, Ng, S.K. and Thong, K.C. (1999). Commercial production of clonal oil palms by tissue culture – Prerequisites, constraints and issues. Paper presented at the Porim International Palm Oil Congress (PIPOC 1999), Febr. 1-6, Kuala Lumpur, Malaysia.

Maene, L.M., Thong, K.C., Ong, T.S. and Mokhtaruddin, A.M. (1979). Surface wash under mature oil palm. In: E. Pushparajah, (Ed.). Proc. Symposium on Water in Malaysia Agriculture, MSSS, Kuala Lumpur, 203-216.

Mielke, S. 1998. The outstanding role of Indonesia in the phenomenal development of the world palm oil industry in the past and in the future. Proc. 1998 Intern. Oil Palm Conf., Bali, Indonesia, Sept. 23-25, 1998.

Ng, S.K. (1977) Review of oil palm nutrition and manuring – scope for greater economy in fertilizer usage. In: D.A. Earp and W. Newall (Eds.) International Developments in Oil Palm. Inc. Soc. of Planters, Kuala Lumpur: 209-233.

Ng, S.K. and Thamboo, S. (1967) Nutrient contents of oil palms in Malaysia: I. Nutrients required for reproduction; fruit bunches and male inflorescences. Malay. Agric. J. 46: 3-45.

Ng, S.K., Thong; K.C., Ooi, S.H. and Woo, Y.C. (1983). Urea, its potential role in a competitive oil palm industry. In: S.K. Ng (Ed.): Compilation of Research and Scientific papers on "The Agronomy, nutrition and fertilization of the oil palm", Agromac Sdn. Bhd. Ipoh, Malaysia, 1997, 463-477.

Ng, S.K., Ooi, S.H. and Leng, K.Y. (1999). Potassium dynamics in the nutrition and fertilizer management for the oil palm (*Elaeis guineensis Jacq.*) in the 21st century. In: A. E. Johnston (ed.). Proc. of the Workshop C 16th World Congress of Soil Science Montpellier, France, 20-26.08.1998. Intern Potash Inst., Basel, Switzerland.

Omoti, U., Ataga, D.O. and Isenmila, A.E. (1983). Leaching losses of nutrients in oil palm plantations determined by tension lysimeters. Plant and Soil 73, 365-376.

Prabowo, N.E., Lubis, T., Fairhurst, T., Foster, H.L. and Nafisah, E.N. (2002). Efficiency of fertiliser recovery by oil palm in Sumatra. In: 2002 International Oil Palm Conference and Exhibition. IOPRI, Bali, Indonesia, 8-12 July 2002, 9 p.

Redshaw, M. (2003). Utilization of field residues & mill wastes. In: T. Fairhurst and R. Härdter (eds.). Oil palm –fertilizing for large and sustainable yields. PPI-PPIC, Singapore, IPI, Basel, Switzerland, 307-320.

Woo, Y.C., Ooi S.H. and Härdter R. (1994). Potassium for clonal oil palm in the 21st century. Proc. 1994 IFA-FADINAP Conference for Asia and the Pacific. Kuala Lumpur, Malaysia (unedited).

Wood, B.J. and Corley, R.H.V. (1991). The energy balance of oil palm cultivation. PORIM Int. Palm Oil Conf., 133-143.

Recirculating nutrient solutions in greenhouse production

Hillel Magen, Coordination China, International Potash Institute

c/o DSW, P.O. Box 75, Beer Sheva, Israel, 84100

Abstract

Environmental laws and regulations support recirculation of drainage water (DW) from greenhouse facilities. The water and nutrients in the DW is of significant value and recirculation system may save up to 40% of water and nutrients. The initial and the setting of critical limits of EC, Na and Cl in the solution dictate the frequency of discharge from the system. The system constantly monitors the nutrient solution for EC, pH and nutrient concentrations. Nutrients are applied according to factors such as plant requirements, transpiration, required content of elements in tissue and level of nutrients in the solution. A frequent level of analysis and monitoring of these factors is required to maintain the stability of the system, to save water and nutrients and to achieve maximum yield.

Introduction

Recirculation of nutrient solutions is increasing steadily in many countries with intensive greenhouse culture. There are several driving forces for the development of these sophisticated systems: 1) restrictive environmental laws and regulations, aiming to reduce nutrient leaching to the environment, 2) significant savings of water and nutrients and 3) better control of nutrient supply.

Recent European Community directives emphasize the need for growers to reduce their nitrate emission. For example, the greenhouse industry in the Netherlands has targeted to reduce the nitrate emission of the glasshouse vegetable production based on closed systems by 80% until 1995 and by 100% until 2000 (Hand & Fussel, 1995). Several other countries are reducing the amount of discharged drainage water (DW) by regulations and/or by subsidizing water recirculation (Bolusky and Regelbrugge, 1992).

Water is a scarce natural resource, but is at a constant total quantity. The sphere of mankind activity is constantly reducing the fraction of fresh water in favour of useless water (Tognoni et al., 1998). According to this report, agriculture uses only 60% of the globally available fresh water. Total protected cultivation is 200,000 ha and the average biomass production is approximately 50kg m^{-3} yr^{-1}. Since water content in this biomass is 90%, the total theoretical usage of water is approximately 100 million m^3 yr^{-1} which is only 0.0037% of total irrigation water in the world. Global usage of irrigation water is 2.7 million $*10^6$ m^3 yr^{-1}, but the actual greenhouse usage is estimated at ~5,000* 10^6 m^3 yr^{-1}, much more than the theoretical value. Calculation of possible savings through the use of recirculation systems shows that a saving share of 30% in quantity will directly save $150 million yr^{-1} (for price of water of $ 0.10 m^{-3}).

The technology involved in such operation requires heavy investments (Bell & Marchant, 1998) that are possible due to new enforcement of environmental laws and regulations (Tognoni et al., 1998) and to significant savings of water and nutrients.
This paper describes recirculation systems in greenhouse, their potential savings and the different approaches applied to the nutrient management in such systems.

Description of the system

Recirculation is a closed system of water, nutrients and plants, in which the nutrient solution that drains from plant's beds is re-introduced to the plants. The preferred water source for such system is that with the lowest salinity (expressed as electrical conductivity, EC) and with minimal content of ions, especially those absorbed in minimal quantity by plants such as Na and Cl. This will allow more circulation and reduces the drainage out of the system. Online EC, pH and nutrient concentration measurement devices are installed at various points in the system to monitor and alter inputs of water, fertilizers and acids. A typical recirculation system is presented in Figure 1.

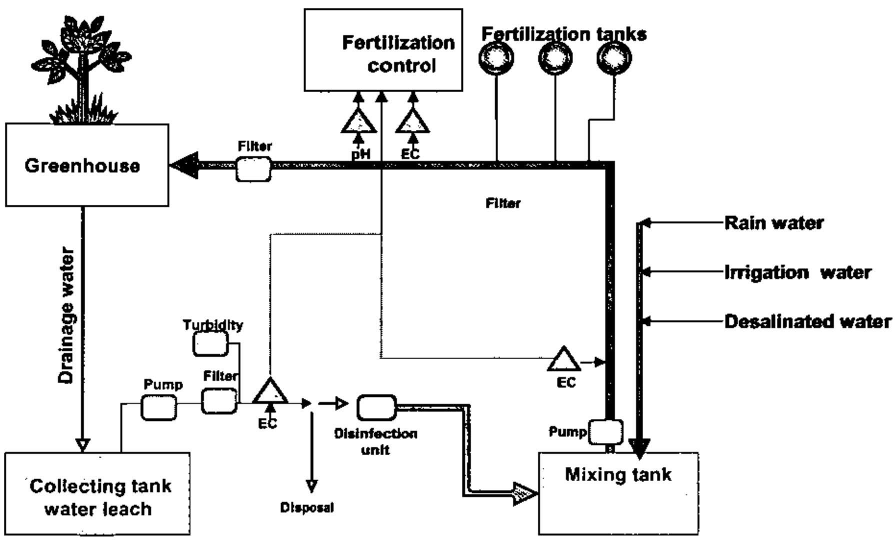


Figure 1. Recirculated greenhouse solution system

The use of rainwater is essential as a diluter when solution's EC builds up. The price of setting up a collection and storage system is high and depends on the precipitation pattern. If rain is concentrated within a short period, volumes of storage become too large for economic return. A typical analysis of irrigation and rainwater is presented in Table 1.

Table 1. Chemical analyses of tap and collected rainwater for rose irrigation (Raviv et al., 1995)

Water Source	pH	EC $dS\ m^{-1}$	Na^{+}	Ca^{++} meq $liter^{-1}$	K^{+}	Cl^{-}	NO_3^{-}
Tap water 0.20		7.1	1.11	4.63	2.50	0.14	6.18
Rain water	7.4	0.13	0.24	0.35	0.04	0.80	0.10

The change from soil-grown crops to soil-less culture growing has not resulted in a disappearance of soil-borne pathogens (Van Os, 1998). In addition, contaminants such as sprays and other chemicals used in greenhouse production threaten the health of plants. The installation of a disinfection or treatment unit to control the level of pathogens and other contaminants is therefore an integral part of the system. Disinfection methods of irrigation water are presented in Table 2. While heat treatment is the most frequent method used in Europe (Van Os, 1998) this may differ in other places. For example, big volume sand and biological filters are used in Israel.

Table 2. Disinfection of recycled nutrient solution (van Os, 1998)

Method	Dosage	Active against pathogens
Heat treatment	$95^{\circ}C$ for 30s	All pathogens
UV radiation	250 $mJ\ cm^{-2}$	All (widely used)
Slow sand filtration	100 $l\ m^{-2}.h^{-1}$; D_{10}<0.4 mm	Phytophthora, pythium
Hydrogen peroxide + activators	?	?
Lava filtration	?	?
Ozonization	10 g ozone per m^3 for 1 h	All
Membrane filtration		All

D=average diameter

Saving of water and nutrients

The cost of recirculating systems is high. Installation of 1 hectare can cost \$ 18,000, but the annual saving from water and nutrients can reach about \$ 4,000 each year (Bell & Marchant, 1998). In Israel, the price of water for farmers is \$ 0.2-0.3 m^{-3}, thus the value of saving 40% in water consumption is in the order of \$ 3,000 $ha^{-1}\ yr^{-1}$. When available water is limited, recirculation is the only way to supply sufficient water for greenhouse production.

The luxury feeding usually used in intensive systems and the relatively high leaching fraction leads to high concentration of nutrients in the drainage water (MacAvoy, 1994). The method employed with soil-less culture demands approximately 30 - 50% leaching fraction. This fraction is simply spilled and diverted out of the growth area.

The combination of high leaching fraction (LF) and the high nutrient concentration in the DW (or LF) leads to a significant amount of wasted nutrients. Typical nutrient concentrations in DW in tomatoes and roses grown in greenhouse are presented in Table 3.

Table 3. Typical average summer run-off nutrient analysis (Bell & Marchant, 1998)

Crop	pH	EC $dS\ m^{-1}$	N-NO3	P	K	Ca	Mg	Na
			----------	----------	mg kg^{-1}	----------	----------	----------
Tomatoes	6.1	2.75	175	22	350	220	75	100
Roses	6.5	2.34	260	25	250	150	42	135

An example of potential saving of potassium from recirculation is presented. Assuming that LF is being recirculated instead of sending LF out of the system:

LF = 20%,
220 days of irrigation with 5 mm day^{-1} = 11,000 $m^3\ ha^{-1}\ yr^{-1}$,
the total amount of LF: 11,000 * 0.2 = 2,200 $m^3\ yr^{-1}$,
2,200m^3 * 350 mg K kg^{-1} = 770 kg K $ha^{-1}\ yr^{-1}$.

Nutrient management

Bar-Yosef (1999) describes the main management topics related to recirculated systems as follows:

- Salinity build-up,
- Root pathogens
- The presence of root exudates and growth substrates dissolution,
- Al^{3+} toxicity (released from substrate),
- Adjusting nutrient and oxygen demand.

The topic of salinity build-up will be described in more detail.

Salinity build-up

Since irrigation water contains an initial amount of soluble ions, mainly those that are not needed in plant nutrition (Na, Cl), the initial EC of nutrient solution should be considered. Build-up of EC is due to accumulation of ions that are not absorbed by plants. The following example (Table 4) shows the nutrient concentrations in the solution of a tomato crop grown in the greenhouse after 3 weeks of applying the treatments (Raviv et al., 1995). In this experiment, the influence of rainwater and recirculation (RCRLN) were tested. Data for the nutrient solution are presented in the upper part of the Table 4 and the respective analysis of DW is at the bottom part.
The treatment with no recirculation (tap, commercial) had a slightly reduced level of EC in the nutrient solution (2.05 compared 2.12 and 2.13 dS m^{-1}) and reduced levels of Cl, Na and Ca concentrations (6.4 compared to 7.4 and 7.8 meq l^{-1}, respectively) but no clear differences and even opposite results for other ions. Salinity in DW has

increased by approximately 50%. In this experiment, a build-up of NO_3 in DW was also observed, suggesting an excess application of this element.

Table 4. Chemical analysis of irrigation and DW of 3 treatments (Raviv et al., 1995)

Treatment	pH	EC dS m^{-1}	Na^+	Ca^{++}	K^+	Cl^- meq $liter^{-1}$	NO_3^-	NH_4^+	PO_4^{3-}
Tap, (Commercial), LF 25%, < 3.5 dS m^{-1}	6.9	2.05	4.8	2.8	4.2	6.4	7.1	3.4	1.1
Tap + rain, RCRLN, < 3.5 dS m^{-1}	7.0	2.12	6.0	3.4	3.8	7.4	7.4	2.1	0.7
Tap, RCLN, < 3.5 dS m^{-1}	7.0	2.13	6.2	3.6	3.7	7.8	7.1	1.9	0.6
DW 1	4.6	3.18	9.5	5.7	6.5	10.2	12.7	0.6	0.5
DW 2	4.8	3.08	10.4	5.8	5.4	11.1	12.5	0.2	0.3
DW 3	4.8	3.18	10.7	5.8	6.0	12.1	12.7	0.4	0.4

Renewing the nutrients in recirculated systems

Management of recirculated systems is complicated because of the "consolidation" of two systems: water consumption and nutrient absorption (Ben Asher, personal communication). If water uptake is higher than that of nutrients, EC will build up and vice versa. Replenishing nutrients should be calculated as per single ion; otherwise a quick excess of ions is caused, leading to spillage of water.
Various factors influence the application of nutrients. A major factor is the nutrient consumption of plants throughout the growing and yielding periods, which was investigated in other field or laboratory experiments, as described in Figure 2 (data from Bar-Yosef, 1999).

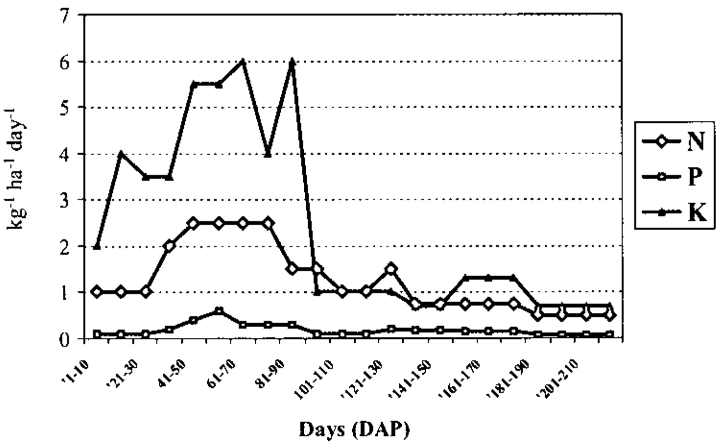


Figure 2. Periodical N, P & K consumption rate (kg ha^{-1} day^{-1}) of greenhouse Tomatoes (Bar-Yosef, 1999)

Bugbee (1996) suggested using both nutrient and watering requirement and combining these via the transpiration to dry matter growth ratio; the plant needs to transpire 300 kg of water to form 1 kg of dry matter. Under normal conditions a ratio of 300:1 is acceptable. At low humidity, the ratio increases to 400 but under high CO_2 levels reduces to 200 or even less. For example, if the desired K concentration in the plant is 4% (40 g kg^{-1}), at a transpiration to dry matter ratio of 300:1, 300 litres must have 40 g of K and the consequent concentration in the nutrient solution is 3.4 mM.
Moreover, essential nutrients can be put into 3 major categories based on speed of depletion from the solution (Bugbee, 1996). Group "1" elements are actively absorbed by roots and removed from the solution in a short time (few hours). The second group (2) elements have intermediate uptake rates and are usually removed from the solution slightly faster than that of water via transpiration. Ca and B (group 3) are passively absorbed from solution and often accumulate in the solution. For example, phosphorous and potassium (group 1) are rapidly absorbed by the plant, so that very low concentrations (µM) in the solution may occur. This is a positive indication of the plant's ability to absorb nutrients, and there is no need to add more of these elements immediately. P concentration of only 0.5 mM is sufficient after the first vigor growth period (Bugbee, 1996).

Table 5. Approximate uptake rates of the essential plant nutrients (Bugbee, 1996).

Group	Type of uptake	Nutrients
1	Active uptake, fast removal	NO_3, NH_4, P, K, Mn
2	Intermediate uptake	Mg, S, Fe, Zn, Cu, Mo, C
3	Passive uptake, slow removal	Ca, B

Recirculated systems are totally based on the nutrient concentration in the solution, without the buffer supply that the soil provides. Two examples of beneficial effect by nutrients usually not considered as plant nutrients are given: 1) Silicon is not known as a plant nutrient in the solutions, but there is evidence for it's role in avoiding toxicity of metals and increased protection against insects (Bugbee, 1996); 2) Chloride, usually regarded as a undesired element, but at concentrations of 8-13 mM increases Ca uptake, decrease blossom-end rot and increases gold specs in tomato fruit (Kreij, 1995).

References

Bar-Yosef, B. 1999. Advances in Fertigation. *In*: Advances in Agronomy (D.L. Sparks ed.). V-65, pp 2-65.

Bell, F. R. and A. Marchant. 1998. The development and implementation of run-off management plans for the collection, containment and disposal of nutrient rich run-off from glasshouse crops, grown in artificial substrates in Guernsey. Proc. IS Water Quality & Quantity in Greenhouse Horticulture. (*Ed*): Rafael Munoz Carpena. Acta Hort. 458, ISHS, pp 395-399.

Bolusky, B. & C. Regelbrugge. 1992. Political perspective on water quality impact. Hort. Technology 2, 80-82.

Bugbee, B. 1996. Nutrient management in recirculating hydroponic culture. Crop Physiology, Laboratory, Utah State Univ. Logan, UT 4322-4820.

De Kreij, C. 1995. Latest insights into water and nutrient control in soil-less cultivation. Acta Hort. 408: Soil-less Cultivation Technology, pp 47-61.

Hand, D. J. & M. Fussel. 1995. The effect of reduced nitrate input on tomato yield and fruit quality. Acta Horticulture 401. Growing Media & Plant Nutrition, pp 319-325.

MacAvoy, R.J. 1994. Nitrate nitrogen movement through the soil profile beneath a containerized greenhouse crop irrigated with two leaching fractions and two wetting agent levels. J. Amer. Soc. Hort. Sci. 119; 446-451.

Raviv, M., Reuveni, R., Medina, Sh. Shamir, Y., Duvdevani, O., Shor, O. and R. Schayar. 1991. Changes in tuff during prolonged cultivation which affect rose productivity. Acta Hort. 294, 99-104.

Raviv, M., Reuveni, R., Krasnovsky, A. and Sh. Medina. 1995. Recirculation of rose drainage water under semi-arid conditions. Acta Hort. 401. Growing Media & plant nutrition, 427-433.

Tognoni, F., Pardossi, A. and G. Serra. 1998. Water pollution and the greenhouse environmental costs. Proc. IS Water Quality & Quantity in Greenhouse Horticulture. (*Ed*): Rafael Munoz Carpena. Acta Hort. 458, ISHS., 385-394.

Van Os, E. A. 1998. Closed soiless growing systems in the Netherlands: The finishing touch. Proc. IS Water Quality & Quantity in Greenhouse Horticulture. (*Ed*): Rafael Munoz Carpena. Acta Hort. 458, ISHS, 279-291.

Nutrient input and evaluation of fertilization efficiency in typical tea growing areas of China

Ruan Jianyun and Wu Xun

Tea Research Institute, Chinese Academy of Agricultural Sciences, Hangzhou Zhejiang 310008

Abstract

A study on nutrient inputs in typical tea producing areas in the West Lake District of Hangzhou and the Xinchang County in Zhejiang Province (Green tea) and Anqi County in Fujian Province (Oolong tea) was carried out in 1998-99. The surveyed tea gardens represented 6.2%, 2.6% and 2.0% of the total areas in the above three regions, respectively. The results showed that the average amounts of nutrient ($N+P_2O_5+K_2O$) input were 738 kg ha^{-1} in West Lake District of Hangzhou, 712 kg ha^{-1} in Xinchang County and 694 kg ha^{-1} in Anqi County with $N : P_2O_5 : K_2O$ ratios of 1 : 0.07 : 0.06, 1 : 0.13 : 0.11, and 1 : 0.25 : 0.26, respectively. There was a tendency that the amount of nutrient consumed increased with the output value of the tea product. In particular the amounts of applied P and K were remarkably larger in tea gardens of high product value than in those of low values. Calculation of an apparent nutrient balance showed that the K input in comparison to the output in 67.2% of the area of the surveyed plantations in Xinchang and 74.8% in West Lake District of Hangzhou was insufficient with deficit values of 12.9 and 22.2 kg K_2O ha^{-1} yr^{-1}, respectively. In about 35.3% of the area of the investigated plantations in Xinchang and 67.2% in West Lake District of Hangzhou, the balance of phosphorus was also negative whereas in most tea fields, there was a surplus input of nitrogen. Soil analysis indicated that the contents of available K in 63-95% of the samples taken from these areas were in the deficiency range (<80 mg kg^{-1}). The study demonstrated the problems of imbalanced fertilization and over-application of fertilizers in some of the tea gardens.

Introduction

Tea is an important commercial crop and there are presently 1.1 million hectare of tea fields, covering hilly areas in southern China. For some rural families in this area, tea production is a dominant source of income. Since 1990's, the main management target has been to gradually shift from obtaining the highest yield to achieve the production of quality tea and to improve the overall economic efficiency. Accordingly, attention has been mainly given to solutions for both the better quality hence higher selling prices and lower production and processing costs. Both yield and quality of tea are greatly influenced by the fertilization program and therefore the input of nutrients is one of the key elements of production. In 1998-1999, the situation of nutrient input in typical tea counties was investigated with the aim to generate the background information on fertilization by farmers or in tea plantations and further to provide a basis for an efficient improvement in the application of fertilizers.

Materials and methods

Investigation Sites

Three typical tea producing regions, i.e. West Lake District of Hangzhou and Xinchang County in Zhejiang Province and Anqi County in Fujian Province, were selected as survey areas. West Lake District of Hangzhou is a traditional green tea producing area, enjoying a high reputation for being the hometown of Longjing Tea with a history of over 300 years. Xinchang County is formerly known for Gunpowder tea, but recently Mingcha (quality tea) production developed rapidly and received recently the name 'The Hometown of Mingcha' from the Ministry of Agriculture. In this county, the value of tea production accounts for one third of its total economic output from agricultural based production. Anqi County of Fujian province is the most important production base of Oolong tea. Tieguanyin and Huangjingui which represent the top oolong tea types produced in China are the most famous products of this county.

Methods

In the above areas, representative farms or plantations were chosen to collect the information on tea area, yield, product value and fertilizer input in 1998. The basic information of the survey is given in the Table 1 and 2. The quality teas of green tea were referred as those made from tender spring shoots usually with one bud together with one or two leaves, which are elaborately processed most often by hand and occasionally by machines. Quality oolong tea is made from vegetatively propagated clones such as Tiguanyin, Huangdan and Shuixian, etc. Based on the data collected, the averages of fertilizer inputs to unit area were calculated.

Table 1. Basic information on tea production in the counties engaged in the survey

Item	Anqi Fujian	Xinchang Zhejiang	West Lake District of Hangzhou Zhejiang
General			
Tea type	Oolong tea	Green tea	Green tea
Total tea area, ha	16,667	4,467	918.4
Total output, ton	13,000	4,175	787.3
Total value, thousand Yuan*	242,000	152,000	44,790
Average yield, kg ha^{-1}	819	1,044	888
Survey			
Number of Tea plantations	20	13	7
Area, ha	331.8	117	83.4
Area as percent of the total, %	2.0	2.6	9.0
Output, ton	328.6	132	88.47
Average yield, kg ha^{-1}	1,226	1,450	1,119

Note:* Yuan stands for RMB Yuan (1 USD = 8.2 RMB), the same below.

The apparent nutrient balance of the tea systems was also calculated as the difference between the output over input. Only nutrients supplied in form of fertilizers (inorganic and organic) were considered in the estimation of the input. For convenience, the biological N_2 fixation and wet or dry deposition of nutrients were not taken into account. The output parameters of nutrients comprise the removals by harvest and pruning, gaseous loss, runoff and leaching which were estimated by experience. The removals of nutrients in the harvested crop were calculated from the yield and the average concentrations of nutrients in the shoots in which N, P_2O_5 and K_2O accounted for 4.5%, 1.0% and 2.5%, respectively. It was assumed that deep pruning was performed every 5 years and the pruned materials (leaves and stems) were completely removed from the fields. The mean biomass weight was 12,000 kg ha^{-1}, containing 1.7% N, 0.5% P_2O_5 and 1.1% K_2O. Therefore, the amounts of N, P_2O_5 and K_2O removed by deep pruning were 40.8, 12.0 and 26.4 kg ha^{-1} yr^{-1}. The percentages of N and K_2O loss by gas, runoff and leaching were 40% for inorganic N, 20% for N from organic manure and 20% for potassium, respectively. Therefore, the apparent balance of each nutrient was calculated according to the equation:

Apparent balance = Fertilizer input – (removal in harvested crop + removal by deep pruning + loss),

where, the removal in harvested crop = yield x nutrient concentration in shoot;

removal by deep pruning = determined by experience data (see the text) and converted to values on annual basis; and

loss = the amount of nutrient input x loss percentages (40%, 20%, and 20% for N from inorganic fertilizers, organic manure, and K_2O, respectively).

Table 2. Basic information on farms/plantations engaged in the survey

Region	Tea type	Value	Area	Total tea		Quality tea	
				Amount	Value	Amount	Value
		Yuan ha^{-1}	ha	kg ha^{-1}	Yuan ha^{-1}	kg ha^{-1}	Yuan ha^{-1}
Anqi, Fujian	Oolong tea	≤45,000	319.8	1,187	13,712	416.4	1,536
		>45,000	12.0	2,455	119,482	954.8	74,297
Xinchang, Zhejiang	Green tea	≤45,000	60.7	1,879	31,824	136.5	19,568
		>45,000	56.5	1,268	108,613	1,136.8	107,495
West Lake District Hangzhou, Zhejiang	Green tea	≤45,000	9.1	932	15,552	92.9	7,753
		>45,000	47.6	1,128	85,607	376.6	58,930

Results

Nutrient input

The area of tea managed by one family farm or in a plantation varied widely from less than one hectare to more than hundreds of hectares. This has led to large differences in fertilizer inputs among farms or plantations. The total input of N+P_2O_5+K_2O in Anqi County of Fujian ranged from 203 to 4,177 kg ha^{-1} and the amounts of N, P_2O_5 and K_2O varied from 38 to 2,644 kg ha^{-1}, from 96 to 683 kg ha^{-1} and from 45 to 1,420 kg ha^{-1}, respectively (Table 3). In West Lake District of Hangzhou in Zhejiang Province, the corresponding values ranged from 327 to 2,104 kg ha^{-1} for total input, 289 to 1,593 kg ha^{-1} for N, from 0 to 357 kg ha^{-1} for P_2O_5 and from 0 to 355 kg ha^{-1} for K_2O. The amounts of total input for the individual nutrients N, P_2O_5 and K_2O in Xinchang County of Zhejiang province ranged from 279 to 1,385 kg ha^{-1}, 243 to 1,116 kg ha^{-1}, from 0 to 219 kg ha^{-1} and from 2 to 488 kg ha^{-1}, respectively. The average inputs of $N+P_2O_5+K_2O$ in Anqi, West Lake District of Hangzhou and Xinchang were 694, 738 and 712 kg ha^{-1}, respectively (Table 3).

Table 3. Average amount of nutrient inputs and sources

Region	Nutrient	Mineral fertilizer Straight	Mineral fertilizer Compound	Organic manure	Total
		--------kg ha^{-1}--------			
Anqi, Fujian	N	399.5	32.9	6.8	439.2
	P_2O_5	74.1	31.3	3.3	108.7
	K_2O	76.0	31.3	8.8	116.1
Xinchang, Zhejiang	N	514.0	25.0	34.0	573.0
	P_2O_5	43.0	16.0	15.0	75.0
	K_2O	3.0	16.0	45.0	64.0
West Lake District, Hangzhou, Zhejiang	N	599.3	40.7	8.0	647.9
	P_2O_5	5.9	32.3	8.0	46.2
	K_2O	0.0	32.3	7.3	39.6

Nitrogen generally comprised 66% to 88% of the total input and was mainly in the form of urea and ammonium bi-carbonate. About 70% of the quantity of P_2O_5 was provided through compound fertilizer in West Lake District of Hangzhou, while in Xinchang 60% was in form of single superphosphate and the remaining P was applied through organic manure and compound fertilizers. In Anqi, more than 65% of the P was provided by straight mineral fertilizers (single superphosphate, calcium magnesium phosphate). The main potassium source was compound fertilizer (80%) in West Lake District of Hangzhou, organic manure (70%) in Xinchang and straight mineral fertilizers (>65%) (muriate of potash or sulphate of potash) in Anqi County. With the exception of K in Xinchang, the total amount of nutrients provided by organic manure was generally small and accounted for 3.2% of the total input in West Lake District of Hangzhou, 13.2% in Xinchang and 2.9% in Anqi.

Table 4. Nutrient input (kg ha^{-1}) and nutrient ratios applied in form of mineral fertilizers to tea fields as affected by product values

Region	Product value (Yuan ha^{-1})	N	P_2O_5	K_2O	$N+P_2O_5+K_2O$	$N:P_2O_5:K_2O$
Anqi, Fujian	≤45000	434.9	103.8	107.2	646.0	1:0.24:0.25
	>45000	607.4	302.9	468.8	1379.1	1:0.50:0.77
Xinchang, Zhejiang	≤45000	362.1	18.8	37.6	418.6	1:0.05:0.10
	>45000	801.9	127.4	110.9	1040.1	1:0.16:0.14
West Lake District Hangzhou, Zhejiang	≤45000	318.7	49.0	11.0	378.6	1:0.15:0.03
	>45000	710.8	45.7	45.0	801.4	1:0.06:0.06

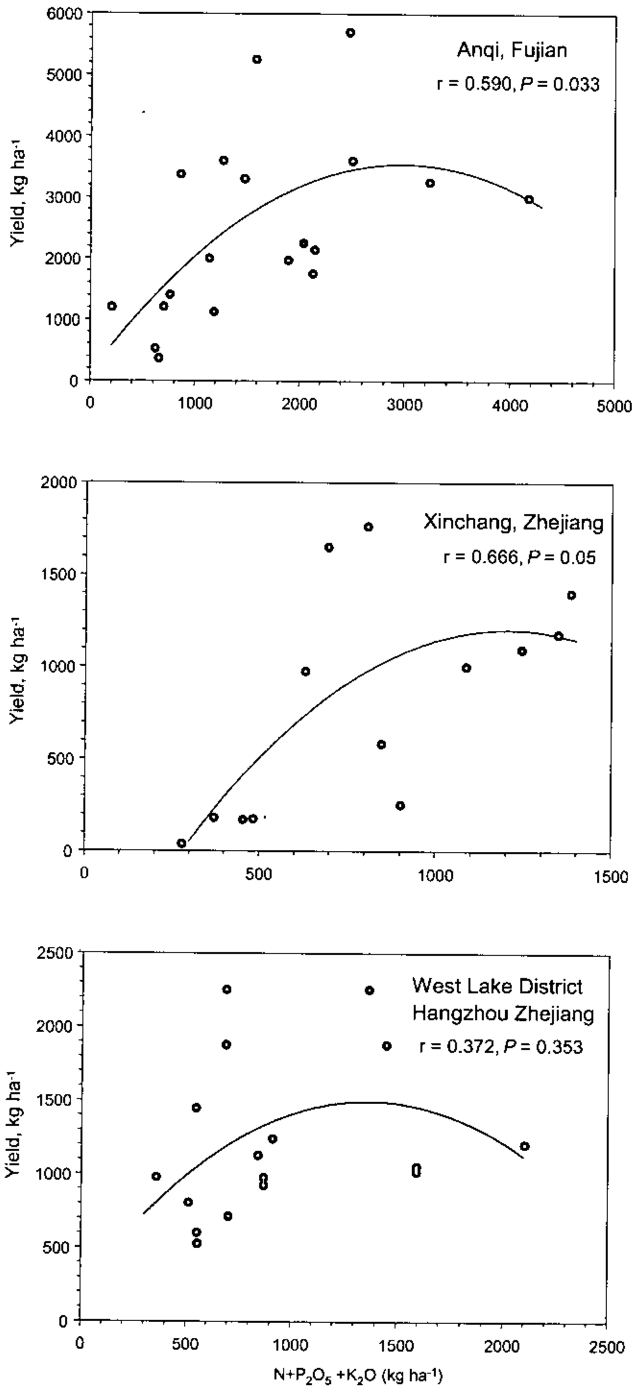


Figure 1. Relationship between tea yields and nutrient inputs in three regions.

Relationship between nutrient inputs, yield and value of tea product

The yield level usually increased with the amount of nutrient input, which could be roughly described by quadratic curves (Figure 1). Compared to fields with a low product value, nutrient inputs in the form of fertilizers increased remarkably in those with higher values. In the fields with a product value beyond 45,000 Yuan ha^{-1}, the amount of nitrogen was doubled while those of phosphorus and potassium was increased by up to 5 times compared to lower values (see Table 4). The latter two nutrients were mainly from increased application of compound fertilizers or organic manure. Therefore, the ratios of phosphorus and in particular potassium to nitrogen were generally higher in these fields than in those of lower values ($\leq$ 45,000 RMB).

The apparent balance of nutrients

In tea fields, the output of nutrients mainly includes removal by harvest and pruning, gaseous loss, runoff, erosion and leaching. Output by harvest is directly related to the yield level, which with regard to N, P_2O_5 and K_2O was 55.8, 12.4, 31.0 kg ha^{-1} in Anqi, 73.5, 16.3, 40.8 in Xinchang and 49.3, 11.0, 27.4 in West Lake District of Hangzhou, respectively. Pruning, either light or deep, is an important agronomic measure that possibly leads to a substantial nutrient net output, depending on the strategy of handling the pruned materials. Usually light pruning is performed 1 to 2 times each year and the pruning material is left in the fields. Consequently no net removal of nutrients out of the system usually occurs by light pruning. On the other hand, deep pruning, that is performed every 4 to 5 years with the pruned material (leaves, stems) removed from the field leads to a distinct net output of nutrients. Though oolong tea and green tea are two different types of tea, the same parameters have been used to estimate the quantity of nutrient removal by pruning since these two tea systems are planted at similar planting density. Based on the assumptions stated in the 'Materials and Methods', the amounts of nutrients removed by deep pruning were 40.8 kg N, 12.0 kg P_2O_5 and 26.4 kg K_2O ha^{-1} yr^{-1}.

Table 5. Apparent nutrient balances of tea (Input - Output)

Region	Nutrient	Negatively balanced tea field		Mean value of
		Number	Area percentage, %	balance, kg ha^{-1}
Anqi Fujian	N	1 (5.0%)*	10.0	169.0
	P_2O_5	0	0.0	87.1
	K_2O	4 (20.0%)	10.2	42.6
Xinchang Zhejiang	N	0	0.0	234.3
	P_2O_5	4 (30.8%)	35.3	42.3
	K_2O	8 (61.5%)	67.2	-12.9
West Lake District of Hangzhou Zhejiang	N	0	0.0	300.2
	P_2O_5	7 (38.9%)	60.1	23.3
	K_2O	9 (50%)	74.8	-22.2

*Data in brackets show the percentage of the number of plantations.

The losses of nitrogen and potassium were 173.6 N, 25.0 kg K_2O ha^{-1} in Anqi County, 223.1 kg N and 13.6 kg K_2O ha^{-1} in Xinchang County and 257.6 kg N and 7.9 kg K_2O ha^{-1} in West Lake District of Hangzhou, respectively. On average, the balances of N,

P_2O_5 and K_2O in Anqi were positive which means that the input surpassed the output. However, in nearly 10% of the fields, based on area, the N and K_2O balances were negative (Table 5). In both West Lake District of Hangzhou and Xinchang, N had a positive balance while phosphorus in about 35.3% of the area of the surveyed tea fields (30.8% farms or plantations) in Xinchang and 67.2% of the area (38.9% farms or plantations) in West Lake District of Hangzhou had a negative balance, although the averaged P balances were positive. In the case of K_2O, about 61.5% of farms or plantations (representing 67.2% of the area) in Xinchang and 50% (representing 74.8% of the area) in West Lake District of Hangzhou did not apply sufficient potassium fertilizer. The average deficits were 12.9 kg ha^{-1} in Xinchang and 22.2 kg ha^{-1} in West Lake District of Hangzhou.

K Status of tea soils

Soil samples which were taken from the surveyed plantations and analysed for exchangeable K indicate that the apparent balance was mostly negative for K. The results showed that, though the exchangeable K content varied from one site to another, K deficiency was rather common in all three regions (Table 6). The lowest average K supply level of the soils was found in the tea fields in West Lake District of Hangzhou where 90% of the tea fields may be regarded as deficient in K. In Xinchang, the mean level of exchangeable K was 71 mg kg^{-1} with 63% of the fields being deficient in K. In Anqi, although the K balance in most of the tea fields was positive, the fields with K deficiency still accounted for 75%. This may be due to the fact that our investigation only reflects the situation of one year whereas the level of exchangeable K reflects the fertilization of many years.

Table 6. Available soil K content (mg kg^{-1}) from surveyed plantations (0-40 cm soil depth)

Region	Number of soil samples	Range	Mean	Percentage of K deficient fields*
Anqi Fujian	40	16-220	70	75%
Xinchang Zhejiang	16	15-164	71	63%
Hangzhou Zhejiang	21	18-162	54	95%

*Critical level of available K by NH_4OAC is 80 mg kg^{-1}.

Discussion

Fertilization is one of the key factors which greatly influences the productivity of tea. According to Shui and Chang (1996), the input of fertilizers contributes by 41% to the annual production in the main tea producing countries such as China, India, Kenya and Sri Lanka. This is greater than the contribution by land (25%) and labour (8%). The presented results also show the close relationship between fertilizer input level and yield and product value. In this study, the mean quantity of total nutrient input ($N+P_2O_5+K_2O$) was as high as 694-737 kg ha^{-1} and in some extreme cases even up to 4,000 kg ha^{-1}. This value was much greater than the current recommendation of 25-27.5 kg (12.5-15 kg N and 12.5 kg $P_2O_5+K_2O$) for every 100 kg made tea (Ruan, 1999) and was about twice as much than in some other tea producing countries. For example, the average input of $N+P_2O_5+K_2O$ in tea fields of Sri Lanka in 1997 was 297 kg ha^{-1}

(Han Wenyan, personal communication). In Kenya, the recommended quantity was about 280-350 kg ha^{-1} (Othieno, 1994). Meanwhile, the presented results also show that the amount of N applied to the fields varied greatly from 279 to 2,104 kg ha^{-1} in the green tea areas (West Lake District of Hangzhou and Xinchang) with an average of 597 kg ha^{-1}. This is more than twice the recommended amount of 214 kg ha^{-1} which is based on yield (for every 100 kg made tea, 12.5 – 15 kg N). This application was also much larger than the 100-300 kg ha^{-1} usually applied to black tea (Owuor 1997). This difference might be explained by the different response to nitrogen with respect to the quality of green and black tea. Whereas for green tea, the quality is closely correlated with the contents of total nitrogen and free amino acids in the leaf (Lu et al., 1994; Mukai et al., 1992), for black tea, however, large nitrogen application may reduce the quality. This is largely due to the decreased formation of catechins, leading to a lower content of theaflavins, brightness and flavour index (Owuor and Odhiambo, 1994). Therefore, to produce a better quality usually smaller nitrogen fertilizer rates are applied to black tea than to green tea.

On the other hand, the presented results showed that the nutrients were not properly balanced. In the three regions, the ratio of N : P_2O_5 : K_2O was 1 : 0.1-0.2 : 0.1- 0.2, distinctly different from those observed in the product (leaf) where it is approximately 1 : 0.22 : 0.56. This shows that insufficient P and in particular too little K was applied as compared to the recommendation of 1 : 0.25-0.5 : 0.25-0.5 for China (Ruan, 1999), 1 : 0.16 : 0.4 for Sri Lanka (Han Wenyan, personal communication) and 1 : 0.25 : 0.25 or 1 : 0.5 : 0.5 for Kenya (Othieno, 1994). In India, the appropriate N : K_2O ratio is in the range of 1 : 0.6 to 1 : 1 (Barbora, 1994). The results from soil analysis and also the field experiments confirmed that more K is needed in the tea production systems of China, showing the significant response of tea to K fertilizer application (Ruan et al., 1999).

Acknowledgement

The financial supports from the International Potash Institute and '151 Project' of Zhejiang Province were acknowledged. The authors thank the assistances of Guanghan Lin, Jianming Cai, Xiangbao Hong, Yuanzhi Shi, Lifeng Ma and Wenyan Han.

References

Barbora, B. C. (1994). Practices adopted in North-East India enhance tea productivity. Proceedings of the International Seminar on "Integrated crop management in tea: towards higher productivity", Colombo, Sri Lanka, April 26-27, 1994. International Potash Institute, Basel, Switzerland. pp. 67-78.

Lu, J. S., Wei, H. F. and Li, C. H. (1994). Composition of major free amino acids in young shoots and effects on quality of tea. J. Southwestern Agric. 7 (Supplement), 13-16.

Mukai, T., Horie, H. and Goto, T. (1992). Differences in free amino acids and total nitrogen contents among various prices of green teas. Tea Res. J. 76, 45-50.

Othieno, C. O. (1994). Agronomic practices for higher tea productivity in Kenya. Proceedings of the International Seminar on "Integrated crop management in tea: towards higher productivity", Colombo, Sri Lanka, April 26-27, 1994. International Potash Institute, Basel, Switzerland. pp. 79-95.

Owuor, P. O. (1997). Fertilizer use in tea: the case of nitrogen. Tea 18, 132-143.

Owuor, P. O. and Odhiambo, H. O. (1994). Response of some black tea quality parameters to nitrogen fertilizer rates and plucking frequencies. J. Sci. Food Agric. 66, 555-561.

Ruan, J., Wu, X. and Härdter. R. (1999). Efficiency of potassium and magnesium in China's tea gardens. In: Proceedings of workshop C organized by the International Potash Institute at the 16th World Congress of Soil Science, Montpellier, France, 20-26 August 1998: Essential role of potassium in diverse cropping system. Ed. A. E. Johnston. pp. 73-86. International Potash Institute, Basel, Switzerland.

Ruan, J. (1999). Balanced fertilization for quality tea production. In: Proceeding of 9th Congress of Soil Society of China. 'Soil Sciences towards 21st century: improvement of soil quality and sustainable development of agriculture'. pp. 160-163. China Environmental Science Publishing House, Beijing.

Shui, S. and Chang, K. (1996). Contributions of technical progress to the tea economy – A quantitative assessment. International Tea Workshop: Advances in tea sciences and technologies and the world tea economy. 1996, July 9-11. Beijing, China.

Nutrient balances of vegetable cropping systems and their control by fertilization in Tianjin

Zhou Yimin, Zhang Jinsheng*, Huang Feng, Zhu Jinghua and Wang Zhengxiang

Soil and Fertilizer Institute of TAAS (Tianjin 300192)
*Information Institute of TAAS Tianjin 300192

Abstract

The soil nutrient balance and fertilization management of vegetable fields were studied by surveying different crop rotation and planting patterns in different areas of Tianjin. Furthermore, results of long-term fixed location trials were included to present and discuss current fertilizer management issues of an important vegetable production area of China. Results for typical vegetable rotations indicate that in the surveyed areas the balance for nitrogen was always positive and application of N exceeded the removal by the crops between 4 and 58%. For P and K, the removals generally exceeded the inputs and for P, between 49% and 88% of the removed P was returned to the fields through mineral fertilization. The ratio between input and output of K was even wider and showed that between only 27% and 71% of the K removed was returned to the field. The situation changed dramatically when the location and the production systems were individually analyzed. In suburban vegetable gardens and under protected cultivation (greenhouse), inputs of N and P were so excessive that sometimes more than 6 times the amount of N removed was applied to the field. For P, the ranges of oversupply were between 80% - 270%. In the more remote from the urban areas located fields the balances were negative, especially when vegetables were cultivated in rotation with field crops. The situation for K was completely different and even in the suburban, protected cultivation systems, the K inputs were dramatically smaller than the removals and only between 0 and 83% of the removed K was returned in form of mineral fertilizer. The long-term trials showed that even when 450kg K_2O ha^{-1} were annually applied to the vegetable rotation, the K balances were clearly negative with 106-418 kg K_2O ha^{-1}. Only in two years when substantial amounts of K were applied through organic manure, the balances were positive. In total of six years with the combination of two applications of organic manure and sufficient application of mineral potassium (450 kg K_2O ha^{-1}), the K balance was positive. The application of 225 kg K_2O ha^{-1} yr^{-1} was too small to balance removals over the time period to avoid that the soil becomes depleted of K whereas the combination of two applications of organic manure and 450 kg K_2O ha^{-1} in the mineral form may lead to an K accumulation in the soil if no losses by leaching, etc. occur.

Introduction

Developing vegetable production and ensuring the supply to urban consumers are the foremost tasks facing urban-suburban type agricultural production in metropolis. In order to achieve the three aims of vegetable production (high yield, high quality and high efficiency), scientific and reasonable fertilization is necessary. Studying the soil nutrient balance and developing rational fertilization practices is therefore of great importance.

Tianjin is located along the bank of the Bohai Sea and lies within the warm temperate zone with a semi-arid monsoon climate. Planting vegetables along the bank or coast of vast alluvial plains such as the northern and southern Grand Canal and Haihe Rive, etc. has a history of at least one hundred years. In recent years, the vegetable fields shifted to the outer suburbs due to the expanding cities. More than 60,000 hectares are cultivated with vegetables and of the total, 2/3 of the area is newly developed. China-wide up to 500 million tons of vegetables are produced annually to meet the need of 900 million urban citizens. However, a significant proportion of the production is also exported. The vegetable production has become an important pillar of the suburban market economy. Along with the fast developing economy and the mineral fertilizer industry, the application of fertilizer to vegetables has been doubled, producing a higher output and income today. However, as the fertilizer application to vegetable fields is lacking a scientific standard and technical advises, cases of reduced output and environmental contamination have been reported, causing an unfavorable image to agriculture. Aiming at further understanding of the vegetable nutrition, this paper tries to give insight into nutrient balances, nutrient contents in the soil, depending on various soil fertility management practices in the vegetable gardens.

Materials and methods

Selection of sampling location

Places of representative cropping systems (including one crop, two crops and three crops per year and five crops per 2 years rotations) were selected for sampling. The sample collection included protected (greenhouse) and non-protected systems. The sites were also analyzed with respect to cultural practices so that depending on those, NPK balances could be determined. The cultivation practices included mulching, protected and open field cultivation with varying degree of management level, depending on the distance from the city. The fertilization practices varied also largely, showing that the intensity of organic manuring increased with the proximity to the urban areas.

Investigation method

The investigation was carried out by interviewing farmers, technical staff and leaders of brigade and inspections at the sites and by analyzing the taken samples.

Budgetary estimate of soil nutrient balance

The soil nutrient balance was estimated according to the nutrient input (organic manure and fertilizer, etc) and removal.

Fixed location trial

In order to study the effect of a varied nutrient supply to vegetable on the potassium balance and to monitor the effect of management practices on soil nutrients, from 1993 to 1998 a long-term fixed position trial was conducted. This comprised three treatments consisting of NP, NPK1 and NPK2. When every planting period was finished, vegetable yield, potassium absorbed by plants and soil potassium content were analyzed and the nutrient balance was calculated.

Result and discussion

The status of NPK balance in vegetable garden soil of different crop rotations

At first, the NPK balance of vegetable gardens cultivated with different crop rotations was investigated. Results show that in open fields the average input was 847 kg N ha^{-1}, 239 kg P ha^{-1} and 369 kg K ha^{-1} whereas the average output was 696 kg N ha^{-1}, 411 kg P ha^{-1} and 602 kg K ha^{-1} (Table 1).

Table 1: Status of NPK balance in vegetable garden soil cultivated with different crop rotations

Location	Type of rotation	Nitrogen			Phosphorus			Potassium		
		Input kg ha^{-1}	Output kg ha^{-1}	Index %	Input kg ha^{-1}	Output kg ha^{-1}	Index* %	Input kg ha^{-1}	Output kg ha^{-1}	Index %
Yangliuqing Xiqing	Cabbage Cucumber Chinese cabbage	840	763	110	240	470	55	360	716	50
Baitangkou Jinnan	Spinach Eggplant Chinese cabbage	794	765	104	151	282	54	225	443	51
Xinlicun Dongli	Tomato Chinese cabbage	713	562	127	190	392	49	135	497	27
Tianmu Beichen	Celery Pimento Cucumber	1,019	643	158	450	606	74	375	714	53
Shuigaozhuang Xiqing	Eggplant Squash	875	743	117	300	342	88	452	638	71
Average		848	695	122	238	418	64	369	602	50

*Note: The index signifies how much of the respective nutrient in % of the plant removal is replaced by fertilization

Comparing the nutrient outputs with the inputs, a nutrient replacement index could be calculated in which output was set as 100. An index of greater than 100 hence signifies that more than has been removed is returned to the field whereas as an index of < 100 indicates insufficient nutrient replacement. The indexes of 122% for N, 64% for P and 50% for K show that N has been applied slightly in excess whereas P and K were clearly undersupplied. With approximately half of the potassium replaced by fertilization, a K deficit is building up over the years, leading to a drastic K depletion of the soils.

The NPK balances in vegetable gardens depending on cropping pattern

The NPK balance in vegetable gardens, depending on differences in cropping pattern, was studied in the following and results indicate that the fertilization level varied between locations and cropping patterns. Comparisons between protected cultivation and open field in the vicinity of the city and outer suburbs showed that the amount of fertilizer applied in protected cultures was larger than in open fields. Furthermore, fields near the city received more than those in the outer suburbs. The experience is that growers apply heavy amounts of fertilizer to cucumber, eggplant and Chinese cabbage due to greater response and higher benefit. The majority of mineral fertilizers applied consisted of nitrogen and phosphorus whereas the use potassium was rather underrepresented. This results in a nutrient imbalance, especially in protected cultivation and in fields near the city. The details (Table 2) reveal that in the rotation of cucumber, cucumber and Chinese cabbage, the total nitrògen applied was up to 3,779 kg ha^{-1} whereas the amount of nitrogen removed by the plants was only 630 kg ha^{-1}. This leads to a replacement index 600%, meaning that six times the amount removed has been applied to the crops in only one year. Similar observations could be made for phosphorus, showing that the applied amounts largely exceed the amount removed by the plants. The replacement index was 158-373%, indicating that rates were adjusted to return 1.6-3.7 times the amount removed by the plants. This may be the reason why there is a positive correlation between the number of vegetables planted per year and the accumulation of phosphorus in the soil. The survey also shows that in the case of potassium, the amounts applied usually did not match the amounts of K removed by the crops. Even in the most intensive protected cultivation only between 56% and 83% of the K removed was replaced by fertilizer application. In open field cultivation, the replacement index of between 0-37% shows that K is clearly neglected and in the long run a severe K depletion of the soil occurs. It seems, there is also a clear trend in the nutrient supply from the vicinity of the field to the urban areas, showing that the nutrient input declines the further away the field is from the city. The amount of fertilizer applied to the field of the outer suburbs and where vegetables were intercropped or rotated with grain crops was much less and often did not meet the demand, even for nitrogen and phosphorus. The replacement index was 41-114% for N, 32-76% for P and 0-83% for K. Furthermore, data revealed that there was almost zero potash applied in the open fields of outer suburbs due to reduced organic manure application. Unbalanced fertilization therefore poses a big threat to sustainable vegetable production.

Table 2. Assessment of the nutrient in different cropping systems

Location	Cropping system	The balance of N			The balance of P_2O_5			The balance of K_2O		
		Input kg ha^{-1}	Output kg ha^{-1}	Index %	Input kg ha^{-1}	Output kg ha^{-1}	Index %	Input kg ha^{-1}	Output kg ha^{-1}	Index %
Mulch protected cultivation	Egg plant, turnip	1,205	761	158	671	180	373	627	1,114	56
	Cucumber, Chinese cabbage	3,779	630	600	701	445	158	793	951	83
Open field cultivation in the suburb	Tomato, cucumber, cabbage	1,404	518	271	624	273	229	0	690	0
	Pimento, Chinese cabbage	1,491	410	364	531	144	369	203	554	37
	Celery, cucumber Chinese cabbage	1,491	582	256	531	292	182	203	871	23
Open field cultivation in the county	Gourd, cauliflower	777	683	114	345	453	76	0	762	0
Rotation of vegetables and field crops	Corn, Chinese cabbage	158	384	41	59	185	32	101	489	21

The effect of fertilization on salinity and accumulation of nitrate in vegetable garden soils

The survey of the effect of fertilization on salinity and accumulation of nitrate in garden soil concentrated on the analysis of two soil depth 0-20 cm and 20-40 cm. The results indicate that heavy fertilization of vegetables increased salinity and nitrate accumulation in these soil depths and there was a clear difference between vegetables either under polytunnels or in greenhouses and the open field (Table 3).

Table 3. Accumulation of salinity and nitrate in vegetable garden soils

Location	Planting pattern	Duration (years)	Soil depth (cm)	Salinity (%)	Nitrate NO_3 (%)	Nitrate Ratio P/O or G/O*
ShangXinkou XiQing suburb	Polytunnel	3	2—20	0.352	0.092	2.6
			20—40	0.208	0.035	11.7
	Open field	3	2—20	0.265	0.035	-
			20—40	0.170	0.003	-
TianMu BeiChen suburb	Green house	16	2—20	0.225	0.047	4.3
			20—40	0.236	0.038	7.6
	Polytunnel	16	2—20	0.161	0.057	5.2
			20—40	0.116	0.023	4.6
	Open field		2—20	0.136	0.011	-
			20—40	0.105	0.005	-
WanXinCun DongLi suburb	Green house	25	2—20	0.207	0.068	3.2
			20—40	0.154	0.058	9.7
	Polytunnel	19	2—20	0.097	0.027	1.3
			20—40	0.130	0.031	5.2
	Polytunnel	6	2—20	0.120	0.024	1.1
			20—40	0.095	0.022	3.7
	Open field		2—20	0.153	0.021	-
			20—40	0.088	0.006	-
ChengGuan BaoDi county	Green house	7	2—20	0.126	0.028	0.8
			20—40	0.067	0.016	0.5
	Polytunnel	10	2—20	0.113	0.027	0.8
			20—40	0.079	0.012	0.4
	Open field		2—20	0.115	0.034	-
			20—40	0.115	0.032	-

*Note: The ratio in the soil contents between polytunnel and open field (P/O) or greenhouse and open field (G/O) was calculated.

Compared with open fields both soil depths showed a significant greater accumulation of salts and nitrate in protected fields (polytunnel and greenhouse). The nitrate accumulation at a depth of 20-40 cm in the protected field was 3.7-11.7 times larger than in the open fields. Further away from the cities in the outer county, there were no differences between the protected and open field in both soil depths. According to the results of 55 samples taken from 10 different locations, it was reported that there was a close correlation between the nitrate content and salinity in greenhouses and poly-tunnels at a depth of 0-20 cm and 20-40 cm, respectively. The coefficient was 0.8432** (n=19) and 0.7281**(n=17), respectively, indicating that applying large quantities of nitrogen increased salinity. This unfavorable influence on vegetable growth was additionally accompanied by an accumulation of nitrate in the vegetable tissue, reducing their edible value. Furthermore, the nitrate which remains in the soil may be leached from the root zone and poses also a certain risk of contaminating the ground water. Therefore, it is important to keep soil nutrients in balance and to use nitrogen, phosphorus and potassium based on the crops' requirements.

Effect of applying fertilizer on the soil potassium balance studied in long-term field trials

The results shown in Table 3 indicate that attention needs to be paid to supplementing potassium to vegetables in order to keep nutrients in balance. A fixed location trial has been conducted for 7 years in an alluvial fluvio-aquic soil in Tianjin, with the treatments NP, NPK1 (112.5 kg K_2O ha^{-1}) and NPK2 (225 kg K_2O ha^{-1}). Every other year, organic manure was applied to the plots. The aim was to find a method of applying potash more effectively so that vegetable yields increase and the soil nutrients are kept in balance.

Effect of different treatments on vegetable yield

Table 4 shows vegetable yields under different crop rotations over the years. The results indicate that potash fertilizer increased the yield of vegetables.

From 1993 to 1998, 16 crops were grown in the trials. In the treatment NPK1, in 8 vegetables, yield increased whereas 7 crops had the same yield as the NP control. Only one crop (fennel) had a lower yield in NPK1 compared to the NP control. In the treatment NPK2, yield increases were observed in 12 crops, in 2 crops yields were the same as in the NP control whereas in 2 crops yields decreased with an average of -5.2%. The results also showed that based on the farmers' application practice supplying potash is efficient in maintaining a consistently good vegetable production. Particularly in years with a high disease pressure, the vegetable fields treated with potash showed a better disease resistance (for example eggplant in 1998).

Table 4. Effect of potash on vegetable yield in a fixed position trial

Location	Plant	Year	Yield NP (kg ha^{-1})	Yield increase (%) NPK1	NPK2
Shuigao-zhuang Xiqing District	Tomato	1993	94,400	1.48	2.12
	Chinese cabbage		134,000	10.67	13.13
	Tomato	1994	35,470	13.05	5.72
	Chinese cabbage		108,600	13.35	17.59
	Rape*		23,800	-1.26	9.66
	Cauliflower	**1995	40,550	7.50	8.66
	Eggplant		39,010	9.79	11.66
	Fennel*		18,130	22.61	16.05
	Tomato	1996	***43,610	-1.38	2.66
	Green turnip		87,070	2.14	14.96
	Fennel		13,080	-12.84	-5.73
	Squash	**1997	37,270	5.90	7.00
	Chinese cabbage		50,610	-0.59	-4.80
	Fennel*		15,300	-2.10	7.10
	Eggplant	1998	***73,570	87.50	35.50
	Green turnip		34,510	-3.39	5.67

Note: *Vegetable planted throughout the winter: No fertilizer applied ,**The year in which organic manure was used, ***Serious disease pressure.

Soil potassium balance under different fertilization methods

The total amount of K taken up in comparison to the amount applied to the various crops in the trial and the estimated potassium balance for the vegetable garden over several years is summarized in Table 5. It is generally known that due to their intensive biomass accumulation and the relative high harvest index (only little amounts of biomass are remaining on the field at harvest), vegetables usually require a larger supply of potassium than other crops, e.g. cereals. Under conditions where no K is applied (NP control), the total amount of potassium removed from the soil by plants was 2,643 kg ha^{-1} over the studied period. During the same time, only 1,828 kg K_2O ha^{-1} were applied, resulting in a deficit of 815 kg ha^{-1} potassium within 6 years or an annual undersupply of 136 kg K_2O ha^{-1}. The yearly supplementation of certain amounts of potassium to the soil (such as treatment K1 and treatment K2) reduced the imbalance between supply and demand. In 1995 and 1997, large amounts of organic manure were applied (15 t ha^{-1} in 1995 and 7.5 t ha^{-1} in 1997) which added another 1,156 kg K_2O ha^{-1} and 672 kg K_2O ha^{-1} to the system. This caused that at the larger rate of K application (NPK2) the overall K balance (over 6 years) became positive and there was a net gain in the soil K supply, unless no K was lost by leaching. Despite the large addition of organic manure in the NP and NPK1 treatment (225 kg K_2O ha^{-1} yr^{-1}), the overall balance remained negative. Though other experience shows that the application of organic manure is also economically beneficial, it seems that its use is limited to the suburban areas, where the material is dumped without spending great efforts on transport, etc. In the remoter areas the use of organic manure was reduced due to labor and transport requirement so that an accumulation of organic manure is occurring in the suburban areas. In combination with larger amounts of mineral nutrients applied in these areas, this practice of applying large amounts of organic manure bears the risk of oversupply of nutrients (see Table 2) with all the negative consequences on product quality, soil quality and potential contamination of ground water. There is therefore a need to make better use of organic manure in the vegetable system by distributing it also to the fields which are in the remoter so-called county vegetable gardens. The recommendation is a combined application of organic manure and mineral fertilizer with emphasis on reducing oversupply of N and P, especially in the suburban protected vegetable gardens, to increase the supply of K and to balance outputs by the crops with inputs both through mineral fertilizer and organic manure application.

Table 5. The budgetary estimate of the potassium input/output balance in the soil in long-term trials

Year	NP			NPK1			NPK2		
	Input of potassium	Removal by plants	Balance	Input of potassium	Removal by plants	Balance	Input of potassium	Removal by plants	Balance
	kg ha^{-1}								
1993	0	776	-776	225	862	-637	450	868	-418
1994	0	451	-451	225	526	-301	450	556	-106
1995*	**1156**	**377**	**779**	**1381**	**450**	**930**	**1606**	**517**	**1089**
1996	0	300	-300	113	363	-250	225	436	-211
1997*	**672**	**325**	**347**	**897**	**475**	**423**	**1122**	**466**	**657**
1998	0	415	-415	225	771	-546	450	800	-351
Total	1828	2643	-815	3066	3447	-381	4303	3643	660

Available potassium changes in the soil with different fertilization methods

Fig.1 shows the condition of available potassium in the soil under different fertilization methods. The field in which the trial was conducted belongs to a newly developed vegetable growing area with a high soil potassium level. But due to the intensive vegetable cultivation, the available potassium content is very variable. If no potash was applied, the potassium level showed a decreasing trend. Thus, if potash was added to the soil, the potassium balance could be kept at a certain level.

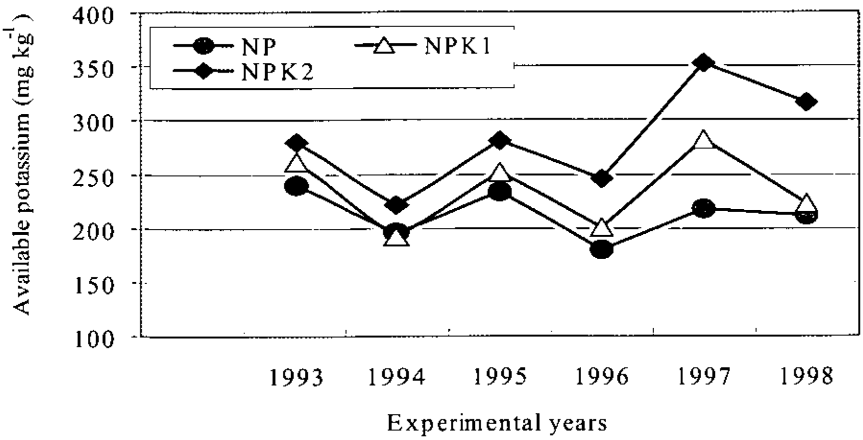


Figure 1. Annual variation in available potassium contents in the soil as affected by different K treatments

Conclusion

1. The NPK balance in open fields cultivated with different vegetable rotations showed that the average input was 847 kg N ha^{-1}, 239 kg P_2O_5 ha^{-1} and 369 kg K_2O ha^{-1} in one year. The average output amounted to 696 kg N ha^{-1}, 411 kg P_2O_5 ha^{-1} and 602 kg K_2O ha^{-1}, showing a nutrient replacement index 122% for N, 64% P and 50% for K. It is indicated that both P and K were insufficiently supplied whereas the K deficit was more serious than that of P.
2. The study of the nutrient balance in open fields in comparison to protected vegetable cultivation showed that the input of NP in protected fields in the urban and suburban areas was much larger than in open fields and exceeded by far the input of protected fields in the county. The nutrient replacement index in protected fields ranged between 158-600% for N, 180-445% for P and 56-83% for K, indicating that the N supply exceeded the N removal between 1.6-6 times, that of P 1,8 to 4.5 times whereas for K the supply covered only 56%-83% of the K removals. The index was smaller, between 225-346% for N, 182-369% for P and 0-37% for K and in the county remote from the city only 41-114% for N, 32-76% for P and 0-21% for K. This shows clear gradients in the nutrient supply between locations, indicating oversupply in the vicinity of cities and an undersupply in the remote fields. A general replacement rate <100 and in certain cases even 0 indicates soil K depletion.
3. The survey of the effect of fertilization on salinity and nitrate accumulation in vegetable garden soil indicated that both mainly occurred in protected fields, because of a great quantity of nitrogen fertilizer being applied. Main accumulation occurred at a depth of 0-20 cm and 20-40 cm, respectively. The nitrate accumulation at a depth of 20-40 cm in protected fields was 3.7-11.7 times greater than in open fields and fields in the county.

4. The study on potassium application in a long-term field trial shows that it was very important to add appropriate amounts of potash to vegetables in order to increase the yield and to improve quality. From 1993-1998, the analysis of 16 in rotation grown vegetables indicated that potash application led to a high yield response, ranging between 5.7% and 87.5%.

Fertility of soils under rubber plantations and fertilizer application in tropical China

Lin Zhaomu, Li Shicong, Cha Zhengzhao and Yu Rangshui

Chinese Academy of Tropical Agricultural Sciences, Danzhou, Hainan 571737

Abstract

The 8 major soil types in the rubber tracts of China are described, showing that their fertility varied considerably, revealing a downward trend after planting of rubber. A consumption and supply analysis of nutrients in prime rubber plantations revealed that the annual consumption of nutrients by rubber trees equalled those coming from the soil. A nutrient depletion of the soils occurs due to additional nutrient losses by runoff, soil erosion, leaching, etc. Fertilizer application promotes the growth of rubber trees and rubber production, showing that young rubber trees, receiving organic manure + N and P fertilizers, grew faster by 7%-20% in Hainan and 24%-177% in Guangdong. Generally, rubber trees planted in fertile rubber plantation soils produced 50% -100% more dry rubber than those planted in less fertile soils. This indicates that increasing the soil fertility by fertilizer application is an effective measure of improving the growth and latex yield of rubber trees. The effect of fertilizers was enhanced by stimulated tapping of the rubber trees.

Introduction

Rubber plantations in China are spread over the provinces of Hainan, Yunnan, Guangdong, Guangxi and Fujian located at the 18° - 24° N, ranging between the northern fringe of the tropics and the southern subtropics. The major soil types are lateritic soils and red soils. The nutrient status of the soils in the rubber plantations in general is rather poor and the rubber trees grow slowly and yields are small. For many years, research has been carried out to obtain more information on the nutritional status of the major soil types and the soil fertility change after planting of rubber trees. The purpose of this study is to look into the aspects of nutrient demand and improvement of fertilizer application to rubber trees in order to raise the soil fertility of the plantations to sustain better growth and larger latex yield of rubber trees.

Soil fertility of different soil types in rubber plantations in China

There are 8 major soil types in China's rubber plantations and their fertility parameters are shown in Table 1. The main occurrence and fertility of these soil types are described in the following.

Granite-derived lateritic soil under tropical rain forest

This soil is found in the hills and low mountainous area in the Southern and Central Hainan. The soil is gravely and reddish yellow and the topsoil has an organic matter content of 24.7 g kg^{-1}, 1.43 g kg^{-1} of N, 38.3 g kg^{-1} of K_2O with high inherent fertility. The topsoil also contains large amounts of exchangeable K^+ and a high K^+/Mg^+ ratio (11-17), usually resulting in occurrence of so called yellow leaf disease which is due to Mg deficiency in rubber plantations.

Granite and schist-derived laterite under tropical monsoon forest

This soil type is found in the hilly areas of Western and Central Hainan. The topsoil has an organic matter content of 16.9 g kg^{-1}, 0.87 g kg^{-1} of N and 22.4 g kg^{-1} K_2O. The exchangeable K^+/Mg^{2+} ratio with 0.6-0.9 is in the adequacy range.

Basalt-derived ferruginous laterite under tropical shrubbery and miscellaneous tree forest

This soil type is found in the hilly areas with slight slope in Northeast Hainan and Leizhou Peninsula of the Guangdong Province. The soil has a thick horizon with a relatively high clay content and has a brownish red colour. The topsoil is relatively rich in organic matter (35.3 g kg^{-1}), N (1.79 g kg^{-1}) and P_2O_5 (1.75 g kg^{-1}) but very poor in total K (only 2.39 g kg^{-1}) and available P (0.8 mg kg^{-1}). Rubber trees, growing on this soil often show P deficiency and an oversupply of Mg, leading to early coagulation of latex during tapping.

Granite and gneiss-derived red soil in south subtropical bracken grassland (Dicranopteis linearis)

This soil type is found in the hilly areas of south subtropical Guangdong, Guangxi and Fujian. The topsoil has a rather small organic matter content (19.1g kg^{-1}) and is poor in N (0.68 g kg^{-1}), P_2O_5 (0.22 g kg^{-1}), available N, P, K and Mg. The fertility is low and rubber plantations can only produce large yields after receiving mineral fertilizers.

Phyllite-derived laterite in tropical bamboo and miscellaneous tree forests

This soil type is found in the south of the Yunnan Province. The soil is clayey and rich in mineral nutrients. The topsoil has a large content of organic matter (36.3 g kg^{-1}) and N (1.62 g kg^{-1}) and is sufficient in exchangeable K^+, Ca^{2+} and Mg^{2+}. But this soil is also poor in P (0.9 mg kg^{-1}). It has a high exchangeable Al^{3+}(1.67 cmol kg^{-1}) content due to soil acidity (pH 4.4 - 4.5), conditions which are detrimental to the growth of rubber trees.

Table 1. Fertility status of major soil types in the rubber tract of China

Soil type	Soil layer	Soil texture (%)			Chemical composition (g kg^{-1})							Avail. P	Exchangeable cations (cmol kg^{-1})				pH
		Sand	Silt	Clay	SiO_2	Fe_2O_3	Al_2O_3	OM	N	P_2O_5	K_2O	(mg kg^{-1})	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	
Granite-derived rainforest laterite	0-20	58.3	15.7	26.0	693	22	174	24.7	1.43	0.39	38.3	3.0	0.560	0.848	0.033	0.363	5.3
	20-100	48.7	14.8	36.5	631	31	226	13.4	0.75	0.34	37.0	0.9	0.193	0.289	0.017	0.905	5.0
Granite-schist-derived laterite	0-20	66.8	13.1	20.1	785	33	100	16.9	0.87	0.49	22.4	2.3	0.153	0.548	0.181	0.296	5.3
	20-100	55.7	16.3	28.0	705	48	145	8.7	0.43	0.50	26.2	0.7	0.116	0.325	0.188	0.476	5.1
Basalt-derived laterite	0-20	16.3	26.9	56.9	305	184	283	35.3	1.79	1.75	2.3	0.8	0.121	0.389	0.112	0.565	4.8
	20-100	23.3	27.8	48.9	305	188	297	16.5	0.80	1.43	2.0	0.5	0.043	0.147	0.091	0.361	4.8
Granite- gneiss-derived laterite	0-20	55.4	19.5	25.1	750	47	123	19.1	0.68	0.22	13.2	1.5	0.062	0.116	0.050	1.206	4.7
	20-100	44.0	19.4	36.7	658	59	178	11.8	0.43	0.24	16.8	0.5	0.056	0.202	0.081	1.399	4.9
Phyllite-derived laterite	0-20	21.6	27.6	50.8	594	77	190	36.3	1.62	0.39	16.2	0.9	0.368	0.391	0.209	1.763	4.5
	20-100	9.2	29.8	61.1	558	83	214	24.5	1.16	0.37	17.2	0.9	0.171	0.189	0.062	1.835	4.4
Granite-derived laterite in bru-shwood	0-20	39.2	8.0	52.9	650	63	165	31.2	1.42	0.43	12.2	1.9	0.602	1.098	0.836	0.437	5.3
	20-100	39.0	17.5	43.5	578	82	213	13.6	0.72	0.35	13.1	0.5	0.359	0.844	0.486	0.884	5.1
Red sandstone and lime stone-derived red soil	0-20	34.8	23.6	41.6	555	97	186	41.9	1.71	0.50	17.5	1.2	0.108	0.827	0.110	1.786	5.1
	20-100	24.5	26.1	49.5	495	119	242	12.2	0.74	0.49	21.0	0.3	0.048	1.600	0.051	1.106	4.9
Shallow-sea de-posit red soil	0-20	67.7	2.7	29.6	800	49	83	16.9	0.73	0.66	2.5	2.5	0.029	0.465	0.124	0.680	4.7
	20-100	62.6	6.4	31.0	730	68	129	8.8	0.43	0.68	7.6	1.8	0.026	0.164	0.027	0.765	4.7

Granite-derived laterite in tropical bamboo and miscellaneous tree forests

This soil type is found in the south of the Yunnan Province. The topsoil is relatively rich in organic matter (31.2 g kg^{-1}), N (1.42 g kg^{-1}), exchangeable K^+, Ca^{2+} and Mg^{2+} and contains less exchangeable Al^{3+} (0.437cmol kg^{-1}) which makes it better suitable for rubber cultivation than the phyllite-derived laterite.

Red sandstone and limestone-derived red soil in south subtropical bracken grassland and brushwood

This soil is found in the south of Guangxi, where abundant rainfall occurs. The soil colour is brownish yellow and it consist mainly of silty clay. The topsoil contains large amounts of organic matter (41.9 g kg^{-1}) and N (1.471 g kg^{-1}) with a wide C/N ratio (14.2). The amounts of available N and P are insufficient whereas the exchangeable Mg^{2+} with 0.11 cmol kg^{-1} is relatively abundant. Al^{3+} with 1.78 cmol kg^{-1} often leads to toxicity and the rubber trees grown in this soil usually suffer from K deficiency.

Shallow-sea deposit-derived red soil in south subtropical sparse grassland

This soil is found in the coastal terrace regions of Guangdong, Guangxi and Hainan. The topsoil is poor in organic matter (16.9 g kg^{-1}), N (0.73 g kg^{-1}) and K_2O (2.5 g kg^{-1}). The rubber trees grow slowly and yields are generally small in this soil due to shortage of N, P, K and Mg.

Soil fertility change after planting of rubber trees in tropical soil

Rubber plantations established on different soil types but from similar clones and similar age were selected, and the unclaimed land with natural vegetation in the vicinity of the rubber plantations was taken as control. Soil samples of the 0-20 cm soil layer were collected and the fertility status was analysed to record the change in soil fertility by using the t test (see Table 2)[(1)].

It was observed that the soil fertility after planting rubber tended to decline, showing also an increasing soil acidity indicated by a decline in pH by 0.22 (Table 2). Most of the soil nutrients were reduced in the topsoil (0-20 cm). The organic matter, N, K_2O, exchangeable K^+, exchangeable Ca^{2+} and exchangeable Mg^{2+} were reduced by 16.9%, 20.6%, 10.5%, 50.0%, 46.7% and 69.6%, respectively. Phosphorus was the only nutrient of which the total content increased by 8.6% and the available P even by 300%. The increase in P content was due to long-term application of P fertilizers. Observations suggest that considerable amounts of soil was lost by erosion. Assuming that during 17 years of rubber cultivation, 15 cm of the topsoil or 150 t soil mu^{-1} (2,250 t ha^{-1} at a bulk density of 1.5 g cm^3) were eroded, the following amounts of nutrients were lost: organic matter at the amount of 4,065 kg mu^{-1} (60,975 kg ha^{-1}), 185 kg mu^{-1} (2,775 kg ha^{-1}) of total N, 99 kg mu^{-1} (1,485 kg ha^{-1}) of total P_2O_5 and 2250 kg

K_2O mu^{-1} (33,750 kg K_2O ha^{-1}). The downward trend of soil fertility after planting rubber indicates that soil and water conservation and fertilizer application should be strengthened after rubber planting to control and reverse this trend for a sustainable utilization of the land.

Table 2. Change of soil fertility of a tropical soil after planting rubber (PR107, age 17, soil layer: 0-20cm)

Sample	Total nutrients (g kg^{-1})				Available P
	Organic matter	N	P_2O_5	K_2O	(mg kg^{-1})
Natural soil	27.10	1.235	0.663	15.07	1.62
Plantation soil	22.53	0.980	0.720	13.49	6.93
% to the natural soil	83.1	79.4	108.6	89.5	427.8
t value	2.216*	3.244**	1.340	0.738	1.688
	Exchangeable cations (cmol kg^{-1})				
	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	pH
Natural soil	0.220	0.471	0.168	2.182	4.92
Plantation soil	0.110	0.251	0.051	2.133	4.70
% to the natural soil	50.0	53.3	30.4	97.8	
t value	2.208*	2.708*	1.884^a	0.290	2.079^a

(Pairing method, using the t test, n = 20, $t_{0.1}$=1.729^a, $t_{0.05}$=2.093*, $t_{0.01}$=2.863**)

Balance between demand and supply of nutrients in prime rubber plantations

A rough estimate was made of the demand and supply of nutrients in prime rubber plantations (Table 3). The annual consumption of nutrients from the soil by prime rubber trees were N = 13.73 kg mu^{-1}, P = 1.37 kg mu^{-1} and K = 6.13 kg mu^{-1} (1 mu =1/15 ha) among which 30%-37% was fixed in the trunk and root system and 39%-58% found in the leaves. Some of these nutrients were returned to the soil through shedding and some of the nutrients can be recycled after the rubber trees are felled. The nutrients removed in the harvested latex were N = 0.75 kg mu^{-1} or 5.5% of the total nutrient uptake, P = 0.24 kg mu^{-1} or 17.5% and K = 1.05 kg mu^{-1} or 17.1% of the uptake. This suggests that nutrients removed by latex comprises only a small proportion of the total nutrient uptake. The soil nutrients in rubber plantations are replenished by litters, precipitation, microbial fixation of N, fertilizer application, etc. The soil of well-managed rubber plantations usually receives annual nutrient applications, equivalent to N = 13.61 kg mu^{-1}, 99.1% of the anticipated N uptake, P = 1.48 kg mu^{-1}, 108.0% of the anticipated P uptake and K = 6.14 kg mu^{-1}, 100.2% of the anticipated K uptake. This discloses that the demand and supply of nutrients in such a fertilization system are balanced. A deficit occurs by the fact that nutrient losses are not only due to uptake and removal but also caused by soil erosion and runoff, leaching and N denitrification. This fact needs to be additionally taken into account. It is hence very important to carry out measures such as water and soil conservation and diagnosis-based fertilizer application to prevent the soil nutrients from being lost.

Diagnosis-based fertilizer application

Fertilizers contribute a large proportion of the nutrient supply in rubber plantations. Under normal fertilizer application (15 kg $tree^{-1}$ yr^{-1} of organic manure to mature rubber trees) the N, P and K supplied accounted for 45.4%, 87.1% and 66.4% of the total nutrient supply, respectively (Table 3). Additional fertilizer application improved the nutritional status of the soil and trees and hence evidently the growth and the latex production of the rubber trees.

Relationship between fertilizer application and the growth of young rubber trees

Experiments and commercial production show that fertilizer application encouraged the rubber tree growth and reduced the immaturity period (Huang and Pan, 1964a). In a fertilizer experiment carried out on the Tuanjie State Farm of the rubber tract of the West Guangdong Province, the young trees grew 22.4 cm in girth without fertilizer application after 7 years, but 47.0 cm with organic fertilizer and NP fertilizer with a fertilizer effect of 109.8% (Table 4), (Huang and Pan, 1964b).

The effect of fertilizer application on young rubber trees grown on different soil types in Guangdong and Hainan Province showed that the growth effect of young rubber trees treated with NP fertilizer in Hainan was 7%-20% (Table 5). It usually takes 7-10 years for the young rubber trees grown without fertilizer applications to be ready for production, but only 5-6 years for those which are well-managed and receive fertilizer, reducing the immaturity period by 1-3 years. In the rubber plantations grown on red soil in the State Farms of the Guangdong Province, a more evident growth effect up to 129%-177% occurred when organic manure was applied. In poor red soil, it takes more than 15 years for the rubber plantations without fertilizer or manure application to grow to a girth size ready for tapping but only 7-8 years for the young trees treated with fertilizer or manure. The young rubber trees generally require no K fertilizer before taken into production, but a little amount of K fertilizer is needed for the rubber plantations in ferruginous laterite and poor red soil. There, it is needed to promote the cold hardiness of rubber trees and their latex regeneration and flow after the beginning of tapping.

Table 3. Annual nutrient uptake by rubber trees and supply of nutrients through fertilizer application

Uptake and supply of nutrients		N		P		K		Remarks
		kg mu^{-1}	%	kg mu^{-1}	%	kg mu^{-1}	%	
Nutrients taken up by trees	Fixed by roots, trunks and branches	4.38	31.9	0.41	29.9	2.28	37.2	Calculated at 25 trees mu^{-1}, average for 33 years.
	Fixed in the leaf biomass	8.00	58.3	0.54	39.4	2.50	40.8	Leaves calculated at 250 kg mu^{-1}
	Needed for latex production	0.75	5.5	0.24	17.5	1.05	17.1	Dry rubber yield calculated at 75 kg mu^{-1}
	Involved in flowering and fruit setting	0.60	4.4	0.18	13.1	0.30	4.9	Seeds calculated at 25 kg mu^{-1}
	Σ	13.73	100	1.37	100	6.13	100	
Nutrient supply	Leaf drops	3.3	24.2	0.11	7.4	1.06	17.3	Leaf drops calculated at 250 kg mu^{-1}
	Rainfall water	1.4	10.3	0.08	5.4	1.0	16.3	Rainfall calculated at 2500 mm mu^{-1}
	Nitrogen fixed by micro-organisms	2.73	20.0					
	Organic manure	1.68	12.3	0.31	20.9	1.88	30.6	Cattle dung calculated at 375 kg mu^{-1}
	Mineral fertilizer	4.50	33.1	0.98	66.2	2.20	35.8	Rubber special compound fertilizer 37.5 kg mu^{-1}
	Σ	13.61	100	1.48	100	6.14	100	
	In % of the nutrients taken up	99.1		108.0		100.2		

Table 4. Effect of different nutrient management practices on girth growth of young rubber trees (Tuanjie State Farm, Guangdong)

Treatment	No fertilizer	C	C+N	C+P	C+N+P
Girth growth over 7 years (cm)	22.4	34.8	31.8	43.3	47.0
%	100	155.3	142.0	193.7	209.8

*Note: C = 5 kg compost tree^{-1} yr^{-1},
C+N = 5 kg compost + 0.125 kg AS** tree^{-1} yr^{-1},
C+P = 5 kg compost + 0.125 kg SSP** tree^{-1} yr^{-1},
C+N+P = 5 kg compost + 0.125 kg AS and 0.125 kg SSP tree^{-1} yr^{-1},
**AS = ammonium sulphate, SSP = single superphosphate,

Table 5. The effect of fertilizer application on the growth of young rubber trees in various soil types

Location	Soil type	Soil N (g kg^{-1})	Soil P_2O_5 (g kg^{-1})	Effect of N fertilizer (%)	Effect of P fertilizer (%)	N + P fertilizer effect (%)
Guangdong	Granite and gneiss-derived red soil in south subtropical bracken grassland	0.35-0.98	0.25-0.74	62-64	60-83	129-177
	Basalt-derived ferruginous laterite in tropical shrubbery and miscellaneous tree forest	1.9-2.1	0.96-1.18	5-6	20-27	24-36
Hainan	Basalt-derived ferruginous laterite in tropical shrubbery and miscellaneous tree forest	0.9-1.0	0.93	5-8	7-9	8-15
	Granite-derived laterite soil in tropical rain forest	1.6-1.7	0.34-0.74	7-11	6-7	7-20

Fertilizer application to tapped rubber trees

The influence of fertilizer application on latex yield of rubber trees increased with tree age. This is due to the fact that rubber trees require larger amounts of nutrients from the soil with increasing age, which means that more nutrients have to be supplied through fertilizer application. Moreover, fertilizer application encourages the girth growth, bark thickening, differentiation and development of latex vessels, etc., which promote the latex production potential and increase latex yield gradually.

Soil fertility, the key factor for high yielding of mature rubber trees

The soil fertility in rubber plantations has a distinct effect on growth and latex yield (Table 6). Comparison of growth and latex yield of two rubber tracts grown at a similar latitude but at different soil fertility levels showed that the soil of the rubber plantations in Yunnan contained 64% more organic matter, 52% more total N, 194% more exchangeable K^+ and 21% more Mg^{2+} as compared to Guangdong and Guangxi (Table 6A). The corresponding leaf levels, dry matter synthesized and latex yield were 55.7%, 104.7% and 45.0% larger, respectively (Table 6B). This indicates that the soil fertility in rubber plantations is consistent with the growth and yield of rubber trees (Xiao and Li, 1991).

Table 6. Soil nutrient contents (**A**) and growth and latex yield of rubber trees (**B**) grown in soils of different nutritional status

A Location	Plantation	Soil nutrients OM (%)	N (mg kg^{-1})	Avail P (mg kg^{-1})	Exch K^+ (cmol kg^{-1})	Exch Mg^{2+} (cmol kg^{-1})
Yunnan West	3	32.8	1.36	1.54	0.215	0.063
Guangdong, Guangxi	5	19.96	0.894	2.24	0.073	0.050
Comparison %		+64.3	+52.1	-31.3	+194.5	+20.6

B	Plantation	Growth and yield of rubber trees: Leaf weight (kg mu^{-1})	Leaf nutrient content (g kg^{-1}) N	P	K	Girth (cm)	Dry matter (kg mu^{-1})	Latex yield (kg mu^{-1})
Yunnan West	3	207.8	33.1	2.50	12.8	73.1	1070.9	76.1
Guangdong, Guangxi	5	133.5	31.3	1.88	9.42	47.2	523.2	52.5
Comparison %		+55.7	+5.8	+33.0	+35.9	+54.9	+104.7	+45.0

Note: The rubber tract is distributed at 22°-22.5° N in Yunnan and at 20.3°-22.0° N in Guangxi and Guangdong. Rubber plantations with clone PR107 at age 17, tapped without stimulation.

Application of fertilizer based on the soil fertility

The soil fertility varied much in rubber plantations with different soil types. The granite-derived laterite soil in tropical rainforest in South Hainan and the basalt-derived ferruginous laterite soil in tropical shrubbery and miscellaneous tree forest in North Hainan differed largely in their nutrient contents (Table 7). The former soil is rich in K and the latter is deficient in K but contains large amounts of available Mg. The granite-derived soil has a 4.6 times larger exchangeable K^+ but 70.5% less exchangeable Mg^{2+}. Therefore, plantations with granite-derived laterite soil are usually susceptible to yellow leaf disease caused by magnesium deficiency.

Table 7. Observed soil fertility parameters in different soil types and recommended nutrient ratios

Soil type	Total N	Total P_2O_5	Avail. P	Exchangeable K^+	Exchangeable Mg^{2+}	K/Mg	Nutrient ratio* N : P_2O_5 : K_2O : MgO
	-----g kg^{-1}---		mg kg^{-1}	----cmol kg^{-1}---		ratio	
Granite-derived red soil in tropical rainforest	1.43	0.39	3.0	0.560	0.033	17.0	1.6 : 1.0 : 0.4 : 0.2
Basalt-derived ferruginous laterite in tropical shrubbery	1.79	1.75	0.8	0.121	0.112	1.1	1.7 : 1.0 : 2.3 : 0
Comparison %	-20	-78	+275	+363	-71		

*Note: Recommended nutrient application ratios, suitable for rubber trees under stimulated tapping.

On the other hand, plantations with basalt-derived ferruginous laterite soil are prone to yellow leaf disease due to K deficiency and early coagulation of the latex. The latter is especially observed on soils with large supplies of divalent cations such as Ca^{2+} and Mg^{2+}. Therefore, it is necessary to apply fertilizer with different ratios of nutrients, according to the soil types of the rubber plantations. For example, for plantations in South Hainan, a nutrient ratio of N : P_2O_5 : K_2O : MgO of 1.6 : 1.0 : 0.4 : 0.2 and for plantations in North Hainan, a ratio of 1.7 : 1.0 : 2.3 : 0 is recommended. The rates recommended are 1.5-2.0 kg $tree^{-1}$ yr^{-1}, using compound fertilizers with a total nutrient content of 27-30% (including trace elements). Trials and experiments proved that with such application the general nutrient deficiencies can be corrected. Dry rubber yield was usually increased by 4.2%-6.9% as compared to the traditional fertilizer application method (Zhong, 1992).

Fertilizer application to rubber plantations, using a stimulated tapping system

Stimulated tapping of rubber trees with ethephon at a reduced frequency with shallow tapping is one of the innovations to improve rubber production. The principle is that stimulants prolong the latex flow time and hence increase latex flow. Observations show that through the increased productivity also the demand for nutrients is increased. Table 8 shows how the nutrient uptake changes in rubber plantations under stimulated tapping, indicating that stimulated trees took up much more nutrients than those, using the traditional tapping system. When calculated at a 30% increase in yield under stimulated tapping the nutrient uptake due to greater latex flow increased by 47% for N, 77% for P, 71% for K and 46% for Mg.

Table 8. Comparison of nutrient consumption between stimulated and conventional tapping

	Tapping system	N	P	K	Mg
Nutrient content in dry rubber (g kg^{-1})	Conventional	7.02	1.24	5.04	1.18
	Stimulated	8.02	1.69	6.65	1.33
	Comparison %	+14	+36	+32	+13
Nutrient loss due to latex flow (kg mu^{-1})	Conventional*	0.53	0.093	0.38	0.089
	Stimulated*	0.78	0.165	0.65	0.130
	Comparison %	+47	+77	+71	+46

*Note: Conventional: Dry rubber yield = 3 kg $tree^{-1}$×25 tree mu^{-1} =75 kg mu^{-1}
Stimulated: Dry rubber yield = 3.9 kg $tree^{-1}$×25 tree mu^{-1} =97.5 kg mu^{-1}

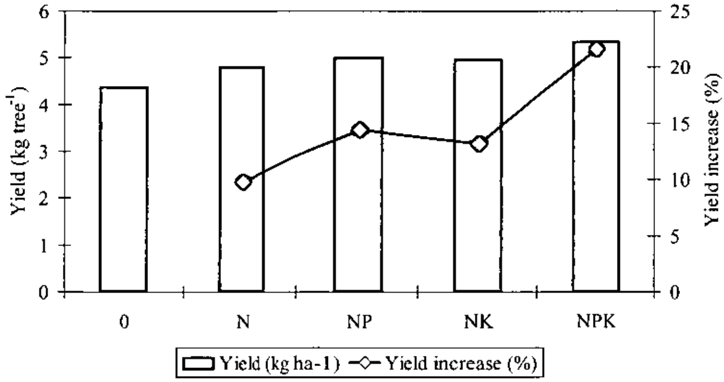
Stimulated tapping with ethephon also increased the nutrient removal with latex flow. This would cause a depletion of the nutrient reserves of the tree trunk if no additional nutrients by fertilizers are supplied. For instance, the leaf N, P and K levels were reduced by 5%-10% after successive stimulated tapping (Table 9). To avoid this nutrient depletion in the leaves which serves as major nutrient source for the synthesis of latex, adequate amounts of nutrients need to be applied.

Table 9. Change of nutrient demand by rubber trees due to stimulated tapping

Location	Treatment	N	P	K	Mg
Team 5, CATAS Experiment Farm, Hainan	Before treatment	40.9	2.43	12.93	3.60
	After treatment*	35.8	1.93	10.45	3.72
	Comparison %	-12.5	-20.6	-19.2	+3.3
Dongfeng Team, Jianshe State Farm, Guangdong	Before treatment	36.0	3.01	10.20	3.10
	After treatment**	29.8	2.62	9.64	3.11
	Comparison %	-17.2	-13.0	-5.5	+0.3

Note: *= stimulated for one year, **= stimulated for three years

To show the effects of an adequate nutrient supply to rubber trees under stimulated and traditional tapping an experiment was carried out at CATAS in Hainan. The results show that the PR107 rubber plantations applied with NPK fertilizer at a rate of 1.75 kg $tree^{-1}$ under regular tapping conditions produced an annual increment of dry rubber yield of 6.6% over 4 years. On the other hand, the plantations treated at a rate of 2 kg $tree^{-1}$ under stimulated tapping system gave an annual 21.6% increase in dry rubber over 4 years of tapping (Figure 1), (Huang and Li, 1982). This indicates that more nutrients are required by rubber trees under stimulated tapping and that fertilizer application produces much better results. The annual application of special rubber compound fertilizer, containing 25%-30% N, P, K will generally satisfy the nutrient requirements by rubber trees under stimulated tapping system and maintain the soil fertility when green manure is applied in deep trenches as it is usually practiced.



Note: N = 0.8 kg ammonium sulphate per tree, P = 0.8 kg single superphosphate per tree, K = 0.4 kg potassium chloride per tree

Figure 1. Yield increasing effect of nutrients applied to rubber trees under stimulated tapping

Conclusions

1) China has 8 major soil types in its rubber tract, varying drastically in their fertility, which shows a downward trend after land reclamation for rubber planting.
2) Organic matter, total N and total K of the soil were reduced by 16.9%, 20.8% and 20.5%, respectively, after 17 years of planting rubber. The exchangeable K^+, Ca^{2+} and Mg^{2+} and pH were also reduced to some extent, and only P was increased, which may be the result of long-term application of P fertilizer to rubber plantations.
3) The estimated nutrient uptake showed that mature rubber trees have an annual nutrient demand of 13.73 kg N mu^{-1}, 1.37 kg P mu^{-1} and 6.13 kg K mu^{-1}.
4) The nutrient supply to the rubber plantations was in the region of 13.61 kg N mu^{-1}, equal to 99.1% of the uptake, 1.48 kg P mu^{-1}, equal to 108.0% and 6.14 kg K mu^{-1}, equal to 100.2% of the annual uptake.
5) These amounts are not sufficient to fully cover the demand since the efficiency of uptake is hardly 100% under field conditions and significant nutrient losses can be expected in the humid climate where rubber is grown. This is especially true for N, which shows a clear deficit in the supply as soon as leaching losses such as erosion, leaching and N denitrification were taken into account. The same is true for the cations K and Mg which are easily lost by leaching particularly on coarse textured, light soils.

6) It is hence necessary to conserve water and soil and apply fertilizer to avoid the decline in soil fertility and to ensure sustainable land use.
7) The N, P and K application by organic manure normally accounts for 45.4%, 87.1% and 66.4% of the nutrient supply to the crop. The differences, including the anticipated nutrient losses need to be balanced by mineral fertilizer.
8) Fertilizer can improve the nutritional status of both the soil and the rubber trees and hence encourage greatly the growth and latex production of the trees. Young rubber trees showed a growth effect of 7%-20% in Hainan and 24%-177% in Guangdong when treated with manure and mineral fertilizer.
9) Fertilizer application caused a distinct effect on rubber yield of mature rubber trees. The dry latex yield of rubber trees was 1.5-2 times larger in fertile than less fertile rubber plantations. This suggests that it is a good practice to improve the soil fertility in rubber plantations.
10) For rubber plantations with different soil types, the fertility varies and hence fertilizer with different nutrient ratios should be applied. The K-rich rubber plantations (on granite-derived soils) should receive fertilizer at a nutrient ratio of N : P_2O_5 : K_2O : MgO, being 1.6 : 1.0 : 0.4 : 0.2. For the K-deficient and Mg-rich rubber plantations (basalt-derived soils), the fertilizer nutrient (N : P_2O_5 : K_2O : MgO) should be adjusted to 1.6 : 1.0 : 0.4 : 0.2.
11) Fertilizer application should be based on the soil nutrient status to correct nutrient deficiency of rubber trees and to overcome in soil nutrient supply. An observation shows that this practice can increase dry rubber yield by 4.2%-6.9% as compared to the conventional fertilizer application without looking at the soil nutrient supply.
12) Rubber trees consumed 46%-77% more nutrients in stimulated than in conventional tapping systems. The successive stimulation usually led to a decline in leaf nutritional levels. In this case, fertilizer application produced an evident increase in rubber yield. The conventionally tapped rubber trees produced 6.6% more yield when NPK fertilizer was applied while the stimulated rubber trees yielded 21.6% more.
13) Organic manure should be incorporated in trenches and annual application of the 1.5 – 2.0 kg tree^{-1} of a concentrated multi-nutrient fertilizer, including N,P,K, Mg and micronutrients should be annually applied to meet the nutritional requirements of rubber trees with stimulated tapping.

References

Lin Deguang (1977). Experimental Design and Statistical Analysis for Tropical Crops. Hainan: South China College of Tropical Crops, 52-55.

Huang Zongdao, Pan Yanqing (1964a). Study of Fertilizer Application System for Rubber Trees in China. Hainan: South China Subtropical Crops Research Institute, 3-6.

Huang Zongdao, Pan Yanqing (1964b). Study of Fertilizer Application System for Rubber Trees in China. Hainan: South China Subtropical Crops Research Institute, 6-27.

Xiao Jizhen and Li Shicong (1991). The fertility of several types of soil in the rubber tract in West Guangdong and Guangxi and the effect of the fertility on rubber tree growth and latex production. Research of Tropical Crops, (1): 36-39.

Zhong Jingyi (1992). Development of rubber special compound fertilizer and its application effect. Research of Tropical Crops. (3): 12-15.

Huang Zongdao and Li Shicong (1982). High yielding (150 kg mu^{-1} –200 kg mu^{-1}) cultural practice for rubber trees in West Hainan. Research of Tropical Crops, (1): 7-8.

Nutrient status and management of tropical fruit crops on the Hainan Island

Xie Liangshang, Pan Shunqiu and Zhang Wen

Soil and Fertilizers Institute, Hainan Province Academy of Agricultural Science 571100

Abstract

Hainan Island accounts for most part of the tropics in China and enjoys favourable conditions to produce tropical fruits. But the soils are strongly weathered, acid, contain small amounts of organic matter and are deficient in total and readily available nutrients. In addition to inherently poor fertility, inadequate nutrient input and imbalance of NPK seriously limit the yield potential of the fruits. The yield of banana is only 22.0 t ha^{-1}, of pineapple 24.6 t ha^{-1} and of mango 4.5 t ha^{-1}. Analysis of soil samples from 73 orchards revealed poor organic matter, total N, total P, and total K as well as readily available N, P and K. According to the classification for nutrient availability during the second soil survey, most of the soil samples were deficient or seriously deficient in nutrients. Though in the recent 10 years, the consumption of mineral fertilizers on the island has doubled, reaching 270,000 t of nutrients in 2001, with an average application of only 150 kg ha^{-1} it may be still regarded as low. The N : P_2O_5 : K_2O ratio of the mineral fertilization has improved to 1:0.32:0.25, but it is obvious that the current. K application cannot meet the high K demand of tropical fruit crops. Our survey revealed that the annual nutrient balance in fruit orchards on Hainan is roughly +20 kg ha-1 for N, -11.8 kg ha^{-1} for P_2O_5 and –123 kg ha^{-1} in terms of K_2O. On this basis, it is estimated that Hainan will need additional 150,000 t of nutrients from mineral fertilizers. Balanced fertilization by supplementing K fertilizers in six demonstration sites has resulted in a significant yield response of banana. The experiments of balanced fertilization in pineapple showed that the application rate of N_{350} K_{800} achieved the best plant growth and the highest nutrient absorption by the plants.

Introduction

Hainan Island, a brilliant pearl inlaid in the South China Sea, has a land area of 3.40 million ha, accounting for 42.5% of the country's total tropical area. On this island, it is all year round summer, it is free from frost and snow, with an annual mean temperature ranging between 22 - 26°C, an annual sun shine of 1,750 - 2,750 hours and an annual solar radiation of 502.4 - 615.5kj cm^{-2}. Under the influence of the tropical monsoon, the island has plenty of rainfall. Though it has distinct dry and wet seasons and 75% - 86% of the rainfall is concentrated in the period from May to October, rainfall and warm temperatures coincide, which is promoting plant growth and cycling of biomass. Favourable water and temperature resources endow the mysterious land with a wide coverage of tropical rainforests. Fragrant mango, pineapple and coconut trees grow everywhere. Rice can be harvested three times per year, sugarcane grows throughout the year and vegetables and melons are planted in fall and harvested in winter.

In terms of landscape of the 3.40 million ha of land, 25.4% are considered mountains, 13.3% hills, 32.6% tablelands and 28.1% terraces and plains. 30% of the land is suitable for farming, 23.9% for tropical crops, 27.3% for forests, 9.2% for grazing and 4.0% consist of surface waters. According to the soil classification, 53.3% are latosols, 10.0% latosolic red soils, 3.6% yellow earths, 2.6% dry red earths, and 8.4% alluvial soils. In 1998, the island had 0.428 million ha of cultivated land (including 0.243 million ha of paddy fields), 0.140 million ha of orchards (including 0.106 million ha of fruit orchards) and 0.426 million ha of tropical crop plantations (including 0.371 million ha of rubber plantations). Agriculture is the most important business and source of income on the island. Plantations, tropical fruits, cereals, vegetable and melon crops in winter and tropical cash crops represent the mainstay of the tropical agriculture.

Production of tropical fruits

The island has a huge variety of fruits, about 61 families, 138 genera, 273 species, including popular fruits like pineapple, litchi, citrus, longan, guava, papaya, banana, carambola, wampee (*Clausena lansium*), etc. Furthermore, special tropical fruits like mango, jackfruit and naseberry (sapodilla) and local specialties of the island such as egg-shaped litchi, rambutan, mangosteen, etc. are found in Hainan. Since 1950, the production of fruits has undergone four phases, restoration from 1950 to 1960, technical renovation from 1960 to 1967, stagnation from 1968 to 1978 and continuous development from 1978 till today. By 1998, the area of fruit tree cultivation had expanded to 0.1062 million ha with a total output of 0.5663 M t (Table 1), which is an increase of about 143.6% and 284.8% compared to 1987 when the island became a province.

Table 1. Cultivation area and output of major fruits on Hainan Island in 1998

Crop	Area (1000 ha)	Yield (kg ha^{-1})	Output (1000t)
Pineapple	147	10,728	1.577
Litchi	156	276	43
Citrus	22	4,955	109
Banana	173	15,347	2,655
Longan	94	96	9
Mango	363	1,860	675
Others	107	-	598
Total	1.062	5,332	5.663

Among the six major fruits, pineapple is grown mainly in Qionghai and Wanning, which both accounted for 58.6% of the province's pineapple production. Litchi, longan and citrus are mainly grown in Qiongshan, Danzhou and Qiongzhong, mango mainly in Changjiang, Dongfang and Sanya. Altogether these three areas account for 45.5% of the province's mango production area. Banana is extensively planted in all 19 counties (cities), with Ledong County ranking first, looking at a cultivated area of 2,584 ha.
In recent years, with the development of an agricultural cooperation between Taiwan and Hainan, numerous Taiwanese businessmen have invested in fruit cultivation on the island. Not only that they brought in capital, they also introduced new fruit varieties and cultivation techniques for high quality and yield, for instance guava, red carambola, passionfruit, etc. to the island.

Soil nutrient status in fruit cultivation

Soil nutrient status

Soil pH

Since Hainan island is located in the humid tropics with high temperature, plenty of rainfall and alternation of dry and wet season, the soils are subjected to strong desilicification and aluminium enrichment, weathering and leaching, which causes that they became acidic over time. According to the findings of Chen Jing (Table 2), the pH value ranges between 4.05 ~ 6.87. 75.4% of collected soil samples were acid and extremely acid, 22.3% slightly acid and only 2.3% neutral.

Table 2. pH value of soils in the mango plantations on Hainan island

pH	Samples tested	Percentage (%)	Classification
4.05~4.50	38	29.2	extremely acid
4.51~5.50	60	46.2	acid
5.51~6.50	29	22.3	slightly acid
6.51~6.87	3	2.3	neutral

Acidity causes that the root systems of the plants are subjected to large Al^{3+} and H^+ concentrations, which affect their ability to extend or penetrate into the soil to effectively absorb available nutrients. The analysis of soils derived from different parent materials in pineapple and banana plantations further revealed that there is a strong P fixation. 36.3 - 87.4% of the collected soils showed this disorder. Between 7.5% - 41.2% were poor in K, 2.0% - 64.3% poor in S, 26.9% - 32.8% poor in Cu, 12.9% - 41.5% poor in Zn, 4.6% ~ 38.4% poor in Mn and 12.9% ~ 70.1% poor in B (Table 3). In total, the extent to which these nutrients became limiting to crop production either through fixation or due to low supply decreases in the following order: P > B > Cu > Zn > K > S > Mn.

Table 3. Proportion of studied soils (%) derived from different parent material which show distinct disorders in nutrients for the production of pineapple or banana

Plantation	Parent material	P	K	S	Cu	Zn	Mn	B
Pineapple	Basalt	87.4	7.5	64.3	32.0	41.5	3.6	70.1
	Sandstone	53.1	21.2	11.4	26.9	12.9	-4.6	63.4
Banana	Basalt	62.9	21.6	44.0	32.8	39.0	16.8	12.9
	Basalt	58.2	41.2	12.6	31.0	32.2	24.2	50.9
	Shallow marine deposit	36.3	16.7	2.0	31.6	25.6	38.4	48.8
Mean		59.6	21.6	26.9	30.9	30.2	15.7	49.2

Soil organic matter

On Hainan, organic substances decompose rapidly due to the favourable water and temperature conditions. Litters can reach 10 - 11 t ha^{-1} every year so that organic matter in natural soils is not as low as generally assumed. Cultivation, however, has rapidly depleted soil organic matter. According to a soil analysis from 5 orchards, the content of soil organic matter ranged between 8.55 g kg^{-1} - 28.8 g kg^{-1} with an average of 15.94 g kg^{-1} (Table 4). On the basis of the nutrient status grading criteria of the second soil survey, the soils are classified as Grade 4, indicating medium to low nutrient contents. The reason for the low soil organic matter content is the fast turnover under hot and humid conditions and the negligence of the use of organic manure in cultivation, besides natural conditions that are adverse to organic matter accumulation in the soil.

Table 4. Soil nutrient status in orchards on Hainan island, depending on parent material

Orchard	Parent material	*n.*	O.M.	Total N	Total P	Total K	r.a. N	r.a. P	r.a. K
			($g\ kg^{-1}$)				($mg\ kg^{-1}$)		
Mango	Granite	4	13.15	0.77	0.26	33.98	70.5	4.04	82.1
	Shallow marine deposit	10	8.72	0.42	0.14	12.91	22.8	3.91	30.8
Banana	Basalt	4	19.60	0.34	0.41	10.62	21.6	17.90	48.0
	Shallow marine deposit	16	9.20	0.24	0.20	8.58	19.1	2.80	52.2
Pineapple	Sandstone	2	8.55	0.58	0.21	8.54	18.9	3.50	32.9
	Basalt	6	11.60	0.62	0.47	5.10	22.4	3.40	18.5
Litchi	Basalt	11	19.20	0.67	0.58	15.87	19.8	5.53	21.4
	Basalt	6	28.80	0.92	0.26	24.92	31.6	4.78	140.1
Longan	Basalt	10	23.20	0.55	1.20	15.90	2.59	19.40	10.0
	Granite	4	17.40	0.79	0.39	21.57	27.7	19.50	110.8
Mean			15.94	0.59	0.37	15.01	27.0	7.18	55.6

Note: *n* = number of samples; O.M. = organic matter; and r.a = readily available.

Soil N

Table 4 shows that orchard soils of various parent materials are seriously deficient in N, in regard to both the average of total N (0.59 g kg^{-1}) and the readily available N (27.0 mg kg^{-1}). In most orchards, small N reserves are caused by a serious soil erosion, resulting from the fact that they are planted on slopes of hills. Moreover, good aeration of the soil promotes the loss of readily available N, mainly in the form of NO_3-N.

Soil P

Low total P content and deficiency of readily available P are common in tropical soils throughout the world. According to our analysis, the total P content ranges between 0.24 g kg^{-1} - 9.2 g kg^{-1}, which - according to the classification systems - falls into class 6 (serious P deficiency). The content of readily available P ranges between 2.8 mg kg^{-1} - 19.5 mg kg^{-1} with an average of 7.18 mg kg^{-1} which signifies class 4 (medium to low). The content of total P of the soil is influenced by its parent material. Soils derived from basalt usually contain larger amounts of total P than soils from granite, sandstone and shallow marine deposits. On the other hand, readily available P is hardly influenced by soil parent material, but by fertilization and fixation to Al- and Fe-oxides (Table 4).

Soil K

The soils derived from granite account for about 96.7% of the total. Since granite is rich in feldspar and biotite, a rather strong K supplying capacity from the weathered minerals can be expected. Among the orchard soils in the study, total K content of soils derived from granite ranged from 21.57 g kg^{-1} to 33.98 g kg^{-1} whereas in soils derived from other parent materials the total K varied in the range of only 5.10 g kg^{-1} to 15.87 g kg^{-1}. Despite the relative abundance of total K, the content of readily available K, however, was small and ranged between as low as 21.4 mg kg^{-1} and 140.1 mg kg^{-1}, indicating that on average, the soils can be classified as availability class 4. Soils derived from granite contained 82.1 - 140.1 mg available K kg^{-1} which qualifies them as class 3 soils in terms of potassium availability.

Nutrient demand of tropical fruit trees

For full fruit production, tropical fruit trees have a high demand for adequate nutrient supply as can be seen from Table 5 where average good yields of the crops and the nutrient uptake is shown. Besides the large nutrient requirement, it is also important to note that a direct comparison between N and K uptake, the listed crops, independent of the facts whether the crop is a woody or herbaceous type, the removal of K is much larger than that of N and P. Especially, banana requires large amounts of K, revealing an optimum N : K uptake ratio of about 1 : 4. Though the yield levels recorded so far in Hainan did not yet reach those in Table 5, it is clearly indicated that K is a predominant nutrient in cultivation of fruits for high yield and quality and that the current fertilization level is not adequate to supply the K needs for improved fruit production on the island..

Table 5. Nutrient uptake of several tropical fruit crops (kg ha^{-1})

Fruit	Yield (t ha^{-1})	N	P_2O_5	K_2O	MgO	S
Banana	40	250	66	1000	140	15
Citrus	50	300	100	400	60	30
Mango	25	165	40	180	125	15
Papaya	50	90	25	130	15	15
Pineapple	50	185	55	350	110	35

Source: Kemmler and Hobt (1985)

Nutrient management for tropical fruit crops

Fertilization practice and related problems

In recent years, the consumption of fertilizers on Hainan increased rapidly, from 0.1056 Mt in 1985 to 0.2119 Mt in 1997 (net nutrient weight, Table 6) or by 100.7%. Nitrogen consumption increased by 34.6%, phosphorus by 38.9%, potassium by 372.0% and nutrients from compound fertilizer by 654.0%. The drastic increase in the consumption of compound fertilizers and K fertilizers are closely related to the rapid development of the cultivation of tropical fruit crops, winter vegetable and melons. The N : K_2O ratio jumped from 1.0 : 0.07 to 1.0 : 0.25 during this period and to 1.0 : 0.29 in 2001 (Table 6). Despite this improvement in the nutrient supply, the current fertilization practice is not only inadequate, but also improper with regard to the N : K ratio taken into account the high demand of tropical fruits (see Table 5).

Table 6. Consumption of fertilizer nutrients in Hainan (1000t)

Year	N	P_2O_5	K_2O	Compound	Total	N: P_2O_5: K_2O
1985	69.0	21.6	5.0	10.0	105.6	1:0.31:0.07
1990	78.2	13.2	15.0	30.0	136.4	1:0.17:0.19
1995	78.2	14.2	18.9	60.0	172.6	1:0.18:0.26
1997	92.9	30.0	23.6	75.4	211.9	1:0.32:0.25
2001	89.0	61.0	26.0	94.0	270.0	1:0.68:0.29

Source of the data: Hainan Statistics Yearbook

The problems of fertilization of fruit trees can be summarized as serious inadequacy of nutrient input, insufficient recycling of organic manure, imbalance between inputs and outputs as well as imbalance in the supply of the various nutrients (inadequate nutrient application ratios) and insufficient supply of other macronutrients and of the whole range of micronutrients.

Serious inadequacy in nutrient input

Hainan has a total of 427,852 ha of cultivated land with a multiple cropping index of 215%. Each hectare receives only 241 kg of nutrients, being only 72.8% of the country's average. If the acreage (172,460 ha) of the tropical cash crops, fruits, tea and medicinal crops that also need fertilization, are included, the average application rate is only 203 kg ha^{-1}. Based on the calculation that 60% of the fertilizers consumed are used on cereals, vegetables and melons, the tropical fruit and cash crops receive only 120 kg ha^{-1} of fertilizer nutrients.

Inadequacy in input of organic manure

Banana exhausts the soil fertility as it creates a lot of biomass and has a short growing cycle. This means that a continued good nutrient buffer has to exist in the soil to adequately supply this demand. Therefore, organic manure becomes essential in building up soil fertility and to create this nutrient buffer for such demanding crops. With the rapid development of the cultivation of winter vegetables and melons, large amounts of organic manure are now absorbed by vegetable gardens. Therefore, the supply of organic manure to orchards sharply declined and only approx. 5 t ha^{-1} yr^{-1} are currently applied. The growers are not used to apply organic manure to pineapple, or making use of pineapple stubs left on the field after harvest of the previous crop. For convenience of field preparation, the crop residues are often burned after collection so that the benefit from the nutrients in the ashes is small. The important function of accumulating organic matter as nutrient buffer in the soil is completely neglected by this practice. Organic manure is also seldom applied to other tropical fruits due to the general shortage because of alternative uses and because of its relatively high prices and the inconvenience of transport.

Imbalance of N/K ratio

The unbalanced N/K ratio is caused by both the demand and the supply situation in the market. The first reason is that most growers use fertilizers in an uncontrolled manner partly due to lack of knowledge that tropical fruit crops are K-demanding plants, they demand and consume more N than K fertilizer. The second reason is that on the market, the supply of N and compound fertilizers dominate over that of straight K fertilizers. Several banana and pineapple growers were surveyed and it was found that they use the following NPK ratios. To banana, they applied 750 kg N ha^{-1} , 570 kg P_2O_5 ha^{-1} and 600 kg K_2O ha^{-1}, at a ratio of 1.0 : 0.76 : 0.80 and to pineapple, they applied 807 kg N ha^{-1}, 214 kg P_2O_5 ha^{-1} and 319 kg K_2O ha^{-1}, at a ratio of 1.0 : 0.26 : 0.40. To optimise production, these ratios appear to low to supply adequate K for the uptake and to make full use of the nitrogen applied.

Imbalance in other macro- and micronutrients

The orchard soils on Hainan lack various macro- and micronutrients (Table 7). Soil samples collected from six orchards show that about 66.7% were below the critical value for Ca, 50.0% for Mg and 83.3% were below the critical value for S. The situation for micronutrients was not much better, revealing that 16.7% were below the critical value for Mn, 33.3% for N, 66.7% for Zn and 83.3% were below the critical value for B. It is clearly indicated that the soils are deficient in micronutrients, except Fe which is relatively abundant. Single superphosphate and potassium sulphate based compound fertilizer (15-15-15) are used to supplement some Ca and S, but no economically suitable commodity fertilizers are available for the supplementation of Mg, B and Zn.

Inadequacy and imbalance of nutrient input seriously limits the potential of the production of tropical fruits. In 1998, the yield of banana was 22 t ha^{-1}, of pineapple 25 t ha^{-1}, of citrus 7.5 t ha^{-1}, of mango 4.5 t ha^{-1}, of litchi 3.2 t ha^{-1} and of longan 2.4 t ha^{-1}. This is far below that of advanced cultivation and shows that fertilizer management has to be improved.

Table 7. Macro- and micronutrients in orchard soils (μg ml^{-1}) based on parent material

Orchard	Location	P.M.*	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Banana	Meiting, Chengmai	Basalt	942	106	3.4	0	1.2	81	12.0	2.1
	Dala, Chengmai	Basalt	942	136	3.4	0	1.6	135	8.2	2.1
	Sanjiang, Qiongshan	Basalt	401	142	9.7	0.2	5.7	205	27.0	1.6
	Chongpo, Ledong	Sediment	160	56	3.4	0	0.6	18	22.0	1.4
Pineapple	Jinjiling, Dingan	Basalt	200	40	42	0	1.3	40	7.7	8.0
	Jiuqujiang, Qionghai	Sandstone	120	39	4.4	0	0.5	407	3.1	1.0
Critical value	(μg ml^{-1})		440	97	12	0.2	1.0	10	5.0	2.0

*: P.M. = parent material

Balance of nutrients for tropical fruit crops

Based on the above described soil nutrient status, nutrient demand of the crops and nutrient input, a rough nutrient balance is made for the tropical fruit crops (Table 8). The results indicate that mango has the smallest nutrient demand which is explained by the extremely small yields. In consequence, this crop shows a calculated surplus in the input of nutrients. The other three crops show a clear undersupply with to a varying extent, depending on crop and nutrient. The banana cultivation reveals a deficit in all nutrients and its deficit of K reaches 478 kg ha^{-1} annually.

If the nutrient budget is made on the basis of the mean yield shown in Table 5, all three macronutrients are in insufficient supply with –90 kg N, -35 kg P_2O_5 and 356 kg $K_2Oha^{-1} \cdot yr^{-1}$. Therefore, in order to achieve the global average yield, every year 25,000 t of N, 26,000 t of P_2O_5 and 102,000 t of K_2O need to be additionally applied, which is equal to two-thirds of the current annual consumption.

Table 8. Budget of nutrients for four major fruit crops (kg ha^{-1} yr^{-1})

Crop	N	P_2O_5	K_2O
Banana	-37	-17	-478
Citrus	32	3.7	-17
Mango	70	11.5	39
Pineapple	15.6	-10	-37
Mean	20	-11.8	-123

Crop response to balanced fertilization of tropical fruit crops

In recent years, with the support of PPIC and IPI, experiments and demonstration of balanced fertilization have been performed on banana and pineapple with significant effects.

Balanced fertilization on banana

Based on five experiments and demonstrations in Qiongshan, Ledong and Chengmai, the yield of banana was 37.4 t ha^{-1} under conventional fertilization and 46.1 t ha^{-1}, about 23.6% larger, when K was supplemented (Table 9). Supplementation of K fertilizers has not only increased the yield but also improved quality and even, advanced maturity by 30 - 86 days, thus raising economic benefit significantly.

Table 9. Effect of K fertilizers supplementation on yield, quality and economic benefit of banana

Location	Treat-ment	Yield (t ha^{-1})	Yield Δ (%)	Length* (cm)	Weight* (g)	Tot. sugar* (%)	Vc (mg kg^{-1})	Net profit (Yuan ha^{-1})	Net profit Δ (%)
Qiongshan	-K	28.8	-	21.1	93.6	14.4	6.6	15,637	-
	+K	37.0	28.9	24.5	153.0	18.3	11.3	62,315	298.5
Qiongshan	-K	31.0	-	19.3	117.2	14.4	6.6	14,947	-
	+K	38.3	23.5	20.1	139.3	14.4	6.6	51,978	247.7
Qiongshan	-K	27.0	-	19.3	113.3	14.4	6.6	7,513	-
	+K	31.5	16.7	21.4	171.4	14.4	6.6	48,315	543.1
Ledong	-K	58.6	-	21.6	145.0	18.5	26.6	81,840	-
	+K	71.6	22.2	23.2	162.0	20.2	27.4	131,190	54.7
Chengmai	-K	41.6	-	21.6	145.0	18.5	26.6	34,410	-
	+K	52.3	25.7	21.6	145.0	18.5	26.6	62,235	80.9

*Note: Length refers to average finger length; weight = average weight of fingers; and Tot. sugar = total sugar content.

According to Tan Hongwei et al. (this volume), crop response of pineapple to balanced fertilization ranges between 4.8% to 37.5%. Experiments on NK balanced fertilization were carried out in Qionghai and Dingan. Results show that NK balanced fertilization promotes growth and development of pineapple and increases nutrient content in leaves, preparing a good foundation for high yield and high quality of pineapple (Table 10). It is noteworthy that the crop response to treatment N_2 (700 kg N ha^{-1}) and treatment N_1 (350 kg N ha^{-1}) differed slightly in plant properties. The N content in leaves was slightly higher in treatment N_2 than in treatment N_1 and dry matter in treatment N_2 even showed a downward trend. In treatment N_1, crop growth and NK contents in leaves rose with the increase in K application rate while in treatment N_2, crop response was not significant, indicating that too much N disturbs the balance between N, K and other nutrients in the plants with significant effect on the metabolism.

Table 10. Effect of NK balanced fertilization on growth of and nutrient content in leaves of pineapple (Jiuqujiang, Qionghai)

Treat-ment	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Dry weight (g)	N	P	K (g kg^{-1})	Ca	Mg
N_1K_0	51.9	73.2	4.7	32.28	13.08	1.20	14.45	18.55	1.28
N_1K_1	53.6	73.7	4.8	35.05	12.02	1.36	22.76	20.18	1.09
N_1K_2	55.4	75.6	5.2	39.46	14.48	1.31	28.22	20.22	1.12
N_2K_0	55.9	69.1	9.9	32.39	14.40	1.20	15.42	19.00	1.12
N_2K_1	55.5	74.0	5.4	37.02	14.18	1.24	21.58	20.76	1.10
N_2K_2	55.9	70.3	5.4	35.38	14.10	1.24	25.08	19.22	1.08

Conclusion

Hainan Island enjoys favourable climatic conditions to produce tropical fruits, but due to strongly weathered, acid soils with low organic matter content fruits suffer from all kinds of nutrient deficiencies. In addition to inherent low fertility, inadequate nutrient input and imbalance of NPK seriously limit the yield potential of the fruits. The yield of banana is only in the region of 22 t ha^{-1}, that of pineapple 25 t ha^{-1} and of mango only 4.5 t ha^{-1}. Analysis of soil samples from 73 orchards revealed that according to the classification system for nutrient availability of the second soil survey, most of the soil samples were deficient or seriously deficient in nutrients. Though in the recent 10 years, the consumption of mineral fertilizers has doubled, the average application is still only around 150 kg ha-1 of nutrients, which is very little in view of a year-round cultivation (cropping index >2) Besides the general insufficient nutrient supply, also the NPK ratio of 1.0 : 0.32 : 0.25 may be regarded as inadequate for sustained large yields. This is particularly evident from the nutrient balance which is negative for most of the tropical crops studied. More emphasis needs to be placed on better nutrient supply, adapting the supply to the crop demand by especially increasing the K application.

Study on sustainable use of tropical forage and grassland in Hainan

Qi Zhiping[1] and Tang Shumei[2]

[1] Tropical field Crops and Animal Husbandry Research Institute (CATAS) Hainan 571737
[2] Agricultural College the South China University of Tropical Agriculture Hainan 571737

Abstract

A long-term trial was carried out on tropical forages in Hainan located in the tropical region of China. The results indicate that the concentration of N and Ca in legume forages were greater than that of grass forages. Because of nitrogen fixation, legume forages absorbed more nitrogen than grass forage. Nevertheless, there was a clear decline in soil nitrogen and organic matter which was less pronounced under legume forage compared to grass forage.

Introduction

The grassland of Hainan is characterized by typical tropical grasses and a few trees and bushes. The tropical grassland can be divided into four types: Savanna, wet grassland, low mountain-tableland grassland and hill-mountain grassland. Although the grass biomass of tropical natural grassland is twice as large as that of temperate zone grassland, the grass suited for fodder is relatively rare and usually located on slopes. The grassland is often mixed with farmland and forestry, leading to competition between agriculture, forestry and animal husbandry.
Hainan has about 117,000 ha of wasteland which could be used for forage crops. Therefore, in recent years, the artificial sown pastures have been gradually enlarged in order to fully exploit the tropical grassland production potentials, to improve the livestock stocking rate and to make rational use of wasteland. Because of the establishment of artificially sown pastures, the production has been increased manifold, undoubtedly accelerating the nutrient cycling of the soil. A long-term trial has been carried out on several tropical forages since 1988, in order to study how a sustainable tropical grassland can be developed.

Materials and methods

The natural conditions

The long-term trial was carried out in the experiment station of the Tropical Field Crops and Animal Husbandry Research Institute of the Chinese Academy of Tropical Agricultural Science.

The station is located at the northern boundary of the tropics, with tropical monsoon climate. The temperature is high and with a lot of rain concentrated in summer and autumn. In winter and spring, the climate is characterized by lower temperature and very dry conditions. The boundary of wet season and dry season is very clear. The annual average temperature is 24.0°C, the absolute highest temperature is 38.3°C and the absolute lowest is 9.1°C. The annual precipitation is 2,160 mm and the annual sunshine reaches up to 1,820 h. The soil in the tested area consisted of laterite. The physicochemical properties of the soil are shown in Table 1.

Table 1. The physicochemical properties of tested soil

Soil	Depth (cm)	Total-N ----($g\ kg^{-1}$)----	O.M.	Available-P ----------($mg\ kg^{-1}$)--------	Available-K	Bulk density ($g\ cm^{-3}$)	pH (H_2O)
Laterite	0-20	0.85	14.39	10.3	163	1.45	5.2
	20-40	0.56	9.69	6.7	83.5	1.52	5.1

Plant material

The tested grass forages were *Panicum maximum Jacq.*, *Paspalum plicatulum*, *Setaria anceps* cv. Nandi, *Chloris gayana* and *Pennisetum purpureum K. Schumach* x *P. typhoideum Rich.*, and the legume forages were *Arachis pintoi*, *Leucaena leucocephala* cv. salvador and *Stylosanensis guianensis* cv. CIAT184. The plot area was 30 m^2 and the plots were replicated three times.

Methods

According to the different biological characteristics of the tested forages, samples were regularly taken to measure dry matter weight and nutrient content. The samples were digested by the H_2SO_4+H_2O_2 method. Total N was determined by the Kjeldahl digestion ammonia steam distillation method, total P with the molybdovanadophosphoric acid colorimetry method and total K by flame photometry. The dry combustion method was used to measure total carbon, Ca and Mg was determined with the EDTA titration method. The soil samples were analyzed by routine methods.

Results and discussion

Nutrient contents of the forages

Nutrient uptake by forage is one of the major characteristics in grassland nutrient cycling. It controls the speed of cycling and dominates the output of nutrients. The determined mean nutrient content is shown in Table 2.

Table 2. Nutrient contents of the tested forages (g kg^{-1})

Species	Nutrient contents				
	N	P	K	Ca	Mg
P. maximum	12.36	2.11	10.71	5.55	3.31
P. purpureum x P. *typhoideum*	12.83	2.12	16.92	3.31	1.95
P. plicatulum	13.91	1.75	13.92	6.92	4.31
C. gayana	8.72	4.67	12.80	3.17	2.31
S. anceps	12.59	2.30	11.92	3.37	1.94
A. pintoi	33.68	1.58	21.37	19.26	3.42
L. leucocephala	46.34	3.43	16.24	8.57	2.92
S. guianensis	27.59	3.93	10.53	14.26	5.10

Note: Data represent the mean of 10 years.

The contents of N and Ca in legume forages were significantly higher than those in graminaceous forages, and those of P, K and Mg showed no difference between legume and grass forages.

Nutrient uptake by the forages

The amount of nutrients taken up is related to the biomass of forage, which varies drastically among forages. Table 3 shows that the amount of nitrogen taken up by legumes was larger than that of the grasses. The N uptake among the three legumes was in the order: *L .leucocephala* > *S. guianensis* > *A. pintoi*. Among the graminaceous plants, the N uptake by *P. maximum* was the highest followed by *P. purpureum* . The yield and nitrogen content as well as N uptake of *C. gayana*was the lowest. Of the eight tested forages, *P. maximum* and *S. guianensis* took up the largest amounts of P followed by *P. purpureum* and *L. leucocephala. A. pintoi* took up the smallest amounts of nutrients. The K uptake of *P. purpureum* and *P. maximum* was significantly higher than that of the others. The Ca uptake of *S. guianensis* was significantly higher than that of the others. Highest Mg uptake was found in *P. maximum* and *S. guianensis*.

Dynamics of soil physicochemical properties in grassland

After 10 years, the cultivated soil of the long-term trial was analyzed to study the effects of different forages on soil nutrients and physicochemical properties. The results are shown in Table 4. The dry root mass of *L. leucocephala* (g kg^{-1} soil) was the greatest followed by *P. maximum*. The roots of *P. maximum* were much better in exploring the soil volume than that of *L .leucocephala*.

Table 3. The nutrients uptake of different tropical forages (kg ha^{-1})

Species	Nutrients uptake					
	DM yr^{-1}	N	P	K	Ca	Mg
P. maximum	29,251	361.5	61.7	313.3	162.3	96.8
P .purpureum	26,151	335.5	55.4	442.5	86.6	51.0
P. plicatulum	11,509	160.1	20.1	160.2	79.6	49.6
C. gayana	6,109	53.3	28.5	78.2	19.4	14.1
S. anceps	9,928	125.0	22.8	118.3	33.5	19.3
A. pintoi	6,343	213.6	10.0	135.5	122.2	21.7
L. leucocephala	1,125	52.1	38.6	182.7	96.4	32.9
S. guianensis	15,690	432.9	61.7	165.2	223.7	80.0

Note: Data represents the mean of ten years.

Table 4. The effect of tropical forages on soil physicochemical properties

Species	Depth (cm)	Roots (g kg^{-1})	B density (g cm^{-3})	Total N (g kg^{-1})	O.M. (g kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	pH (H_2O)
P. maximum	0-20	5.033	1.43c	0.85	13.5	1.7	25.7b	4.49
	20-40	1.184		0.34	5.4	0.7	16.4	4.92
P. purpureum	0-20	3.732	1.50b	0.76	12.0	2.7	15.8c	4.92
	20-40	1.558		0.54	8.2	1.7	5.3	5.42
P. plicatulum	0-20	2.537	1.46bc	0.77	12.0	2.6	18.2bc	4.55
	20-40	0.850		0.55	8.4	1.2	7.7	4.94
C. gayana	0-20	2.526	1.58a	0.73	1.0	1.9	2.6c	4.64
	20-40	0.904		0.49	7.3	1.2	5.8	5.33
S. anceps	0-20	4.414	1.47bc	0.74	10.7	2.8	9.5c	4.72
	20-40	1.078		0.50	7.1	1.1	6.0	5.33
A. pinto	0-20	1.607	1.43c	1.30	18.9	2.4	42.7a	4.91
	20-40	0.861		0.61	9.5	1.2	23.2	5.12
L. leucocephala	0-20	7.492	1.39c	1.09	15.6	2.2	35.3ab	4.82
	20-40	0.758		0.56	8.8	1.3	23.3	5.41

As nutrients are mainly absorbed by small and fine roots, the ability of graminaceae to take up nutrients was generally better than that of legumes. Different forages varied in amount and weight of roots, inevitably causing the change of the soil physicochemical properties. The bulk density was also influenced by the type of forage. Lowest impact on bulk density was found under *C. gayana*. Compared to that *L. leucocephala, P. Maximum* and *A. pintoi* had the strongest effect on decreasing the bulk density and hence improving the physical conditions for root growth in the soil.

Table 5. Variation of soil physicochemical properties after 10 years

Species	Depth (cm)	B. density (g cm^{-3})	Total N (g kg^{-1})	O.M. (g kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	pH (H_2O)
P. maximum	0-20	-0.02	0	-0.89	-8.6	-137.3	-0.71
	20-40		-0.22	-4.29	-6.0	-67.1	-0.18
P. purpureum	0-20	+0.05	-0.09	-2.39	-7.6	-147.2	-0.28
	20-40		-0.02	-1.49	-5.0	-78.2	+0.30
P. plicatulum	0-20	+0.01	-0.08	-2.39	-7.7	-144.8	-0.65
	20-40		-0.01	-1.29	-5.5	-75.8	-0.16
C .gayana	0-20	+0.13	-0.12	-3.29	-8.4	-150.4	-0.56
	20-40		-0.07	-2.39	-5.5	77.7	+0.23
S. anceps	0-20	+0.02	-0.11	-3.69	-7.5	-153.5	-0.48
	20-40		-0.06	-2.59	-5.6	-77.5	+0.23
A. pintoi	0-20	-0.02	+0.45	+4.51	-7.9	-120.3	-0.19
	20-40		+0.05	-0.19	-5.5	-60.3	+0.02
L. leucicephala	0-20	-0.06	+0.24	+1.21	-8.1	-127.7	-0.38
	20-40		0	-0.89	-5.4	-60.2	+0.31

However, after planting the other forages, it was found that the bulk density was higher or significantly higher in comparison to the soil values determined at the beginning of the trial, indicating that the soil was slightly or seriously degraded after planting *P. purpureum, P. plicatulum, C. gayana* and *S. anceps*.

Under the same cultivation conditions and management practices both the total N and O.M in the 0-40 cm soil layer were decreased after planting grass forages for 10 years, but significantly increased after planting legume forages (Table 5). This is mainly explained by the ability of legume forage to fix nitrogen from the atmosphere. According to the experiment, 81%-89% of N in *Arachis pintoi* came from the atmosphere. A large number of deposited litter and dried roots returned substantial nitrogen and organic matter to the soil. A great quantity of available K and P was consumed by both forages, leading to a 4 to 6 times decrease in available P and 10 times decrease in available K for grass forages and 4 times reduction for legume forages. The available K in the soil planted with legumes was significantly larger than in soil planted with graminaceous forages. After 10 years of planting the seven major tropical forages, the topsoil showed also a tendency of acidification.

Intercropping graminaceous and legume forages

It was reported that the effect of grasses and legume forages on soil properties and nutrient consumption was different. By intercropping graminaceous with legume forages, the soil physicochemical properties and nutrient utilization could be improved by combining crops with deep and shallow, big and small roots. The nitrogen fixation ability of the legume forages could supply a certain proportion of nitrogen needed by the grasses. Graminaceous forages could supply some available P to legume forages, since their roots are more efficient to extract fixed P from the soil and transform it into a more available form. Without application of P fertilizer, this strategy, however, leads to a depletion of the P resources of the soil.

Increasing P and K fertilizers

According to our observations, the input of P and K was clearly insufficient, causing a serious deficit of available P and K. It is necessary to use P and K fertilizers in order to achieve a high yield and a good quality in tropical forages and to ensure efficient nutrient cycling in tropical grassland. The rate of P and K fertilizers can be calculated according to the annual uptake by forages. An experiment on a lateritic soil revealed that the yield of *Stylosanensis* could be increased 23.8% by applying 96 kg ha^{-1} P_2O_5. With the model of P and K efficiency, the optimum economical fertilization rate for *Stylosanensis* could be predicted as 114 kg ha^{-1} for P_2O_5 and as 126 kg ha^{-1} for K_2O. Dry matter reached up to 9,005 kg ha^{-1}. However, it was not suitable to apply too much K fertilizer (>180 kg ha^{-1} K_2O), as it has shown the decrease of the protein content of *Stylosanensis*. The application of P and K increased soil available P and K as well as the ability of legume forages to fix nitrogen. P and N fertilizers had to be applied at the same time. Other experiments showed that the application of 1 kg N could increase the fresh grass yield of *Setaria anceps* cv. Nandi by 150 kg ha^{-1}.

Applying lime

In our experiment, acidification occurred in the topsoil after growing continuously forages for ten years. Most soils cultivated with tropical grassland forages were acid or strongly acid and the exchangeable Ca and Mg contents were very low. The application of lime was necessary in order to neutralize the acidity and to supply Ca to the forages. Some experiments showed that applying lime to acid grassland could not only neutralize soil acidity, but also decreased the K concentration in the soil solution so that the risk of K leaching has to be compensated by additional K application.

Conclusions

1) The tested forages showed that legumes contained larger contents of N and Ca than in the grasses. The nutrient contents of P, K and Mg showed no difference between the legumes and grasses.
2) Legumes removed more nitrogen than grasses. The N uptake among the three legumes were in the order: *L. leucocephala* > *S. guianensis* > *A. pintoi*. Among the graminaceae, *P. maximum* took up the largest amount of N followed by *P. purpureum*.
3) Graminaceous forages consumed more total soil N and organic matter than legume forages. After planting the 7 major tropical forages, the available P and K contents were decreased to a large extend and the topsoil tended to acidify. Thus, it is suggested that the amount of P and K fertilizer and lime applied should be increased in tropical forage production.