Proceedings of the IPI Golden Jubilee Congress 1952-2002 held at Basel, Switzerland, 8-10 October 2002

Volume 1: Invited papers

Feed the soil to feed the people
The role of potash in sustainable agriculture

Edited by A.E. Johnston

International Potash Institute
Basel, Switzerland
2003

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Edited by

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Opening Session

Policy issues related to food supply and the environment

Welcome address

E. Wyss

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

Esteemed guests and delegates,
Friends,
Ladies and gentlemen,

It gives me great pleasure to welcome you on behalf of the International Potash Institute to the Golden Jubilee Congress of IPI.

"Feed the soil to feed the people", the title of the Congress could not be more appropriate. Increasing food shortages in Southern Africa and other regions of the developing world questions again whether Malthus was correct in his prediction that sooner or later the increase in population will exceed the ability of farmers to feed them. Of course, poverty, uneven distribution of food, social unrest and natural disasters may be some of the reasons for the current food crisis in Africa and other places. However, depleting soils of essential plant nutrients and thus, decreasing the soil's ability to produce food cannot be excluded. Progressively more and more reports show negative nutrient balances on food producing land, meaning that more nutrients are removed from the field with the harvest than are replenished with either organic manures or mineral fertilizers. The causes of, and issues over soil nutrient mining and its effect on soil fertility will be a major feature of this Congress.

In welcoming you here today, I would like to say few words about the International Potash Institute for the benefit of those of you who are not familiar with its structure and activities.

Founded by the German and French potash producers in 1952, IPI initially had its headquarters in Berne, Switzerland. As a non-govemmental and non-profit making organization, IPI is currently supported by the European and Neareast Potash Industry with its headquarters in Basel. Over the years, its aims have changed somewhat in response to the changing needs for food production in different parts of the world.

Because it has interests over a wide geographic area, IPI strives to balance its efforts to satisfy what are currently the different needs of developing countries, seeking adequate food and food security, and the developed countries seeking food quality and safety. Hopefully all countries will one day need both in equal measure.

Potassium is an essential plant nutrient and when the supply is adequate it contributes to both yield, quality and stress resistance in crops. But often lack of a visual response to applying potassium has meant that it has tended to be the forgotten nutrient. IPI will continue to promote the use of potassium as an essential part of balanced fertilization. This concept implies applying all plant nutrients in manures or fertilizers, in the correct amounts to ensure optimum economic yields and quality and maintain soil fertility while minimizing any adverse environmental effects from their use. The current aims of IPI can be summarized as follows:

- to initiate and support research on the effect of balanced fertilization on crop yield, quality and stress resistance
- to collect and transfer the knowledge through demonstration trials, seminars and publications
- to inform scientists and decision-makers involved with food production about the requirements of agriculture at the field level, especially the need for nutrients
- and, by promoting balanced fertilization, to contribute to maintain or restore soil fertility and to safeguard the environment.

I am very pleased to inform you that scientists from more than 30 countries have accepted our invitation to come to Basel to give papers, present posters and contribute to panel and general discussions on their views on how best to feed the soil to produce quality food within the present policy, economic and environmental constraints. May I wish all delegates a stimulating and fruitful time in the formal presentations and pleasant social gatherings in my home town of Basel.

Thank you very much.

The International Potash Institute in retrospect and prospect

A. Krauss

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Nutrition of plants, mysteries in the past

The systematic cultivation of land to produce food started in China more than 6000 years ago. These early farmers used organic material and soil eroded from the hills to "*fertilize*" the crops (Zitong *et al.*, 2002). In Europe, almost 2000 years ago, the Roman author Lucius Junius Moderatur Columella stressed the need to apply "*fertilizers*" because "*the soil will not be tired and doesn't age when it receives fertilizers*" and the farmer "*can have a higher yield when the soil is supported by frequent and appropriate fertilization*" (from Morgenthaler & Siemes, 1987).

With respect to soil fertility in medieval Europe, Antoine Laurent de Lavoisier (1743-1794) played a major role. His fundamental discovery that fermentation is a chemical reaction helped scientists and philosophers to realize that soil fertility also lay in physical and chemical processes. He quickly recognized that the famines in Europe, fairly common in those days, were linked to lack of plant nutrients. By using animal manure, yields doubled and he clearly demonstrated that the manure had contributed to the fertility of the soil.

The idea of using animal and human excrements and organic waste as sources of humus was discussed in Europe systematically and promoted by German, Austrian and French scientists during the 18th and 19th centuries. However, in the early years of the 19th century, first Sprengel and then Liebig showed that it was not the humus as such but the mineral nutrients it contained that nourished plants. This led to systematic field trials, like those done by Lawes and Gilbert in Rothamsted, UK, on the nutrient requirements of crops, and the production of mineral fertilizers, like single superphosphate from bones by Lawes and Gilbert (Johnston, 1994) and "Patentdünger", developed by Liebig (Mengel, 2000).

Liebig showed that potassium is one of the major essential plant nutrients. It had, however, been long known as potash, because it was extracted from the ash left in iron pots after burning wood. The early use of potassium (K) was for soap and glass manufacture. With the discovery of the importance of K in crop nutrition, demand increased, but its production from wood ash could not cope with the increased requirement. However, in 1856 potash deposits were discovered in Germany and, after various technical problems were solved, large-scale production of potash fertilizers started in 1861 at Stassfurt.

problems of water use (Madrid, 1958), K and crop quality (Brussels, 1966), K in plant biochemistry and physiology (Uppsala, 1971), K in tropical soils (Abidjan, 1973) and K fertilizer use and plant health (Izmir, 1976), to name only few.
Proceedings of Congresses and Colloquia, the Potash Review, the Green Bulletin, the International Fertilizer Correspondent (ifc), together with crop specific Bulletins as well as the Research Topics aimed to provide scientists with references, students with basic knowledge and advisors and farmers with information applicable to their farming situation.
Very early, IPI also looked beyond Europe and established missions around the world, either on its own or in collaboration with what is now the Potash and Phosphate Institute, PPI/PPIC headquartered in the USA. The most comprehensive mission was the POTASCHEME in India, 1957-62, which had both expatriates and a large number of local staff. Other missions were founded in subsequent years in Argentina, Brazil, Peru, Uruguay, East Africa, South Africa, former Rhodesia, Hong Kong, Iran, Japan, Korea, Singapore, Taiwan, and in Montpellier, France for the Mediterranean region.

IPI towards its Golden Jubilee

In the spirit of the progress made in fertilizer use during the 1970s, UNIDEP (1978) forecast an increase in N consumption from 54 Mt at the time of the IPI Silver Jubilee to 145 Mt N in 2000 while phosphate use was forecast to more than double from 30 Mt to 76 Mt P_2O_5, and potash from 25 Mt to 67 Mt K_2O.
However, these forecasts, especially for K and phosphorus (P) were not realized. The energy crisis, large set-a-side programs and financial constraints in the early 1980s considerably depressed the growth in consumption of potash and phosphate fertilizers; the use of N was less affected.
The situation on the global fertilizer market depreciated further when fertilizer use in the Former Soviet Union, FSU, and in Central/Eastern Europe, CEE, almost collapsed after the economic reform. Between 1988, the peak of the global fertilizer use and five years later, 1993, N use declined by 9%, P use by 24% but K use plunged by 39%. Lack of funds, no credit facilities, unclear land titles, no market structures, redistribution of land to inexperienced former owners, lack of knowledge and, last but not least, no promotion and education are some of the reasons of the considerable decrease in fertilizer use in the former command systems of FSU and CEE. In the western world, financial constraints, another round of set-a-side programs, growing ecological concerns, and also better utilization of organic manures, improved fertilizer use efficiency, better nutrient management were responsible for a steady decline in use of mineral fertilizers; the use of potash, again, declining most. For example, potash use in the FSU declined from 7 Mt in 1988 to currently 0.7 Mt K_2O; in the CEE from 2.7 Mt to 0.6 Mt and in Western Europe (WE) from 5.9 Mt to currently 3.6 Mt K_2O, a decline of almost 40%. Nitrogen in contrast was not so badly effected. In the FSU it declined only from

11.3 to 9.3 Mt; in the CEE from 4.6 to 2.3 Mt, and in WE from 11.3 Mt to currently 9.3 Mt N, i.e. a decrease of less than 20%. These differences in the use of N and K fertilizers illustrate the earlier comment that in times of economic constraint farmers prefer to use N for its immediate effect on crop production at the expense of potash.

Changes in the use of mineral fertilizers in developing countries were different to those in the rest of the world. From 1978, when IPI celebrated its Silver Jubilee till now, fertilizer use increased steadily from 21 Mt to 55 Mt N, from 8 Mt to 22 Mt of P_2O_5 and from 3 to 12 Mt of K_2O. This large change can be illustrated by the following comparison: since 1978, the developing countries share of global N use increased from 38% to 67%, P_2O_5 from 25% to 67%, and K_2O from 13% to 53%.

However, in spite of this obvious progress in fertilizer use in the developing world the problem of soil K mining remains. Currently, the use of N fertilizers is of the same order of magnitude as the N removed by crops, as in developed countries. But the use of potash in developing countries replaces only 20% of the K removed by crops, i.e. the K removed by crops in the developing countries is about 45 Mt K_2O more than what is applied in potash fertilizers. For example, China has a deficit of 14 Mt K_2O, India a deficit of 8 Mt K_2O and Sub-Saharan Africa more than 4 Mt K_2O. Even in the developed countries, the annual deficit is almost 4 Mt K_2O. The P balance is also negative but to a lesser extent than K.

IPI at the present time

A number of factors have had a considerable impact on the structure and activities of IPI.

- The sponsors of IPI, the European and Near East potash industry were seriously affected by the substantial decline in the global potash demand at the end of the 1980s, and, in consequence, less financial support was available. IPI had to be reorganized and this included the transfer of the Head Office to Basel in 1990.
- The rapidly emerging deficit in the K balance (K applied minus K removed) in developing countries and the inevitable consequences for soil fertility and the sustainability of agricultural production required the re-orientation of the regional activities of IPI towards developing countries.
- Soil and plant research in many Institutes and Universities in West European countries was re-oriented towards environmental issues related to fertilizer use with the focus on N and P. Potassium per se is not considered as a potential polluter and consequently, much less research effort was devoted to K. However, this often overlooked the fact that soil K mining with inadequate potash use has an indirect effect on the environment when the efficiency of inputs, like N fertilizers, is lessened.
- With this trend in agricultural research in many countries and organizations, IPI lost its scientific support in West Europe and additionally and very importantly, the direct industry support through the closure of the Büntehof Research Station

in Germany and Aspach-le-Bas Research Station in France for economic reasons.

In response to this new environment, IPI has adopted a decentralized approach.

- Regional activities became more focussed on China, SE-Asia, India, Near East and North Africa, Latin America, and also on Central/Eastern Europe and the FSU.
- Agronomists from member companies were commissioned as IPI Coordinators to conduct regional activities on behalf of IPI.
- Cooperation with agricultural research institutions in various regions were established to provide scientific support, e.g. with ISSAS in China, ICAR in India, EMBRAPA in Brazil, SWRI in Iran, RISSA in Romania, to name only a few.
- The form of international events has also changed. There are more regional workshops and seminars instead of large annual conferences. Last year IPI conducted, together with the local cooperators, workshops and symposia in Argentina, China, Czech Rep., Belarus, Bulgaria, Hungary, India, Jordan, Poland, Romania, Russia, Ukraine.
- Closer contacts were created with the ultimate client, the farmer through on-farm trials, field days and training courses, e.g. for fertigation.
- IPI publications are now presented in more than 20 languages and address the broad spectrum of educational abilities in many developing countries including local advisors and farmers.
- Last but not least, IPI uses up-to-date information transfer. Its website www.ipipotash.org is well received; a Chinese version being produced and a Spanish version is being considered.

Future challenges for IPI

Much of the immediate future challenge is for knowledge transfer especially to poor farmers and their advisors in developing countries.

- Growth in the global population but with shrinking resources

When IPI celebrates its 75th anniversary, the global population may have reached some 8 billion and more than 80% will be in what are now developing countries; and these people will need food. Rosegrant *et al.* (1995) consider that there could be an increase in cereal output from currently 2 Bt to about 2.64 Bt by 2020. However, if there is an increasing conversion of cereals into meat, cereal demand is expected to reach 3.4 Bt by 2020. But if cereal production since 1950 is extrapolated to 2020, the estimated output of around 2.4 Bt is far below the expected requirement unless yields per unit area and therefore total production can be increased substantially.
Following past trends, by the year 2030 developed countries may still have 0.41 ha/capita, but developing countries will only have 0.12 ha/capita, the area that is

already reality in China. And the quality of land likely to remain available for agriculture will be less than ideal due to severe competition from urbanisation, industrialisation and civic needs.

The trend in land availability will apply also to water. Between the foundation of IPI and the present, global water use has almost quadrupled. Asia, for instance, increased water use from 865 km^3 in 1950 to 3,187 km^3 in 2000. At the same time, the per capita water availability in Asia decreased from 9,600 to 3,300 m^3 (Rosegrant, 1997). Pinstrup-Andersen *et al.* (1997) estimate that withdrawal of water in developing countries will increase by 43% between now and 2020, with the demand for domestic and industrial purposes doubling and reducing the supply for agriculture.

Numerous field trials around the world have shown that when fertilizers are applied in a balanced manner, according to crop requirement and site-specific conditions, substantial yield increases can be achieved. Rice in Vietnam given N yielded either 4 or 5.5 t/ha, depending whether K was omitted or applied.

However, ignorance, misinterpretation of soil test results and economic constraints prevent the application of balanced fertilization with adequate use of potash. For example, for rice, urea is the major source of N and N use efficiency is low. Alternate water logging and drying out of the soil creates conditions that render fertilizer recommendations more difficult. IPI, in part, sponsors a multinational research program with IFA, PPI/PPIC and SDC, and conducted by IRRI, which studies nutrient dynamics in rice soils. The results so far show that balanced fertilization increases not only yields and improves the quality, but also improves N use efficiency. More results from basic research are still required to understand nutrient efficiency in other farming systems and soils so that advice to farmers can be improved.

An issue of considerable concern is the assessment of nutrient stocks in soils. For example in some soils, K mining is seriously threatening soil fertility. At the same level of initial soil fertility, a large negative nutrient balance will deplete nutrient reserves faster than a smaller deficit. In the first case, the farmer loses opportunity yield earlier than in the latter. Still, there is a lack of information on the rate of nutrient depletion in many farming systems, especially for K, because the dynamics of the exchange processes make it impossible to develop simple models. More basic research is needed to understand and to manage K to achieve economically viable production and maintain soil fertility.

In the context with the growing scarcity of water for agriculture, micro-irrigation systems have been developed, and their acceptance has increased rapidly. Since the 1980s, the area with micro-irrigation increased from 0.4 Mha to currently 3 Mha and no doubt there will be further increases. The technique is available and IPI utilizes the results and experience from applied research to inform farmers how best to manage nutrients with this new technology.

- Urbanization and changing food habits

With increasing income, people's food habits change from subsistence foods to fruits, vegetables and animal protein. Simultaneously, the quality of food becomes an important criterion in the market with concern about the safety of food, and the ability of the food to supply vitamins, anti-oxidants or other components required for health.

In relation to the growing demand for quality food, a farmer who does not produce to the required standard loses his competitiveness in the market. Consequently, there is a need to demonstrate in the farmer's field that balanced fertilization benefits crop quality. Appropriate quality management also builds up confidence between the producer and the customer, opening up new markets and making access to credit easier.

Transfer of food from the rural to the urban areas also means the transfer of nutrients contained in the food. Assuming that almost 50% of the current population lives in urban areas and consumes at least half of the globally produced food, this is equivalent with a transfer of about 85 Mt $N+P_2O_5+K_2O$ into the towns, with little of these nutrients being returned to the land. For example, EFMA estimates that only 2% of nutrients applied in the agriculture of the European Union derive from recycled urban waste. Decision-makers should be made aware on the risks involved in these nutrient transfers from the rural to urban areas or across regional or national borders if the nutrient cycle is not supplemented with adequate inputs of mineral fertilizers.

Balanced fertilization also improves the resistance of crops to pests and diseases, which could reduce the need for pest control and thus, lower the risk of residue levels above critical limits. Critical limits for residues from agrochemicals play an increasing role as a non-tariff barrier in export sales of agricultural produce.

An important aspect of changes in food habits is the corresponding change in the spectrum of crops grown. During the last 25 years, the increase in the area growing fruits, vegetables, oilseeds and soybean in particular, has greatly exceeded the increase in the area growing cereals. With changes in cropping, there are also changes in the overall nutrient requirement. Cereals, for instance, can exploit soil K much better than vegetables or soybean because of their much larger root systems. On the other hand, the K removed with leafy vegetables is many times larger than that in cereal grains.

- The organic movement

Issues about the safety of food, including recent concerns in Europe, have been one of the driving forces for some consumers to purchase organically produced food. The market volume of organic food is steadily increasing, some governments plan to convert a proportion of their food producing land to organic husbandry up to 20% e.g. in Germany. However, measurable differences in the quality of food produced in organic systems and on conventional farms have yet to be detected provided the conventional farmer follows Codes of Good Agricultural Practice.

Farmers should be encouraged to fully utilize the nutrients in organic manure and recyclable organic residues. However, recycling alone cannot close the gap in nutrient supply caused by the losses in products sold off the farm. Calculations from India show that even if all potential sources of organic manure and waste were returned to the field, the K balance would be highly negative. This is in contrast to N, which benefits from the N fixed by leguminous crops. Nutrient balances of organic farms in the UK show the same trend, a positive balance for N and a negative balance for K. Also the introduction of agro-forestry to recover leached nutrients by deep rooting species and recycled leaves cannot compensate for the loss of nutrients removed with the harvested crops.

Farmers, especially in developing countries, together with politicians and decision-makers, must be convinced that the production of safe and healthy food is not the privilege of organic farming, it can also be achieved on conventional farms as long as they manage their farming systems appropriately.

- Potassium and rural development

The deficit in the K balance in developing countries is steadily increasing, while that in many developed countries is becoming negative. Decreasing yields, poorer quality, increased incidences of pests and diseases, greater susceptibility to climatic stress will be observed more frequently as a result of depleting soil K reserves. A lower income and higher production costs with declining soil fertility prevent farmers investing in soil fertility, and declining soil fertility eventually leads the farmer into the poverty trap.

On the other hand, numerous on-farm field trials have repeatedly proved that investing in soil fertility, i.e. in balanced fertilization, is profitable. Field trials in India showed returns of 4-18 rupees per rupee invested in potash. It is essential to demonstrate in farmer's fields that there are benefits from balanced fertilization, which prevent them falling into the poverty trap. With a larger income the farmer is inclined to purchase more non-agricultural products, which in turn attracts other business, creates jobs and by that, contributes to rural development.

- Resources and environment

The competition for shrinking natural resources will become tougher in the future and this will put more pressure on agriculture to increase the productivity of the remaining land, water and energy. How effective balanced fertilization can contribute has been shown in field trials in Hungary. Sugar beet of low quality produced by unbalanced fertilization required about 5 t more beet to be transported and crushed to produce one ton of white sugar compared with beet grown with balanced fertilization and with a larger % sugar.

Another example from China showed that with farmer's practice, some 140 kg/ha nitrate remained in soil after the harvest of cabbage. This nitrate was at risk to loss by leaching or denitrification. With adequate K, the residual nitrate in the rooting zone was only 35 kg/ha.

Also in China, if fertilizer use had not increased, an additional 350 Mha of arable land would have been required to achieve the same total produced as today.

- Globalization and the World Trade Organization

With increasing world trade and hence competition, farmers will only be competitive if their produce meets the appropriate quality standards. Quality can be expressed not only in terms of nutrition, appearance, freedom from pests, diseases and residues and the content of a particular constituent, but also whether the crop has been produced in an environmentally friendly way. An adequate K supply is a key factor in achieving crop quality and this can be achieved through balanced fertilization.
Increasing globalization of world trade in agricultural commodities means an increased transfer of nutrients. Asia for example exports around 230,000 t K and Latin America about 1.1 Mt K in oilseeds and oilseed meal cake. The European Union in contrast imports some 1.26 Mt K with oilseeds and oilseed meal cake. Farmers exporting K from their land need to be aware of the long-term consequences in terms of soil fertility.

- Biotechnology and future nutrient needs

High yielding varieties, hybrids, gene modified organisms and biotechnology are, without doubt, necessary inputs to feed future generations. Irrespective to the present concerns about genetically modified organisms (GMOs), with increasing yield potential, the demand for nutrients must increase as well. This applies particularly to K because maximum uptake is restricted to a rather short period of time during rapid vegetative growth. Daily uptake rates of up to 10 kg/ha K are not uncommon. Only soils that are well supplied with K are in the position to meet this level of demand so fertilizer recommendations have to be adjusted accordingly.
By breeding varieties resistant to pests, diseases and climatic stress, the yield potential increases and this may convince farmers to replace nutrients, especially P and K, removed from the farm in the produce that is sold. Farmers require the correct information on how to improve soil fertility.

- Multifunctionality

Farming not only produces food and feed but also impacts on the landscape and the environment. Yoshida (2001) estimated the economic value of the multifunctional role of agriculture in Japan at some USD68.8 billion. He took into consideration flood prevention, conservation of water resources, prevention of erosion and landslides, organic waste disposal, air purification, climate mitigation and preserving amenities for recreation and relaxation. For example, plants adequately supplied with nutrients and growing well are in a much better position to reduce runoff and erosion. However, farmers are not yet adequately compensated for these roles. Nevertheless, farmers will increasingly have to integrate crop production into this multifunctional role and the fertilizer industry needs to show how appropriate fertilizer use can support this effort.

Conclusion

After fifty years of promotion of balanced fertilization in many parts of the world, it is appropriate to ask if there is still a need to continue regional activities promoting balanced fertilization in view of the obvious easy access to information through publications, seminars, the internet, etc.

Definitely, there is still a need for knowledge transfer to create an awareness amongst all stakeholders in food production about the risks and consequences of soil nutrient mining, especially K.

Unfortunately, the majority of farmers in developing countries does not have access to written information and prefer learning by seeing. Direct contact with them creates an atmosphere of confidence and increases the probability of them following the advice provided on the benefits of balanced fertilization and the dangers of soil nutrient mining. Farmers need advice on how to leave the vicious circle of declining soil fertility and the failure of re-investment, but there must also be the correct economic frame if the trend is to be reversed.

Extension workers and fertilizer advisors must be aware of the problems and consequences of soil nutrient mining. However, very often extension workers in developing countries lack both the means and the knowledge to adequately inform the farmers. Thus, the fertilizer associations must continue to take their part in the further education of the extension services.

There is still a need for support from research, especially to understand and to nutrient availability in soil. Following the philosophy "from the land to the lab and from the lab to the land", those working with farmers can be the catalyst to initiate the research required and transfer the results back to the farmer.

The fertilizer associations must also play their part in educating decision-makers about the consequences of soil nutrient mining and the benefits of balanced fertilization. The latter not only increases yields, but also improves quality and stress resistance in crops. Increasing yields with adequate fertilizer contributes to rural development, to food security and to safeguarding natural resources together with protecting the environment.

Finally, the fertilizer industry should continue to support and promote the need for adequate nutrient supplies. The customer will appreciate good advice and service from the fertilizer industry, while at the same time improving its image with ecologists and environmentalists.

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Human nutrition and access to food

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Introduction

At the beginning of the 21st century, humanity faces a glaring contradiction: the persistence of food insecurity amidst plenty. Without significant changes in policies in both developed and developing countries, over the next two decades hundreds of millions of people will remain food insecure and millions of children will die annually from malnutrition, in spite of projected gains in food availability.

Food security past and present

As of 1998 (the last year for which data are available), there were 776 million (M) food insecure people in developing countries (Figure 1) (FAO, 2002). Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 1996). The world has made progress – albeit too slowly and very unevenly – in reducing hunger. Since 1970, the number of food insecure people in developing countries has declined by nearly 20%, from 959 M, and the food insecure percentage of the population has dropped dramatically, from 37 to 17% (FAO, 2000a; 2002).

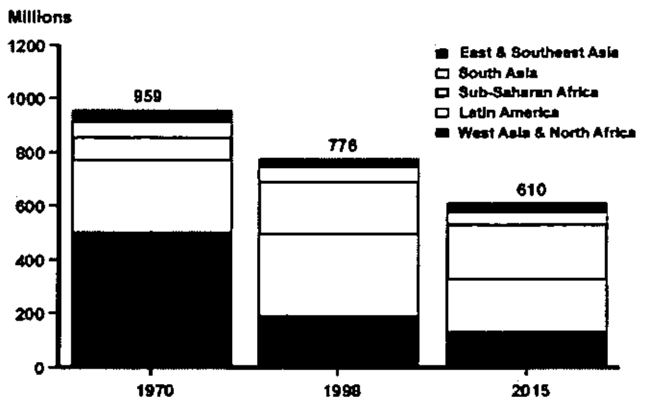

Fig. 1. Number of food-insecure people, 1970, 1998 and 2010 (Source: FAO, 2000a & b, 2002).

Food availability rose 26% to 2,667 calories per person per day, or more than enough for everyone to meet their minimum requirements if supplies were distributed according to need (Figure 2). Per capita cereal production gains attributable to the Green Revolution led to lower real cereal prices, to the benefit of poor consumers (Kerr and Kolavalli, 1999). The International Food Policy Research Institute (IFPRI) projects that food availability will increase in all regions during 1997-2020 (Rosegrant *et al.*, 2001)[1].

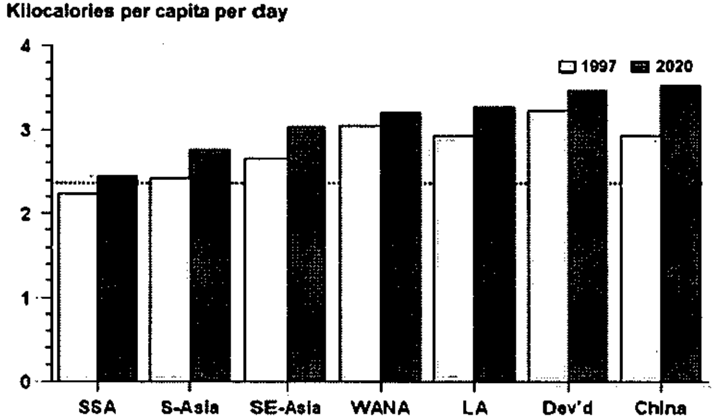

Fig. 2. Daily per capita calorie consumption, by region, 1997 and 2020. The dashed horizontal line represents minimum calorie requirements (Source: Rosegrant *et al.*, 2001).

South Asia and Sub-Saharan Africa are home to over three-fifths of all food insecure people. Due to the high rate of population growth, the number of food insecure South Asians rose 14% over 1970-98, even as the food insecure portion of the population fell from 37 to 24%. The incidence of food insecurity in Africa remained unchanged, and at 34% is the highest of any region. The number of food insecure Africans more than doubled, from 88 to 194 M, as a result of widespread poverty, population growth, environmental degradation, declining food production per capita, and violent conflict (FAO, 2000a, 2002). The Food and Agriculture Organization of the United Nations (FAO) projects that in 2015, the food insecure population of the developing world will fall to 610 M. This is far short of the 1996 World Food Summit goal of no more than 400 million food insecure people in 2015 (FAO, 1996 and 2002).

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[1] Projections using IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) cited in this paper are from June 2001 and reported in Rosegrant *et al.* (2001), which also provides a detailed description of the model.

Child malnutrition

In 1997, 166 M children under the age of five (31% of the preschool children in the developing world, compared to 46% in 1970) were malnourished (Figure 3) (Rosegrant *et al.*, 2001). Inadequate nutrition is a factor in 5 M developing-country child deaths annually. Those who survive face impaired physical and mental development. This scourge compromises future health, productivity, and food security, and undermines both economic growth and equity (WHO, 2001; Flores and Gillespie, 2001). Between 1970 and 1995, the number of malnourished preschoolers in the developing world declined by 37 M (Smith and Haddad, 2000). South Asia and Sub-Saharan Africa are home to 71% of the malnourished preschoolers (Rosegrant *et al.*, 2001). Birth weights of less than 2.5 kilograms (kg) are a major factor leading to child malnutrition, and usually result from poor maternal nutrition. In effect, malnutrition is passed from one generation to the next (ACC/SCN and IFPRI, 2000).

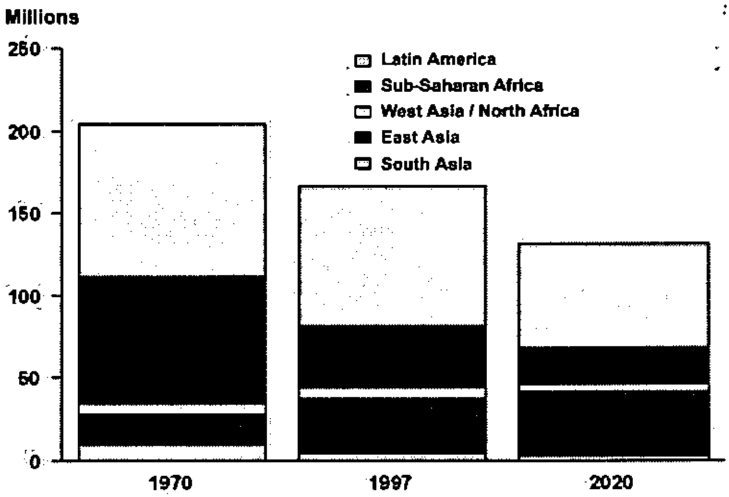

Fig. 3. Number of malnourished children by region, 1970, 1997 and 2020 (Source: Rosegrant *et al.*, 2001).

With business as usual, IFPRI projects that by 2020, the number of malnourished preschoolers in developing countries will decline by just 21% from 1997, to 132 M. In Sub-Saharan Africa, the number of malnourished children is expected to *rise* 18% (Rosegrant *et al.*, 2001).

"Hidden Hunger"

Deficiencies of micronutrients – vitamins, minerals, and trace elements – are pervasive. Two billion people suffer anemia, due mainly to iron deficient diets, including 56% of pregnant women in developing countries and 76% of pregnant women in South Asia (Figure 4). Anemic women have a 23% greater risk of maternal mortality. Their babies are more likely to be born prematurely, have low birth weights, and die as newborns. Anemic preschoolers face impaired health and limited learning capacity. Even when iron deficiency does not progress to anemia, it can reduce work performance. It causes annual economic losses of nearly 2% of gross domestic product (GDP) in Bangladesh, over 1% in Pakistan, and nearly 1% in India, and these losses equate to a total of $5 billion per year (ACC/SCN, 1997; ACC/SCN and IFPRI, 2000; Gillespie and Haddad, 2000; WHO, 2001). Vitamin A deficiency affects 100-140 M children, mainly in Sub-Saharan Africa and South Asia. One-quarter to half a million go blind each year, and half of them die within 12 months of losing their sight (WHO, 2001; ACC/SCN and IFPRI, 2000).

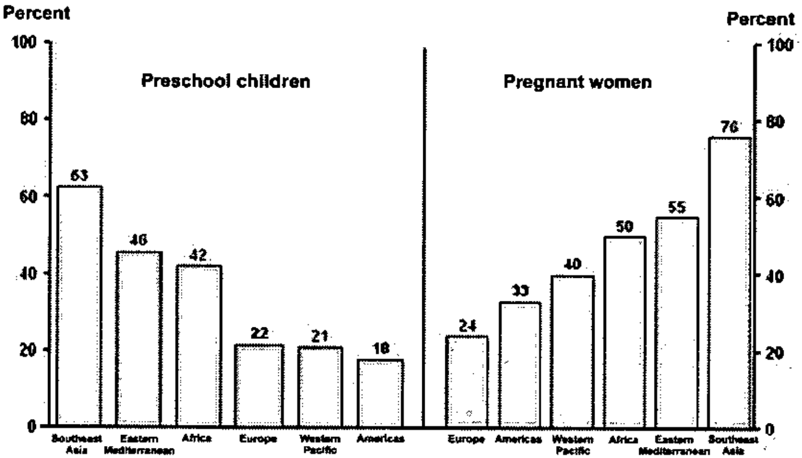

Fig. 4. Prevalence of anemia in preschool children and pregnant women by region, 1999 (Source: ACC/SCN and IFPRI, 2000).

Causes of food insecurity

Poverty is the principal cause of food insecurity. Additional factors leading to food insecurity include powerlessness, conflict (Figure 5), discrimination (based on gender, age, race, and ethnicity), and unsustainable natural resource management (Cohen, 1994). Hunger endures amidst adequate food supplies mainly because food insecure people cannot afford the food that is available, and lack land and other resources to produce food for themselves.

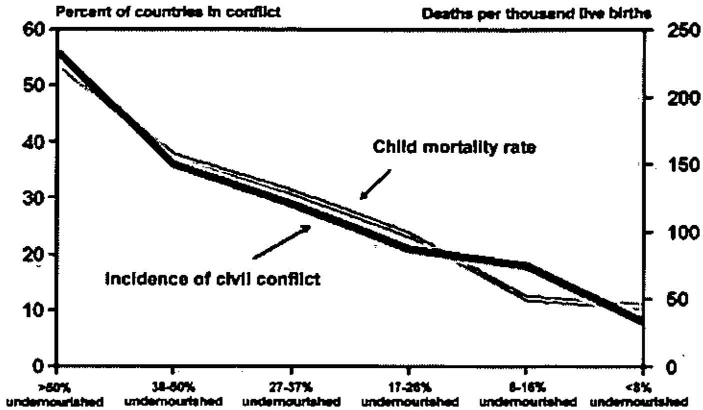

Fig. 5. Food security, civil conflicts and child mortality, 1990-96 (Source: FAO, 1999; Note: Countries grouped by prevalence of under-nourishment).

Globally, 1.2 billion people (20% of the world's population) live on the equivalent of less than $1 a day (Table 1); 70% of them live in South Asia and Sub-Saharan Africa (World Bank, 2001a). Despite rapid developing country urbanization, 75% of poor people live in rural areas (IFAD, 2001).

Table 1. People living on less than $1 per day, 1990, 1998, and 2015 (millions of people, M, and percent, % of population) (Source: World Bank, 2001a).

	1990		1998		2015 (optimistic)		2015 (pessimistic)	
	M	%	M	%	M	%	M	%
Developing world	1300	29	1200	23	777	13	1000	16
Sub-Saharan Africa	242	48	302	48	361	40	462	47
East and Southeast Asia	452	28	267	15	65	3	101	5
South Asia	495	44	522	40	297	18	426	25
Latin America and the Caribbean	74	17	61	12	43	7	58	9
West Asia and North Africa	6	2	6	2	5	1	6	2

Note: The optimistic scenario for 2015 assumes moderate, broad-based economic growth worldwide, while the pessimistic scenario assumes slower growth and rising inequality.

Household surveys in a number of countries indicate that child malnutrition rates for the poorest 20% of households significantly exceed those of the wealthiest 20%. The World Bank projects that in 2015, poverty will persist at high levels in South Asia, and will increase substantially in Sub-Saharan Africa (World Bank, 2001a).

Factors affecting future food security

Rising food demand

Income growth, population growth, urbanization, and associated changes in dietary preferences all affect food demand. IFPRI projects income growth in all regions between 1997 and 2020, with slowest growth in Sub-Saharan Africa (Rosegrant *et al.*, 2001). Urban population in developing countries is expected to double between 2000 and 2020 (UN, 2000 and 2001). When people move to cities, they tend to shift consumption to foods requiring less preparation time and to more meat, milk, fruit, vegetables, and processed foods (Garrett and Ruel, 2000). Meat demand in developing countries is expected to increase 92% between 1997 and 2020 (Figure 6), stimulating a strong increase in demand for maize for livestock feed (Figure 7). IFPRI projects declining real cereal prices between 1997 and 2020, but at a slower rate than in the 1980s and 1990s (Figure 8). Demand for cereals will outstrip production in developing countries (Figure 9) (Rosegrant *et al.*, 2001).

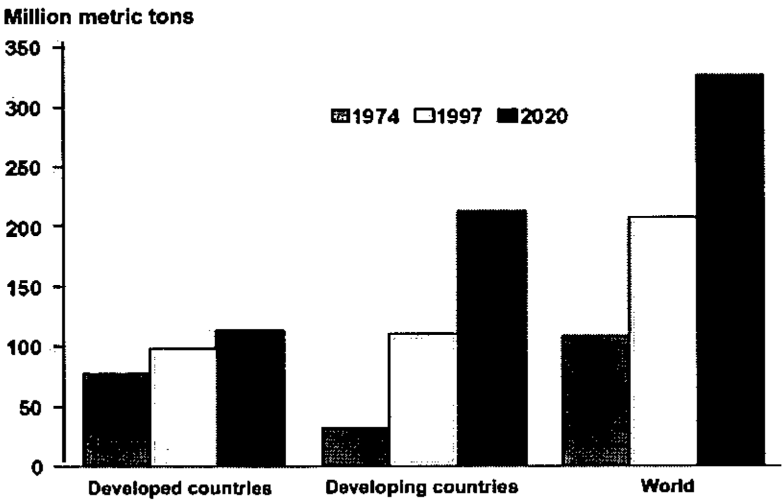

Fig. 6. Total meat demand by region, 1974, 1997 and 2020 (Source: Rosegrant *et al.*, 2001).

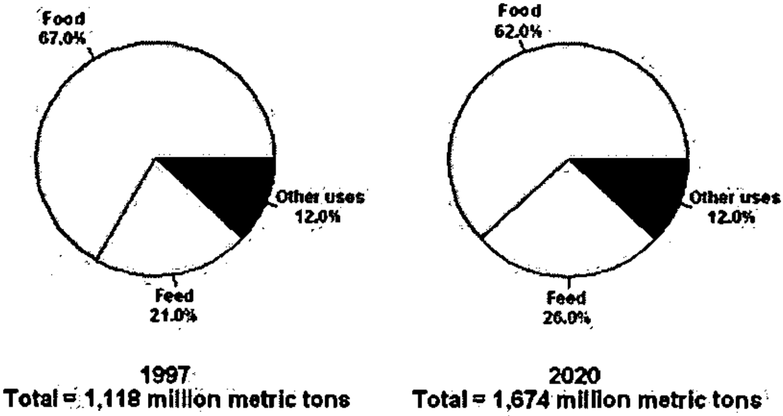

Fig. 7. Share of food, feed and other uses in total cereal demand of developing countries in 1997 and 2020 (Source: Rosegrant *et al.*, 2001).

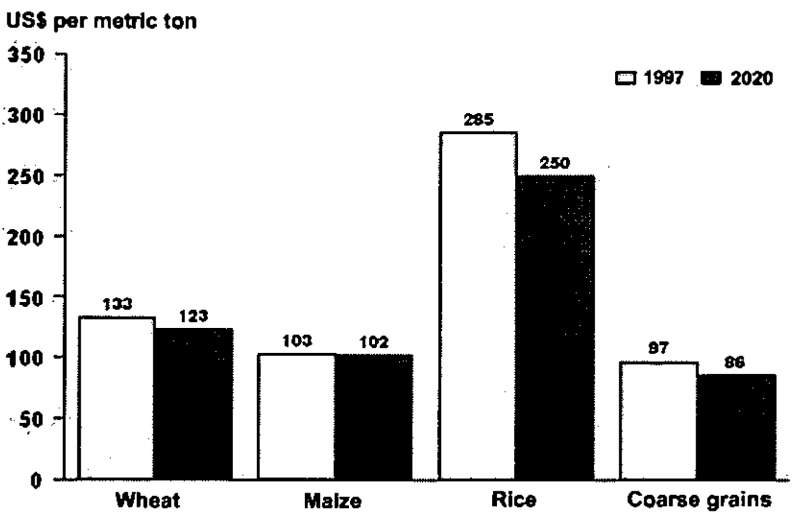

Fig. 8. Cereal prices per crop, 1997 and 2020 (Source: Rosegrant *et al.*, 2001).

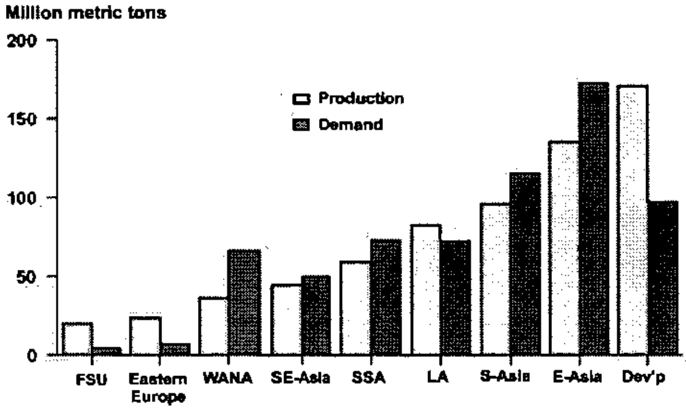

Fig. 9. Cereal production and demand, increase by region, 1997 to 2020 (Source: Rosegrant *et al.*, 2001).

Globalization

Globalization offers developing countries significant new opportunities for broad-based economic growth and poverty alleviation, but it also carries significant risks, including the short-term inability of many industries in developing countries to compete, potential destabilizing effects of short-term capital flows, increased price risk exposure, and worsening inequality within and between nations. Continued protection and subsidization of domestic agriculture and increasing food safety concerns in industrialized countries may limit developing countries' market access. Africa's share of world agricultural trade continues to decline rapidly (Figure 10).

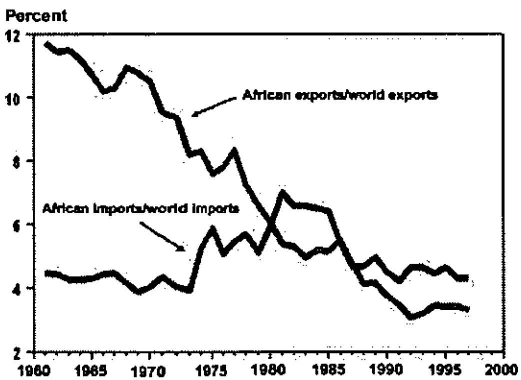

Fig. 10. African share of world agricultural trade, 1961-1997 (Source: Mukherjee and Harris, 1999).

Forty-five of the poorest countries (30 of them in Africa) owe $235 billion to external creditors. Most of these countries cannot afford to make payments, due mainly to low prices for their primary product exports (Catholic Relief Services, 2001; Pettifor, 2000). Appropriate policies and institutions are needed to guide globalization to benefit low-income people (Diaz-Bonilla and Robinson, 1999; Pinstrup-Andersen *et al.*, 1997, 1999).

With the end of the Cold War, official development assistance (ODA) became a much lower priority for industrialized-country governments. Aid from the principal donor countries fell 21% in real terms from 1992 to 1997 (Figure 11). Since then, ODA levels have increased somewhat, but the aid provided in 2000 was still 8% less than in 1992. Between 1995 and 2000, aid to low-income developing countries fell 23%. Aid to Sub-Saharan Africa declined 31% and fell from 31 to 25% of ODA, while aid to South and Central Asia fell 9%, and aid increased to higher-income countries in Eastern Europe and East Asia (OECD, 2000 and 2001). Food aid levels have fluctuated considerably since the mid-1990s (Figure 12), because the United States, the largest donor, ties assistance to U.S. domestic farm surpluses (WFP, 2001; Clay and Stokke, 2000; Cohen, 2000). In the wake of the September 11, 2001 attacks in the United States, several major donors have indicated that they will increase aid but it is unclear whether they will target resources to poverty reduction and sustainable development in poor countries.

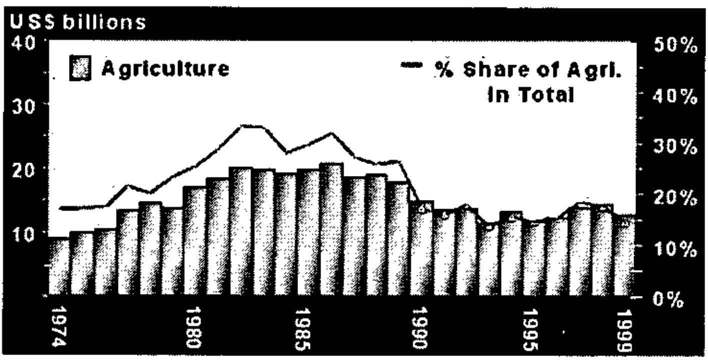

Fig. 11. ODA, external assistance to agriculture (Source: FAO, 2001b).

Technological change

New technological advances in molecular biology, energy, and information and communications offer potential benefits for poor people that may advance food security. However, there are serious concerns about what amounts to scientific and technological *apartheid*, wherein technological progress focuses primarily or even exclusively on non-poor people in industrialized countries (Serageldin, 1999). Rapid changes in the financing, management, and organization of agricultural research may require new policies to assure that low-income people benefit. The private sector accounts for a growing share of global agricultural R&D, and subjects both products and research processes to intellectual property rights protection (Pardey and Beintema, 2001).

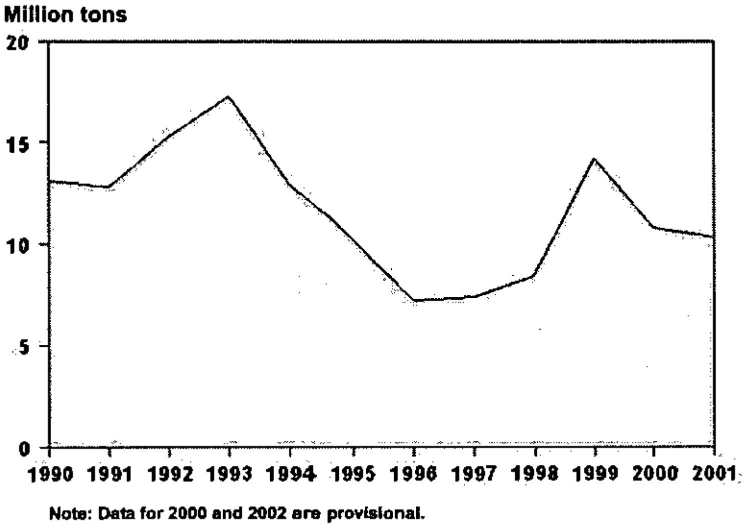

Fig. 12. Global food aid deliveries, 1990-2001 (Source: WFP, 2002).

Environmental factors

Environmental factors also impinge on food security. Unless properly managed, fresh water may emerge as the key constraint to global food production. Developing countries are projected to increase water withdrawals by 43% between now and 2020, with the share of domestic and industrial uses in total water demand doubling at the expense of agriculture (Rosegrant *et al.*, 2001). Comprehensive water policy reform is needed to help save water, improve use efficiency, and boost crop output per unit (Rosegrant and Ringler, 2000). Policies aimed at achieving food security must incorporate the likely consequences of climatic change. Agriculture accounts for 20% of the "greenhouse gasses" that lead to warming. Agricultural activities lead to increases in carbon dioxide (CO_2) emissions, but can also absorb CO_2 (Wilson, 2001; Agence France Presse, 2001; Annan, 1999).

Health and nutrition

A global health crisis is afflicting the impoverished and impoverishing those affected. Infectious diseases such as HIV/AIDS, malaria, and tuberculosis, together with a variety of chronic diseases caused in part by obesity, all compromise food and nutrition security in many developing countries. The interaction of inadequate dietary intake and disease leads to malnutrition, disability, and death (Flores and Gillespie, 2001).

There is nothing inevitable about the rather bleak food security outlook presented here. If developing and developed countries alike implement appropriate policies and establish appropriate institutions, progress against food insecurity and child malnutrition could accelerate substantially. Some of the key policy actions are outlined below.

Broad-based agricultural and rural development

Given the rural center of gravity of poverty, broad-based agricultural and rural development is essential for food security. For every new dollar of farm income earned in developing countries, income in the economy as a whole rises by up to $2.60, as growing farm demand generates employment, income, and growth economy-wide (Delgado *et al.*, 1998). Well-functioning and well-integrated markets, along with supporting institutions and infrastructure, are critical (Kherallah *et al.*, 2000), but markets alone cannot assure equity. Policies must assure that rural poor people, including women, have access to:

- Productive resources, including land, water, tools, fertilizer, pest management, technical assistance, and credit;
- Yield increasing crop varieties – including pest-resistant and drought- and salt-tolerant varieties – improved livestock, and other yield-increasing and environment-friendly technology;
- Opportunities to participate in export crop production; and
- Primary education, health care, clean water, safe sanitation, and good nutrition.

Policies and programs must be supported by good governance – rule of law, transparency, sound public administration, democratic and inclusive decision making, and respect for human rights. Trade, macroeconomic, and sectoral policies must not discriminate against agriculture (Tweeten and McClelland, 1997; Drèze and Sen, 1989; Sen, 1999). Agricultural and rural development programs must engage low-income people as active participants, not passive clients (Kherallah *et al.*, 2000; Pinstrup-Andersen, 1993; Cohen, 1994).

Women play a central role as producers of food, managers of natural resources, income earners, and caretakers of food and nutrition security. In Africa, when women farmers obtain the same levels of education, experience, access to services such as extension, and farm inputs as male farmers, they increase staple food crop yields by 22% (IFPRI, 2000).

Unfortunately, many developing country governments view agriculture as a declining sector, and have put resources instead into industry and urban development, which tend to have more powerful constituencies (World Bank, 1997). In 1998, developing countries with a high incidence of food insecurity devoted just 5% of their expenditures to agriculture (FAO, 2001a). On average, low-income countries allocate 13.3% of government budgets to military spending (World Bank, 2001b).

For their part, ODA donors must reverse the precipitous decline in ODA to agriculture, which in 1998 was 8% below the 1990 level in real terms (Figure 11). The share of agricultural aid going to Africa declined from 30% in 1990 to 21% in 1998 (FAO, 2000c and 2001a).

Pro-poor agricultural research

Public investment in agricultural research that can improve small farmers' productivity in developing countries is especially important for food security. It can boost agricultural productivity, thereby reducing gaps between food production and demand, further broad-based income growth, and lower unit costs in food production. Pro-poor agricultural research must join all appropriate scientific tools and methods, including agroecology/organic farming, conventional research, and modern agricultural biotechnology techniques, such as genetic engineering, with better utilization of farmers' own knowledge. Agricultural R&D must put farmers in decision making roles, fully informing them of options for improving productivity, reducing risks, and increasing their families' well-being. Agricultural research must pay greater attention to sustainability, the role of property rights and collective action in farmers' technology adoption and resource management practices, and to resource-poor areas (Hazell, 1999; McCulloch *et al.*, 1998). The private sector is unlikely to undertake much research needed by poor developing-country farmers because expected profits are unlikely to cover investment costs. On average, developing countries invest just 0.6% of agricultural GDP in public agricultural research, compared to 2.6% for developed countries (Figure 13). The average annual growth rates of public agricultural research expenditures in developing countries in the first half of the 1990s were significantly below those of the late 1970s, and in Sub-Saharan Africa, the rate turned negative (Figure 14). Aid donors' contributions to international agricultural research have stagnated over the past dozen years (Pardey and Beintema, 2001).

Tackling child malnutrition

IFPRI research has found that improvements in women's education accounted for 43% of the reduction in child malnutrition in developing countries between 1970 and 1995. Improvements in per capita food availability accounted for an additional 26% of the reduction. (Figure 15) (Smith and Haddad, 2000).

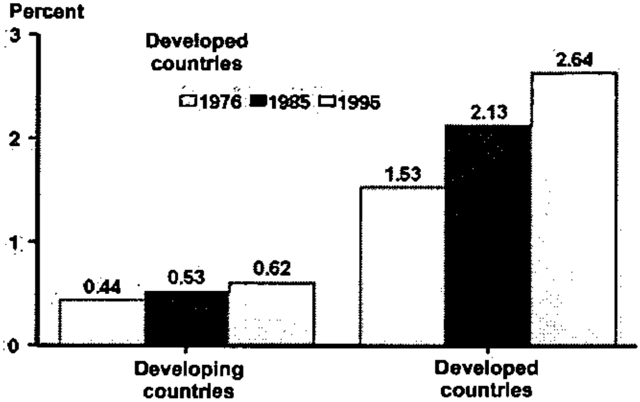

Fig. 13. Public agricultural research in percent of the value of agricultural production (Source: Pardey and Beintema, 2001).

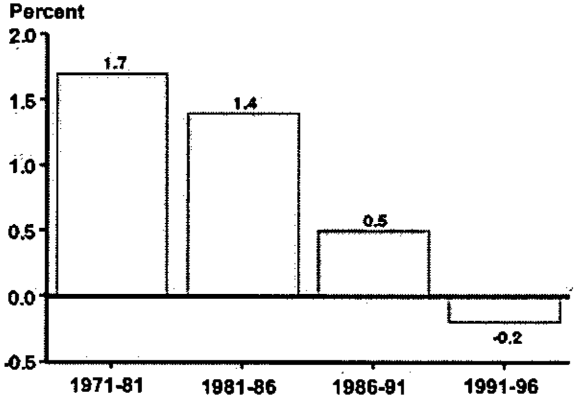

Fig. 14. Annual increase in public agricultural research expenditures in Sub-Saharan Africa, 1976-96 (Source: Pardey and Beintema, 2001).

Yet, in addition to low public investment in agriculture, developing country governments often drastically under-invest in education. Globally, only 46% of school-aged girls are enrolled. Since 1990, aid to education has consistently accounted for 10% of ODA, even as aid levels have fallen (Watkins, 2001; UNICEF, 2000).

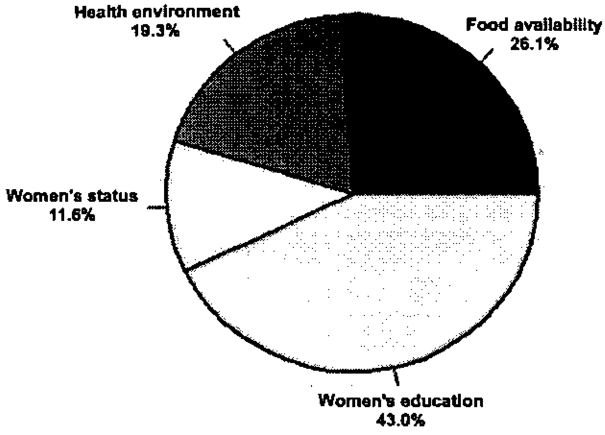

Fig. 15. Estimated contribution of major determinants to reductions in child malnutrition, 1970-95 (Source: Smith and Haddad, 2000).

Fighting micronutrient deficiencies

Food fortification and supplementation are cost-effective approaches to reducing micronutrient malnutrition. Promotion of dietary diversity has great promise for improving iron and vitamin A intakes. Development of iron- and vitamin A-rich staple crops through conventional breeding and biotechnology ("biofortification") may be more sustainable than supplementation or fortification, as it only requires a fixed, one-time investment. All of these strategies should be viewed as complementary, not either-or choices (Bouis, 2000; WHO, 2001).

Making globalization work for poor people

Developing countries must participate effectively in global agricultural trade negotiations, pursuing better access to industrialized countries' markets. Coalitions with some higher income countries may help improve their bargaining position, e.g., the Cairns Group, which brings together developing and developed country non-subsidizing agricultural exporters. The United States, the EU, and Japan cannot expect the developing world to endorse one-sided agricultural trade liberalization *ad infinitum*. Without appropriate domestic economic and agricultural policies, however, developing countries in general and poor people in particular will not fully capture potential benefits from trade liberalization (Diaz-Bonilla *et al.*, 2000; Pinstrup-Andersen *et al.*, 1997, 1999; Diaz-Bonilla and Robinson, 1999).

Meeting health challenges

Governments and international agencies should address health risks as a key part of their food security strategies. When problems interact and coexist, integrated solutions can achieve multiple benefits and be more cost-effective. Food supplements for nutritionally vulnerable pregnant women may be linked to primary health care programs. Multiple micronutrient supplementation can reduce micronutrient malnutrition and low birth weight, and prevent malaria. Drip irrigation, which reduces water waste, also reduces the habitat of malaria-spreading mosquitoes. Food and agriculture programs must integrate efforts to prevent and mitigate the spread of HIV/AIDS (Flores and Gillespie, 2001).

Conclusion

Implementing the policy changes outlined here will be expensive, and will require difficult political choices. But the task is far from impossible. IFPRI forecasts that developing countries will make public investments of $579 billion in irrigation, rural roads, agricultural research, clean water provision, and education during 1997-2020. Increasing this figure to $802 billion would reduce the projected number of malnourished preschoolers from 132 M to 94 M by 2020. If total expenditures by developing-country governments stayed constant at 1997 levels, the investments needed to achieve the more favorable outcome would amount to just 4.9% of government spending. Moreover, on an annual basis, the total additional investment represents just 5% of current annual military spending in low- and middle-income developing countries (Rosegrant *et al.*, 2001; World Bank, 2001b). Progress toward sustainable food security is clearly possible. Achieving it depends upon the willingness of governments, international agencies, nongovernmental organizations, business and industry, and individuals to back their anti-hunger rhetoric with action, resources, and changes in behavior and institutions.

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Trends in agricultural and environmental policies in developed countries

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Trends in agricultural and environmental policies in developed countries

The key message of this paper is that concerns related to the environment and sustainable development are increasingly important for the formulation and implementation of agricultural policies, and have become a major driving force for agricultural policy reform.

The principles of agricultural policy reform

By definition, policies are constantly evolving to respond to changing economic circumstances and to new societal demands. However, in the case of agricultural policies, the persistent reference to "reform" over the last few decades means that a more systemic and profound modification than the usual process of change, was required. This pressure for reform dates back to the end 1970s and early 1980s, when it appeared that the post-war policies geared mainly to increasing production through price support, market intervention and border protection, were no longer relevant. Indeed, rapid technological progress and structural changes, trade barriers and domestic production support led to a build-up of farm surpluses that were stocked or exported with subsidies. Pressure on world prices, "trade wars", substantial budgetary costs, market distorsions were among the most negative consequences of this basic unbalance.

Political pressures for reform developed everywhere, and the first political recognition of this need took place in the context of the 1987 OECD Ministerial Council. Then OECD Ministers agreed on a substantial reform of agricultural policies, based on the principle of reducing support (in particular price support which is the major source of distorsions) and protection at the border. On the other hand, they also recognised the need for direct payments, in particular for environment and rural development. The foundations for reform of agricultural policies were laid down in a manner which reveals a real foresight and which is still valid today in essence. In parallel, the launch and long negotiations of the Uruguay Round "translated" those principles at the international level, leading to the Uruguay Round Agreement on Agriculture (URAA) as part of the 1994 Marrakech Agreement.

At the same time, the environmental concerns became much more visible, as shown by the Report of the World Commission on Sustainable Development (the Bruntland Report) which defined sustainable development as providing for the needs of the present generation without compromising the ability of future generations to meet their own needs. The Rio "Earth Summit" of 1992 led to "Agenda 21", incorporating commitments by all countries to sustainable development policies, some of them being closely related to agriculture.

This brief historical reminder shows clearly that the new approach to agricultural policy and the political commitment to sustainable development were initiated more or less at the same time, progressed in parallel, and became more and more interlinked up to the present situation where environmental issues are one of the key determining factors of agricultural policies.

The implementation of agricultural policy reform at the international level

The Uruguay Round Agreement on Agriculture (URAA) constitutes a major breakthrough as it includes for the first time agriculture within an international trade agreement. It includes commitments on "three pillars": improvement of market access through the reduction of tariffs (following the "tariffication" process which converted all types of border protection measures into tariffs only, like for industry), reduction of export subsidies, and reduction of domestic support. Although the three "pillars" are strongly interrelated, the element which is most relevant for environment is the disciplines on domestic support. Mention should also be made of the relevance for agriculture of other parts of the Marrakech Agreement, such as the Sanitary and Phytosanitary Agreement, the TRIPS and TBT Agreements, and more generally the new dispute settlement procedure within WTO.

The fact that domestic support has been included is a recognition of the strong interrelationship between trade and domestic policies – a major conclusion of the OECD work. The URAA makes a distinction between three types of support: the Amber Box measures which are considered as production and trade distorting (mainly all forms of price support) and therefore subject to reduction commitments; the Blue Box measures which are exempt from reduction commitments because they are linked to supply control (reflecting a political agreement between the US and the EU at the end of the negotiations), and the Green Box measures which are exempt from reduction commitments because they are considered as non-distorting, or minimally-distorting. In the developed countries, the environmental measures constitute the most important part of these Green Box payments. They are also important for the developing countries, but in those countries the range of measures falling under the Green Box is wider.

Generally speaking, the concrete impact of the URAA has been rather limited, even if all countries have legally complied with their commitments. Agricultural tariffs remain much higher (on average 60%, with peaks up to 500% or more) than for industrial goods (in the range of 5% to 10%). Export subsidies are still effective, although they are considered as the most distorting form of measures. For domestic support, most countries had no difficulty to comply with reduction commitments, and their level of support was significantly below the authorised level, with the exception of Japan, Korea, Norway and Switzerland which were close to the limit. This is explained *inter alia* by the fact that the base year for the reduction calculations was 1986, an all-time record for agricultural support, and by the general switch towards Blue Box and Green Box payments. Today, 60% of total domestic support in OECD countries belongs to these two boxes, and is therefore exempted from reduction commitments. Over a ten-year period, the total Green Box payments within OECD doubled. Whether all Green Box measures are really non-, or minimally, production and trade distorting, may be discussed however. When the level of direct payments becomes as high as it is today in some countries, it may be argued that they do have, as a whole, a major impact on investment and production decisions by farmers. The whole issue of "decoupling" needs, therefore, further theoretical and empirical analysis.

The "Doha Development Agenda", agreed upon by the WTO Ministerial meeting in November 2001 has led to a new round of negotiations, including on agriculture as provided for by Article 20 of the URAA. These negotiations are now in full speed in Geneva. At this stage, they reveal, not surprisingly, a very wide range of starting positions. Without entering into all the details of this negotiating process, three facts are relevant in the context of this paper. First, the "non-trade concerns" play a greater role in the negotiations, and they include of course environment and rural development (as well as food security, food quality, etc). Second, the developing countries play a much greater role in the negotiations than during the URAA, although they are in very different positions in relation to agricultural trade. Third, a number of the most difficult issues have a "cross-cutting" character as they are discussed in the context of the agricultural negotiations themselves, as well as in more general, non-sectoral, parts of the negotiations. This is particularly relevant for the "new issues", such as geographical indications, food safety (e.g. the "precautionary principle"), competition policy, and to some extent environment. This being said, the agricultural negotiations themselves take place mainly within the "three pillars" of the URAA – an "architecture" that is not questioned. The Green Box is generally accepted (although some negotiators have a different view on domestic support as a whole), but its content and magnitude may be discussed for the reasons mentioned above (for example, the introduction of a "cap" on all Green Box measures has been mentioned). However, one can expect that the measures which have a strong and uncontroversial environmental character are unlikely to be questioned, provided evidence can be shown that they are nonproduction distorting, and effectively beneficial for the environment (ie. "DOUBLE-GREEN").

An assessment of the implementation of agricultural policy reform

The reform process implemented in all OECD countries led indeed to greater market orientation and lower support and protection since the mid-1980s, but wide differences remain across countries and commodities. Despite the increase in direct payments, price support and other production-linked support remain the major form of support (80% of the total today, compared with 90% ten years ago).

In 2001, for OECD as a whole, total support to agriculture (TSE) amounted to USD 311 billion, i.e. below the two previous years. This corresponds to 1.3% of total OECD GNP, compared with 2.3% in 1986-1988. The differences among countries remain very large, as support to producers as a percentage of the value of production (PSE) ranges from 1% in New Zealand and 4% in Australia, to more than 60% in Japan, Korea, Norway and Switzerland. The PSE level is about 35% in the EU, around 20% in Mexico, Canada and the United States. The variation among commodities is also striking, with a PSE level of 80% for rice, 45% for sugar and milk (the three "rice-pudding" commodities!), 36% for wheat and beef, and below 30% for poultry, pig meat and maize.

The major change over the last fifteen years has been the shift from market price support to direct payments not based on output. The decline in the share of market price support has been particularly strong in the EU (from 95% to 75%), in Iceland (from 100% to 85%) and in Switzerland (from 90% to 68%). On the other hand, there has been no similar trend in Japan or Korea.

The evolution of agricultural policies in individual countries is therefore mixed.

The 2002 OECD Monitoring and Evaluation Report concluded: "although there has been some progress in agricultural policy reform, it has been slow, variable and insufficient". OECD Agricultural Ministers themselves had agreed at their last meeting, in 1998, that "more needs to be done".

The proposal issued by the EU Commission in July 2002 for a further reform of the CAP in the context of the Mid-Term Review requested by the 2000 Agreement would represent a positive step in the direction of a more market-oriented agriculture, while ensuring that the new priority expectations of society would be met. The objectives of this new proposal are in line with previous policy reform decisions, but they give even more priority to environment and rural community, and to the simplification and coherence of policy. The Commission proposes further cuts in price support for major commodities, and outlines various scenarios for the reform of dairy policy. The most innovative aspects of the proposal relate to the introduction of a decoupled system of direct payments per farm, based on historical references and conditional upon cross-compliance to environmental, animal welfare and food quality criteria. This single farm-income payment, which would cover most, but not all products at the beginning, would have the advantages of being fully compatible with the WTO Green Box requirement (no link whatsoever with a specific product), of allowing producers to react directly to the market, and of reducing the transaction costs of policy. The shift-away from production-linked support would be reinforced by the introduction of "compulsory dynamic modulation" of direct payments: all payments would be reduced by 3% per year up to a 20% reduction, but with a significant "franchise" for small producers (5000 EUR gross return for a two full-time work units) which would exclude 75% of farms (but represent only 15% of direct payments). The maximum sum of payments for a farm would be 300,000 EUR. The amount saved by this "modulation system" would be given to Member States for "second pillar" actions to target specific rural needs, including on the environmental aspects. The addition of a new chapter on food quality would further strengthen the second pillar of the CAP. This whole programme would of course respect the overall budgetary ceiling defined by the EU Council for the CAP until 2006.

This proposal will certainly lead to intensive debate among Member countries, but it is an excellent example on the way in which the reform principles agreed upon fifteen years ago can be implemented in a practical manner, achieving a rather good balance among the many objectives, expectations and constraints surrounding agricultural policies. Market orientation and competitiveness, social and income considerations, food quality and safety concerns, and environmental and rural objectives are all well taken into account.

The reform of the Swiss Agricultural Policy also gives a very high priority to environmental considerations, with a very strong increase in direct payments for ecological purposes and a number of specific environmental measures. It deserves a full analysis, which will be done in another context.

On the other hand, the new US agricultural policy (the US Farm Security and Rural Investment Act of 2002) seems to go in another direction. The new Act would allow for an additional spending of USD 82.8 billion over the ten-year period, compared with the expenditure which would have resulted from the continuation of the 1996 Farm Bill. Of this total additional spending, nearly 70% would be devoted to commodity programmes – not a step in the direction of "decoupling". This being said, the new Act also puts more emphasis on conservation, rural development and forestry.

This shows that discussions on agricultural policy reform are likely to remain very tight, both domestically and internationally. The difficult drafting negotiations around the agricultural paragraphs of the Doha Declaration, the new phase of the WTO negotiations, are clear evidence of the difficulties to be expected in the near future. Once again, there will be a very close interdependence between the discussions on domestic reform, in particular within the EU, and the international negotiations.

Agricultural policy reform and the environment

The role played by environment as a driving force for agricultural policy reform is not only reflected in the substance of the policy, as outlined above, but also through institutional changes at the domestic level (merging of Ministries dealing with agriculture, environment, rural development, consumers' affairs, etc – for example recent changes in the Netherlands and the United Kingdom), and through closer connections between international negotiations on trade and on environment.

Generally, agricultural policy reform should lead to better "targeting" of policy measures to achieve desired outcomes, and to greater transparency, in particular in the environment domain. However, the interrelationships between agricultural policy and the environment are complex, and required a careful approach, based on a serious analysis of the scientific and economic parameters rather than on dogmatic preconceived ideas. Among the many facets of this interrelationship, two points should be highlighted.

- First, farmers' property rights should be clearly identified. Farmers should be liable for the cost of environmental damage resulting from "bad farming practices", and on the other be paid for the services provided to the society which cannot be paid for through market mechanisms. In other words, the "polluter pays" principle and the "provider gets" principle are two facets of the internalisation of environmental costs and benefits.
- Second, this problematique is of direct relevance to the concept of the "multifunctionality" of agriculture, which is so important for Europe (and Japan and Korea). In this context, the key questions are: whether there is "jointness" between commodity production and the provision of other services (such as environmental outcomes), whether these services can be paid for by markets (or through creation of new markets) and, when the "public good" character of the service is proven, which type of public policy would be the most efficient. In many cases, the most efficient policy may well be a non-sectoral policy, rather than agricultural policy itself.

Conclusions

First, agricultural policy reform should, globally, have positive effects on the environment thanks to a better targeting of input use, thereby reconciling economic and environmental objectives. The removal of environmentally harmful subsidies – as agreed by OECD Ministers in 2002 and reflected in the Johannesburg Declaration- would be a major factor.

Second, agricultural policies need to be complemented with environmental and rural policies to account for those externalities and public goods that are not covered by markets.

Third, the level of policy action has to be different, depending on the spatial dimension of the environmental issue. In some cases, it is local and site-specific (landscape), and requires therefore action at the local level. Some issues are both local and global, such as biodiversity, and require action at all levels. Others are definitely global in nature, such as climate change.

Fourth, the complexity of the relationship between agriculture and the environment requires more information, quantitative and qualitative. Hence the priority to be given to the further development of agri-environmental indicators, such as those developed by OECD and the EU. This requires a strong multidisciplinary approach.

Fifth, Government policies should not be seen as the only way to improve the environmental impact of agriculture. In the contrary, the role of markets, and the creation of markets for the new types of goods and services, should be given more prominence as innovative ways to improve environmental performance.

Sixth, the international dimension of the agriculture-environment interface has been well recognised in the Johannesburg Summit. Within the broad context of sustainable development, a high priority has been attached to the management of natural resources, in particular for agriculture and fisheries. Improving the "coherence" of policies, in particular in the OECD countries, should be the key objective. The best way to express this urgent need for policy coherence and for substantial policy reforms is to recall a fact – i.e., the fact that OECD support to domestic production – in particular agriculture, fisheries and energy- amounts to 6 or 7 times the amount of official development assistance (ODA) from OECD countries to developing countries.

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Issues of sustainable agriculture in developing countries

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The major driving forces shaping future transformation of food and agricultural production will be appreciably different from those prevailing for much of the 20th century[1] . Population growth and technological change aimed at raising yields were the main driving forces for much of the last half century (FAO, 2000a). This will continue to be the case in some developing country regions. The main driving forces in the future will be increasingly income growth, shifts in consumption patterns and technological change shaped by environmental objectives and social concerns about the safety of agriculture rather than by yield maximisation. Moreover, the driving forces will operate increasingly through the market e.g. pricing of fertilizers and pesticides to reflect their full environmental costs, and consumer resistance to genetically modified crops, respectively, and not only via regulatory measures as was the case in the past.

One does not have to look back over the whole of the last century to detect major departures from the long-term trend. During the past decade or so major shifts in technologies and social pressures have brought about changes in how agriculture is performed. In particular, how the soil and plant nutrients are managed, e.g. the rapid adoption of no-till and the emergence of organic agriculture, respectively, discussed later. Other breaks from the trend are possible, and the cone of possibilities gets wider and wider the further one projects out into the future, with marked regional differences. The focus of this paper is therefore the next 30 years rather than the whole 21st Century, and in doing so it concentrates more on developing rather than developed countries and on crop rather than livestock production. Particular attention is given to how improvements in fertilizer use efficiency (FUE) and water use efficiency (WUE) will play a major role in the transformation of agriculture, and to the inter-dependence of larger yields and better natural resource management.

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[1] This paper draws heavily on the analysis completed for FAO's latest long-term projections (FAO, 2000), a multidisciplinary exercise involving most of the technical units and disciplines present in FAO. As such it reflects FAO's 'collective wisdom' regarding probable future developments as far as can be judged given present-day knowledge. The underlying analysis covers more than a hundred individual countries and forty individual crop and livestock commodities. It attempts to sketch out the likely evolution of key variables rather than a normative view of the future. The projections are not trend extrapolations in that they incorporate some probable deviations from past trends. The base year is the three-year average 1995/97 and projections are made for the years 2015 and 2030.

With these restrictions in mind, the main features of agricultural transformation over next 30 years are considered to be:

- A slow down in the expansion of arable land in developing countries.
- 80% of incremental crop production coming from larger yields and cropping intensity.
- Improved FUE.
- Continued growth in the area of land that is irrigated.
- Improved WUE because of higher water charges and better technologies.
- Continued expansion of no-till and other forms of conservation tillage.
- Greater adoption of organic agriculture.
- Fast growth of the livestock sector.
- Adoption of climate change mitigation measures.

This paper is devoted to an assessment of these features following a discussion of the major driving forces for the agricultural transformation, and a brief overview of projected crop production.

Major driving forces for agricultural transformation

The 1990s marked an important transition from the agricultural development pathways of the 20th Century to those of the 21st Century, with notable shifts in the driving forces for land use and land cover change and plant nutrient management. Dominant amongst the changes in driving forces for plant nutrient management were factors causing direct or indirect improvements in FUE, WUE and integrated pest management (IPM).

In the developed countries the driving forces for higher FUE were both regulatory and economic with the EU being the most stringent in physical restrictions on fertilizer application rates and the most advanced in the use of pollution taxes. In the developing countries, however, the driving forces were largely economic as the removal of fertilizer and pesticide subsidies encouraged farmers to us them more efficiently.

In the developed countries there was a contraction of the agricultural cropland in use as physically and economically marginal land was taken out of production because of falling commodity prices, agri-environment policies and international trade concerns (Baldock *et al.*, 1996). Similarly, mineral fertilizer and pesticide use is stagnant as a result of low commodity prices, implementation of agri-environment policies and an emerging shift in (affluent) consumer preference in favor of organic foods (FAO, 2000b).

A comparable pattern was starting to emerge in some of the developing countries but for different reasons. Cropland expansion was slowing down generally because of lower population growth rates, and also from the lack of suitable land left to develop, particularly in South Asia and China. Fertilizer use growth is declining because of economic and technical reasons rather than agri-environmental concerns.

That is, falling commodity prices and consequent lower marginal returns to fertilizer use.

General pattern of global and regional crop production

Global aggregate crop production is projected to slow down from 2.2% annually in the 30 year period ending in 1997 to 1.3% annually in the 1995-2030 period (Table 1). For the developing countries as a group, the corresponding growth rates are 3.1 and 1.6% respectively. The reasons for this continuing deceleration in the global crop production growth are:

- Slowdown in population growth;
- The growing share of the population at income levels at which demand saturates;
- In many countries, and particularly in Sub-Saharan Africa, economic growth will be insufficient to overcome poverty so a significant proportion of the population will continue to be unable to buy all of their food needs.

Sub-Saharan Africa is the only region where growth rates are projected to increase slightly, though this is highly dependent on the assumptions that there is faster per capita income growth and resolution of their current crop nutrient supply problem (FAO, 1999; FAO, 2000a; Nabhan, 1999).

Table 1. Annual crop production growth (percentage per annum).

	1967-97	1995/97-2030
Sub-Saharan Africa	2.1	2.4
Latin America and Caribbean	2.6	1.7
Near East / North Africa	3.0	1.6
South Asia	2.8	1.9
East Asia	3.6	1.2
All developing countries	3.1	1.6
same excl. China	2.8	1.8
same excl. China and India	2.8	1.8
Industrialized countries	1.4	0.8
Eastern Europe and the FSU	-0.1	0.8
World	2.2	1.3

At the individual crop level, however, above average growth rates are projected. An increasing share of the increment in cereal production will be for livestock. Hence maize production in the developing countries is projected to grow at 2.0% annually against 'only' 1.1% for wheat and rice combined. This feature will be particularly strong in China where maize production is expected to nearly double, whilst wheat and rice production are expected to grow only marginally. Similarly, growth rates for oil crops and green vegetables are projected to grow at above average rates because demand for them is strongly influenced by the increasing demand for meat, milk and other high income products (FAO, 2000a).

Agricultural transformation over the next 30 years

Slow down in the expansion of arable land

The developing countries have some 2.8 billion ha of land with a potential for rainfed agriculture at yields above a 'minimum acceptable level'. Of this land, some 960 Mha are already under cultivation. Most of the remaining 1.8 billion ha however cannot be considered as land 'reserve' since the bulk of it is very unevenly distributed. Most of the land 'reserve' is concentrated in a few countries in South America and Sub-Saharan Africa with little need for it. Many countries in South Asia and the Near East / North Africa, in contrast, have virtually no suitable land left to cultivate, and much of the land not in use is unsuitable or unavailable for agriculture. Reasons for the latter include physical or chemical constraints, or other uses for forest, wildlife conservation, or human settlement.

The global arable area expanded by 158 Mha (or 11%) between 1961/63 and 1995/97. Regional aggregation, however, hides two opposite trends, namely an increase of 173 Mha in the developing countries and a decline of 14 Mha in the developed countries. The latter decline has been accelerating over time (-0.25% in the industrialized countries and -0.51% in Eastern Europe and the FSU over the last ten years, 1987-1997) as international trade pressures, agricultural reforms and efficiency gains stimulated the abandonment or redeployment of marginal lands (e.g. through set-aside schemes). The driving forces for this decline are expected to continue.

The emergence however of a trend towards a de-intensification of agriculture in these countries (due to increasing demand for organic products and for environmentally-benign cultivation practices), and a possible (minor) shift of agriculture to temperate zones towards the end of the projection period (due to climate change), would militate against this decline in arable area, so that the net effect of these countervailing forces could be a roughly constant (or only marginally declining) arable area in the group of developed countries. Arable area expansion at the world level therefore would more or less equal that of developing countries.

Arable land expansion will be restricted to the developing countries and by 2030 will have slowed down to about half the rates of the past 30 years (Table 2). The net increase between 1995/97 and 2030 is projected to be 120 Mha. Regionally, as in the recent past land expansion will be restricted largely to Latin America and Sub-Saharan Africa, but with potentially serious situations elsewhere, especially as a result of the cultivation of steep slope lands.

Although the arable area in developing countries may expand by 120 Mha over the projection period, the harvested area could expand by 176 Mha (or 20%) due to increases in cropping intensities (see next section). The increase of harvested land over the historical period (1961/63 to 1995/97) was 211 Mha (or 36%). Sub-Saharan Africa may account for one-third (59 Mha) of the increase in harvested land, an increase of 1.0% annually over the projection period, the largest rate of increase in all regions.

Table 2. Total potential arable land and area in use.

	Annual growth % p.a.		Land in use, % of potential million ha	
	1961-97	1995/97-2030	1995/97	2030
	(1)	(2)	(3)	(4)
Sub-Saharan Africa	0.86	0.65	21	26
Latin America	1.26	0.55	18	22
Near East/ North Africa	0.42	0.22	76	82
South Asia	0.18	0.13	84	88
idem excl. India	0.37	0.15	90	95
East Asia	0.91	0.07	57	58
idem excl. China	0.89	0.41	47	53
All above	0.71	0.34	32	36
idem excl. China	0.67	0.43	30	34
idem excl. China / India	0.85	0.50	25	30
Industrialized countries	0.08		45	
Eastern Europe / FSU	-0.16		52	
World		0.35		35

Source for columns (1) - (2): FAOSTAT, November 1999. Columns (3) - (4) for developing countries include also arid and hyper-arid land with irrigation potential.

Sources of growth of future crop production

The rate of cropland expansion in the developing countries is projected to be less than half of the projected growth in crop output. It follows that the key to the transformation of agriculture will be land use intensification and the better management of off- and on-farm sources of plant nutrients.

Although crop production in developing countries is projected to increase by 70% between 1995/97 and 2030, this represents a considerable slow down in the growth of crop production as compared with the past 30 years (Table 2). About 80% of the increase come from higher yields (with a contribution to growth of about 70%) and of higher cropping intensities (multiple cropping and reduced fallow periods) and only 20% from arable land expansion.

Table 3. Sources of growth in crop production (%)[2].

	Arable land expansion		Increases in cropping intensity		Harvested land(*) expansion		Yield increases	
	1961 -1997	1995/97 -2030	1961 -1997	1995/97 -2030	1961- 1997	1995/97 -2030	1961 -1997	1995/97 -2030
Sub-Saharan Africa	41	25	24	13	65	38	35	62
Latin America and Caribbean	47	30	1	22	48	52	52	48
Near East / North Africa	14	13	15	20	29	33	71	67
South Asia	7	5	14	12	21	17	79	83
East Asia	26	5	-6	12	20	16	80	83
All developing countries	24	20	5	11	29	31	71	69
same excl. China	24	23	12	13	36	35	64	65
same excl. China and India	31	27	14	15	45	43	55	57
World	15		8		23		77	
All developing countries								
crop production - rainfed		21		11		32		68
crop production - irrigated		27		15		42		58

(*) Harvested land = arable land × cropping intensity

[2] The results shown in Table 3 should be taken as rough indications only. Historical data for arable land for many countries are unreliable and data on cropping intensities almost non-existent. The projections are the aggregate end-result of a detailed investigation of present and future land / yield combinations for 34 crops under rainfed and irrigated cultivation conditions for 93 developing countries.

The overall contributions of the three sources of growth in crop production (arable land expansion, yield growth and increases in cropping intensities, i.e. increasing multiple cropping and shorter fallow periods) are given in Table 3. There has been widespread discussion about yield growth potential, yield gaps, and the masking of productivity loss from soil degradation by gains from fertilizers and improved cultivars (Pingali and Rosegrant, 1998). FAO concludes that in the main the potential exists to meet the projected yields provided the farmer incentives are there. About 80% of the projected growth in crop production in developing countries would come on account of intensification in the form of yield increases (69%) and higher cropping intensities (12%). This share would go up to 90% and higher in the land-scarce regions Near East / North Africa and South Asia. The results for East Asia are heavily influenced by China: excluding this country, intensification would account for just over 70% of crop production growth in East Asia. Arable land expansion would remain an important factor in crop production growth in many countries of Sub-Saharan Africa, Latin America and some countries in East Asia, although much less so than in the past[3].

The contribution of intensification to cereal production will be above the average for all crops (Table 4). About 80% of growth in wheat and rice production will have to come from increases in yield. While for maize the expansion of harvested land will continue to be major contributor to its production growth, and possibly even more so than in the past. These differences can be explained in part by differences in land availability. The bulk of wheat and rice is produced in the land-scarce regions of Asia and the Near East / North Africa, while maize is the major cereal crop in Sub-Saharan Africa and Latin America where many countries still have ample room for area expansion (see below).

Table 4. Sources of growth for major cereals in developing countries (%).

	Harvested land expansion		Yield increases	
	1961 - 1997	1995/97 - 2030	1961 - 1997	1995/97 - 2030
Wheat	30	22	70	78
Rice	29	19	71	81
Maize	38	49	62	51

Though yield growth will remain the mainstay of crop production growth, annual growth in yields of most crops over the projection period will be much lower than in the past. For example, cereal yield growth in developing countries is projected at 1.0% annually, as compared with the 2.5% recorded for 1961-97, and 1.9% for

[3] The results shown in Table 3 should be taken as rough indications only. Historical data for arable land for many countries are unreliable and data on cropping intensities almost non-existent. The projections are the aggregate end-result of a detailed investigation of present and future land / yield combinations for 34 crops under rainfed and irrigated cultivation conditions for 93 developing countries.

1987-97. This deceleration is mainly a consequence of the deceleration in the growth of demand for agricultural products. Inter-country and to a lesser extent inter-regional differences in yields are wide and are projected to remain so (FAO, 2000a; FAO, 2000b). They reflect in part differences in agro-ecological conditions and in part differences in agricultural management practices.
Underlying this yield growth will be four input factors: fertilizer, which will be considered in this section and improved cultivars, irrigation and better natural resource management, that will be dealt with later.

Improved fertilizer use efficiency

Fertilizer use (nutrients $N+P_2O_5+K_2O$) in the developing countries is projected to increase by 1.0% annually from 79 Mt in 1995/97 to 112 Mt in 2030, and globally from 134 to 182 Mt over the same period (Table 5). This is a substantial slowdown compared with the 3.5% annually for 1987-97), and much less than the projections of others (Smith, 2000). FAO's projection reflects improved nutrient uptake efficiency that tends to be associated with larger yields and is contingent on the assumption that governments will act to raise fertilizer use efficiency by:

- measures to improve the management of other sources of plant nutrients, including organic recycling, irrigation and no-till;
- greater incentives to farmers to use mineral fertilizers efficiently through precision farming, nutrient budgeting, cover crop management, etc;
- greater incentives to fertilizer companies to produce better formulations;
- the introduction of fiscal measures to reduce environmental externalities;
- the strict implementation of environmental protection regulations;

The slowdown also reflects the expected continuing reduction in agricultural production growth because of lower population and food demand saturation. Fertilizer use per hectare is projected to grow from 90 kg in 1995/97 to 107 kg in 2030 (the level of use as at present in the developed countries). East Asia would reach a fertilizer use of 180 kg/ha, but per hectare levels in Sub-Saharan Africa would remain very low, not enough to eliminate nutrient mining in many areas.
Higher fertilizer use will continue to have both positive and negative impacts on the environment. Organic and mineral fertilizers will help to replace the nutrients removed by crops, and build up soil organic matter (SOM). Groundwater nitrate contamination, however, will continue to be an issue in some developed countries and may increasingly become a problem in developing countries. Increasing fertilizer use may also cause some eutrophication of lakes, reservoirs and ponds in specific locations and lead to soil acidification.
Conversely, although fertilizer use in Sub-Saharan Africa is projected to rise slightly (Table 5), it can be questioned whether this can occur quickly enough to prevent further lasting damage from nutrient mining and soil compaction. The former problem was first highlighted by analyses conducted for FAO in the late

1980s. The latter has come to light more recently, and is not the compaction related to the use of heavy machinery that is common in some developed countries, but arises in low input systems with the decline in soil organic matter content and the consequent damage to soil structure.

Table 5. Fertilizer consumption: historical and projected.

	1961/63	1995/97	2030	1961-1997	1987-1997	1995/97-2030
Total	nutrients, Mt				% p.a.	
Sub-Saharan Africa	0.2	1.1	2.2	6.0	0.6	1.9
Latin America	1.1	9.4	15.9	6.3	2.1	1.6
Near East / North Africa	0.5	5.7	8.3	7.6	0.0	1.1
South Asia	0.6	18.1	27.2	10.0	4.3	1.2
South Asia excl. India	0.2	4.0	6.1	9.7	4.2	1.3
East Asia	1.7	44.4	58.8	9.7	4.2	0.8
East-Asia excl. China	0.9	8.9	12.4	7.2	3.4	1.0
All above	4.1	78.7	112.4	8.8	3.5	1.1
All above excl. China	3.3	43.3	66.0	7.9	2.9	1.2
All above excl. China and India	2.9	29.1	44.9	7.1	2.2	1.3
Industrialized countries	24.6	45.9	58.3	1.5	-0.5	0.7
Eastern Europe and the FSU	5.3	8.4	10.8	1.8	-17.3	0.8
World	34.3	133.9	181.6	3.9	-0.9	0.9
Per hectare	kg / ha				% p.a.	
Sub-Saharan Africa	2	8	11	4.6	-2.4	0.9
Latin America	15	73	92	5.0	2.0	0.7
Near East / North Africa	11	80	97	6.7	-0.4	0.5
South Asia	3	79	104	9.4	3.6	0.8
South Asia excl. India	6	99	127	8.6	3.6	0.7
East Asia	9	147	180	8.9	3.1	0.6
East-Asia excl. China	15	93	106	5.8	2.1	0.4
All above	7	90	107	7.9	2.4	0.5
All above excl. China	7	65	78	6.8	1.7	0.6
All above excl. China and India	10	60	71	5.8	0.9	0.5
Industrialized countries	125	206	253	1.1	-0.9	0.6
Eastern Europe and the FSU	27	54	61	2.4	-15.9	0.4
World	35	107	124	3.3	-1.5	0.5

Note: kg/ha for 1995/97 is calculated on basis of 'adjusted' harvested land data.

Wider adoption of organic agriculture

The shift into organic agriculture is strongest in Europe, although there is an organic farming movement in the USA. The land area involved in the EU increased from about 900,000 ha in the early 1990s to around 10 Mha by the end of the decade. Nonetheless domestic production of organic products has been unable to keep up with demand in the UK and a few other countries, and has encouraged the switch to organic farming in a number of developing countries exporting high-value fruit and vegetables to the EU. Organic products now represent about 10% of the food market. The percentage has commonly doubled in the past five years and will continue to grow rapidly driven by changing consumer demand.

If the same trend takes place in other developed regions and subsequently in developing countries, then it will have a major impact on mineral fertilizer demand and FUE. Assuming, for example, that the cropland in the EU switching to organic farming had been receiving average mineral fertilizer rates, then the reduction in fertilizer use is around 200 kg/ha. It follows, therefore, that if the market for organic foods continues to grow at 5-10% per year then there will be a significant reduction in the long-term use of mineral fertilizer. Lower environmental impacts from nitrous oxide emissions and ground and surface water nitrate pollution will only occur, however, when the manure replacing mineral fertilizer is managed well. The impact would be less in North America and Oceania where fertilizer application rates are lower, but the reduction could still be substantial.

Moreover, if the switch to organic farming is associated with greater and better recycling of crop and animal wastes then SOM levels will rise with consequent improvements in FUE and WUE as discussed above (Shaxton, 1998). Ammonia nutrient losses to the environment that originate from livestock production, however, exceed the losses that originate from fertilizer application by at least a factor 2 while nitrogen oxide emissions are approximately equal (FAO, 1997). Intensive livestock units are a major source of environmental damage (Hendy *at al.*, 1995, de Haan *et al.*, 1998).

Expansion of irrigated land

Irrigated agriculture in developing countries currently provides about 40% of all crop production and almost 60% of cereal production (Table 6) yet accounts for only around 20% of the arable area (FAO, 2000a). The importance of irrigation goes beyond these gross contributions. First, the output is more stable and hence the contribution to food security is greater. Second, since the risk of crop failure is lower farmers are more confident about getting an economic return to the use of mineral fertilizers. Third, the larger and more stable soil moisture content can raise FUE.

Irrigation is expected to play an increasingly important role in agriculture in the developing countries, with its the current circa 40% contribution to total crop production rising to 47% by 2030 (Table 6).

Table 6. The share (%) of irrigated production in total (developing countries only).

	All crops			Cereals	
	Arable land	Harvested land	Production	Harvested land	Production
1995/97	20	29	41	38	58
2030	22	32	47	43	63
increment 1995/97-2030	38	49	56	71	72

Source: FAO, 2000a.

The irrigated area in developing countries is projected to expand by 23% (or 45 Mha, from 197 Mha in 1995/97 to 242 Mha in 2030), and by 34% in terms of harvested area (Table 7). With current policies and technologies, this expansion in irrigated agriculture would require a 12% increase in water withdrawals for agriculture at a time when there is intense competition for water from other sectors. This expansion, therefore, is dependent on large improvements in irrigation WUE (from 43 to 50% on average).
Some analysts have questioned whether irrigation can continue to expand and provide the above benefits. According to the International Water Management Institute (IWMI) about 2 billion people in 45 countries will be facing physical water scarcity by 2025, because they lack sufficient water resources (IWMI, 2000). FAO projections, however, show that with modest and technologically feasible gains in WUE by irrigated agriculture, the expansion of irrigation should in general not be a constraint to food production nor to meeting the water needs of other sectors.

Improved water use efficiency

Agriculture accounts for 60 to 90% of total water withdrawals in low and middle-income developing countries, and WUE is very low in the range of 25 to 50% (Molden, 1997). It is also poor in the domestic and industrial sectors where the absence of effective pollution controls limits the potential for water re-use by agriculture. Thus there is major potential for meeting agricultural and overall water needs by raising WUE.
There are four trends favouring an increase in WUE that suggest that both the projected increase in irrigated area to 2030 and the re-allocation of water from agriculture to other sectors are physically achievable. First, countries are increasingly adopting full water pricing for consumers. Second, user groups are playing a greater role in the operation and management of irrigation systems. Third, flood and furrow irrigation systems are being replaced by more efficient controlled application techniques. In the USA, for example, greater WUE in irrigation between 1980 and 1995 resulted in a 11% drop in water use.

Table 7. Irrigated (arable) land: data and projections.

	Irrigated land in use					Annual growth		Land in use as % of potential		Balance	
	1961/63	1979/81	1995/97	2015	2030	1961 to 1997	1995/97 to 2030	1995/97	2030	1995/97	2030
	(million ha)					% p.a.		%		million ha	
	(1)	(2)	(3)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sub-Saharan Africa	3	4	5	6	7	2.1	0.8	14	19	32	30
Latin America	8	14	18	20	22	2.4	0.6	26	32	50	46
Near East / North Africa	15	18	27	30	33	1.9	0.7	60	77	17	10
South Asia	37	56	78	85	95	2.2	0.6	55	67	64	47
idem excl. India	12	17	23	24	25	1.9	0.2	82	89	5	3
East Asia	40	59	69	78	85	1.5	0.6	62	76	43	27
idem excl. China	10	14	18	22	25	2.0	0.8	40	52	29	23
All above	103	150	197	220	242	1.9	0.6	49	60	206	160
idem excl. China	72	105	146	164	182	2.1	0.7	43	54	192	156
idem excl. China / India	47	67	91	103	112	2.0	0.6	40	50	134	113

Fourth, increasing labour costs seem likely to force a shift from transplanted to dry seeded rice leading to large reductions in water use.
FAO therefore considers it feasible to raise irrigation efficiency from 43% in 1996 to 50% on 2030 in 93 developing countries (Table 8). This will help to contain the increase in agricultural withdrawals at a relatively low level (about 12% for the period of the study) and save around 330 km^3 per year of water. Conversely, however, if there is not increased investment in greater WUE and drainage, there could be growing problems from the lowering of water tables, salinization and waterlogging. Over extraction of groundwater could lead to several Mha of irrigated land going out of production.

Table 8. Annual renewable water resources and irrigation water requirements.

Region	Renewable water resources (RNR) km^3	Irrigation efficiency 1995/97 %	Irrigation withdrawals in 1995/97 as % of RNR	Irrigation efficiency 2030 %	Irrigation withdrawals in 2030 as % of RNR
Sub-Saharan Africa	3406	42	2	44	3
Latin America	12793	26	1	29	2
Near East /North Africa	392	50	58	65	67
South Asia	2007	49	37	58	41
East Asia	8483	38	7	42	8
All developing countries	26635	43	7	50	8

Growth in livestock production

Livestock production now accounts for 40% of the global gross value of agricultural production (and for more than 50% in developed countries), and is projected to grow at almost double the rate of crop production, that is, 2.5 to 3.0% annually. In the medium-term, increases in the number of animals will remain the main source of growth in meat production. Progressively, however, higher carcass weight will become more important as a source of growth in beef, mutton and poultry production, and likewise for higher off-take rates (shorter production cycles) in pig and poultry production. An increasing share of livestock production in developing countries will move away from multipurpose systems to specialised commercial intensive production systems. This will also lead to a change in the composition of animal feeding stuffs with the share of concentrates increasing. Naturally, there are wide inter-regional differences in these developments depending on the availability of land, feeding stuffs, labour and capital.

These trends are important to plant nutrient management (PNM) and FUE in three main ways. First, growth in livestock numbers has a large knock-on effect on feed grain and oilseed production. Problems here include (a) coarse grains production is generally more prone to lead to soil erosion induced loss of nutrients, and (b) coarse grains production is commonly associated with soil nutrient mining in both developed and developing countries. Large areas of land growing wheat and maize in Australia, Canada and the USA are nitrogen (N) and phosphate (P) deficient (OECD, 1999). Secondly, with the growth in organic agriculture, farmyard manure (FYM) becomes an important source of plant nutrients. Thirdly, livestock densities in parts of both the developed and developing countries now exceed the levels at which excreta can be applied safely to the soil and vegetation resulting in serious environmental damage. An increasing number of developed countries led by the Netherlands are placing major restrictions on livestock densities and on the rate and timing of manure applications to crops and pastures (de Leeuw, 1998; MAFF, 1998).

Uncertainties of the 21st Century and the Agricultural Transformation

Two uncertainties have a major bearing on FUE and WUE, namely climate change and public concerns about GM crops and other modern technologies.

Climate change

Some 15 years of research on climate change has seen an end to some of the unrealistic and unfounded suggestions made in the late 1980s for mitigating climate change e.g. reducing paddy rice production because of its contribution to greenhouse gas emissions (GHGs). The research has clarified the positive impact that increased atmospheric carbon dioxide can have on photosynthesis and water use efficiency by certain crops and consequently on FUE. It has not, unfortunately, reduced much of the uncertainty regarding the timing, location and magnitude of the impact of climate change on agriculture (Hadley Centre, 1999).

Consequently the impact of climate change on agriculture remains uncertain, but in all likelihood it will be minor before 2030. The associated rise in GHGs, however, although detrimental in the long-term, could already be having positive impacts on crop production which may be maintained through to 2030 as a result of increased photosynthesis (the CO_2 fertilization effect), and improved WUE. These impacts plus small changes in precipitation, could on the whole be beneficial in temperate zones (more suitable land and larger yields), while some tropical regions, and notably Sub-Saharan Africa, could suffer some losses.

There are two possible exceptions to the conclusion that the climate change impacts will be small up to 2030, namely greater frequency of extreme events (although this change in frequency is still not widely accepted) and sea level rise. More frequent extreme events in Sub-Saharan Africa, for example, could involve more intense rainfall, and hence greater loss of soil nutrients through water erosion, and conversely, more droughts and lower soil moisture levels, both leading to a lower FUE and plant nutrient availability. Likewise a rise in sea levels (15-20 cm by 2030) would damage all coastal areas (mangrove destruction, salt water infiltration, etc.), and could adversely effect FUE.

What is more certain, however, is the positive role that improved plant nutrient management can make, for example by; (a) reducing the impact of agriculture on climate change through lower GHG emissions, and (b) mitigating climate change in a range of ways including:

- raising the productivity of existing crop and pasture land thereby reducing the need for further deforestation and drainage of wetlands;
- lowering nitrous oxide emissions from mineral fertilizers and livestock wastes through better fertilizer, water and waste management;
- increasing carbon sequestration through no-till and organic farming techniques;
- improving the physical and chemical structure of soils by re-building of soil organic matter levels, thereby increasing soil aeration, rainfall infiltration and soil moisture retention.

Intensification and the associated productivity gains

These will lower GHG emissions by reducing the need to convert forests and wetlands to agriculture (Table 9). Land savings from R&D related intensification since 1960 are estimated to have been in the range 170-620 Mha (CGIAR, 1999). These include for example savings from improved forage/livestock are equated with about a 50 Mha reduction in the area of permanent pasture required. More conservative assumptions place the total gains at 100-250 Mha, but these may underestimate the benefits from intensification arising from improved access to production inputs and product markets which are partly, if not largely independent of R&D.

Table 9. Reducing pressures for deforestation through improved crop and pasture management.

1 ha managed under these sustainable options	Can save this number of hectares from deforestation each year
Flooded rice	11.0
Low-input cropping	4.6
High-input cropping	8.8
Legume-based pasture	10.5

Source: Brady, 1996 from Bandy *et al.*, 1993.

Lowering nitrous oxide (N_2O) emissions

Agriculture is the dominant anthropogenic source of this GHG with mineral fertilizer use (20%) and animal wastes (13%) being the main causative factors (Mosier and Kroeze, 1998). N_2O formation is sensitive to climate, soil type, tillage practices, type and placement of fertilizer.

FAO projects slower growth of N fertilizer use compared with the past (Table 5). Depending on progress to raise FUE, the incremental increase up to 2030 in total fertilizer use could be as low as 36%, involving similar or even smaller increases in the direct N_2O emissions from fertilizer and the indirect emissions from N leaching and runoff. However, current N fertilizer use in many developing countries is very inefficient. In China, for example, which is the world's largest consumer of N fertilizer, it is not uncommon for half to be lost by volatilisation. Better on-farm fertilizer management, wider regulatory measures and economic incentives for balanced fertilizer use and reduced GHG emissions, together with technologieal improvements such as more cost-effective slow-release formulations should reduce these losses in the future.

Increased carbon sequestration

Total global non-harvested residues (primarily crop stalks and roots) for 15 of the most important crops have been estimated to been some 4.7 billion t in 1995/97 and are projected to rise to 7.4 billion t by 2030 (FAO, 2000a). Depending on the region, these residues amount to between 2.4 and 6.2 t/harvested ha. These values are higher than those used for other global estimations (Lal and Bruce, 1999), but similar to those found in sub-national studies in Australia, Canada and the USA ((Dalal and Mayer, 1986; Douglas *et al.*, 1980; Voroney *et al.*, 1981). Under tropical conditions, residues can be mueh higher with cowpeas giving up to 24 t/ha (Diels *et al.*, 1999). It has been assumed that for most crops 25-50% of residues are returned to the soil as organic matter, and that half of this biomass is carbon, then carbon sequestration by the 15 most widely grown crops could rise from 584-1168 Mt/year to 910-1820 Mt/year by 2030 (Table 10).

Table 10. Estimated carbon sequestered per year by cropland soils.

	Total carbon (Mt)		Carbon (t/ha)	
	1995/97	2030	1995/97	2030
Sub-Saharan Africa	32 - 63	70 - 140	0.30 - 0.60	0.47 - 0.94
Latin America & Caribbean	59 - 118	106 - 212	0.62 - 1.23	0.80 - 1.59
Near East / North Africa	26 - 52	44 - 88	0.49 - 0.97	0.70 - 1.41
South Asia	93 - 186	169 - 338	0.51 - 1.03	0.87 - 1.73
East Asia	176 - 352	265 - 529	0.82 - 1.65	1.18 - 2.36
Industrial countries	155 - 310	203 - 405	0.83 - 1.66	1.05 - 2.11
Transition countries	50 - 100	70 - 141	0.41 – 0.82	0.49 – 0.98
World	590-1181	927-1853	0.61 - 1.23	0.84 - 1.69

If one scales this up to include the harvested area for the remaining crops the global estimate for 2030 rises to 1167-2334 Mt carbon, which is substantially higher than other recent estimates (GCSI, 1999; Lal and Bruce, 1999; Batjes, 1999).

These estimates do not specifically take account of the potential gains from conservation tillage nor from improved soil erosion control. However, the switch to conservation tillage systems, which started in the late 1960s in developed countries and in various developing countries in the 1970s, could add to the amount of carbon sequestered (Friedrich, 1996; Derpsch, 1998). The area under conservation tillage grew very rapidly between 1983/84 and 1996/97 (Table 11) and with no-till increasing more than eight fold between 1986-96 (Hebblethwaite and Towery, 1997). There are large areas of South and East Asia where conservation tillage could be applied but as yet is hardly used. On the Loess Plateau of China, for example, its use is barely out of the experimental stage; yet it could help to sequester some 4 Mt C/year (CCICED, 1999).

Table 11. Area under conservation tillage systems (1000 ha).

Country	1973/74	1983/84	1996/97
USA	2200	4800	19400
Canada			6700
UK	200	275	
France	50	50	
Australia	100	400	1000
New Zealand	75	75	
Argentina			4400
Brazil	1	400	12000
Mexico			490
Paraguay			500

Source: Derpsch (1998); Lal and Bruce (1999).

If it is assumed that another 150 million ha (25%) of the rainfed cropland will be using conservation tillage by 2030, a modest assumption compared with the GCSI (1999) assumption of 217 Mha by 2020. And if this land sequesters 200 kg carbon/ha/year (Lal *et al.*, 1999) this would represent a further 30 Mt carbon/year, as well as other environmental benefits in the form of reduced soil erosion and better water retention, plus savings in fossil fuel use of 55-78% (Frye, 1984).

Public concerns about GM crops and other modern technologies

During the latter half of the 20th century, the impact of modern technologies on the environment and food quality moved from being the concern of a small minority in developed countries to a widespread public issue having a major impact on legislation, production technologies and food demand in developing and developed countries. The latter was most apparent in the rapid growth in demand for organic foods discussed earlier, albeit largely in OECD countries, but also in developing countries like China and Malaysia (CCICED, 1995; COAG, 1999). This growth in demand was driven, in part, by environmental concerns, but also by the public view that organic food is healthier than that produced from conventional high-input agriculture, though the scientific evidence for the latter view is not strong (Food Standards Agency, 2000).

These environmental and health considerations now form the background to the public opposition to the use of genetically modified organisms, and particularly GM crops. There are pronounced national and regional differences in the strength of this opposition. It is relatively limited in the USA, for example, but up to 75% of those questioned in some German surveys wished to avoid GM foods. It is difficult to determine how these attitudes will change in the future, and whether the same pattern will be repeated in most developing countries. There is also uncertainty and only limited public awareness regarding the environmental trade-offs involved in the use of (Tiwari, 1999). On the one hand, herbicide tolerant crops are bred using GM technologies that may carry uncertain and as yet un-quantified environmental risks (ODI, 1999). On the other hand, they can have a number of quantifiable benefits including (a) bring about a net reduction in herbicide use (Griffiths, 1998), (b) increase crop productivity (James, 1997) and (c) increase carbon sequestration (Lal *et al.*, 1999; Lal and Bruce, 1999). These uncertainties have a major bearing on fertilizer demand and FUE, because a 10% saving in crop yields from pest damage or weed competition by the use of GM technologies can be equated with a comparable saving in land and fertilizer.

Conclusions

By 2030, world population will be approaching its peak and 5,000 years of arable land expansion will be almost over. Growth in food and agricultural production will be largely dependent on land use intensification and on technologies that are increasingly focused on minimising impacts on the environment (from mineral fertilizers, pesticides and intensive livestock production) and maximising resource use efficiency (particularly of water) rather than on improving yields.

The overall picture coming from the FAO analysis is for agricultural production to become:

- primarily demand driven rather than supply driven, that is, by qualitative changes in consumer preferences;
- more technology dependent with technologies being based on the application of science to raising the productivity of natural processes rather than that of external inputs;
- less damaging to natural resources and the environment.

Arable land in the developing countries is projected to increase by only 12% (120 Mha) over the period to 2030, most of it in the "land-abundant" regions of South America and Sub-Saharan Africa with an unknown but probably considerable part of it coming from deforestation. In terms of harvested land, the land area would increase by 20% (176 Mha) because of increasing cropping intensity. The rest of incremental production will come from land use intensification. FUE and WUE are projected by FAO to play a major part in meeting food demand with only modest increases in mineral fertilizer use over the next 30 years (c. 0.9% annually) though with considerable regional differences, 1.9% in Sub-Saharan Africa and 0.8% in East Asia.

The uncertainties about climate change and the public acceptance of GM crops and other new technologies, as well as those concerning the long-term growth in demand for organic foods, have an important bearing on mineral fertilizer use, FUE and WUE.

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Session 2

Economic and social issues to achieve sustainable and viable agriculture

Social and economic issues related to sustainable agriculture

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Introduction

Sustainable development, as defined in the Brundtland report (1987), for the agricultural and rural sector raises the question of how to ensure sufficient, affordable, and high quality food for everyone in a growing world population while at the same time protecting the earth's natural resources so that future generations can prosper. Conflicts over the use of scarce land and water resources between food production and expanding industries and urbanization are increasing. These economic, social, and environmental issues related to sustainable agriculture constitute what is called the critical triangle of agricultural and rural development (Vosti and Reardon, 1997). The existing short-term trade-offs as well as the perceived long-term synergies between these three sets of issues pose a challenge for natural and social scientists, policy makers and other stakeholders in the agribusiness sector, nature conservation, and in rural as well as urban development (Figure 1).

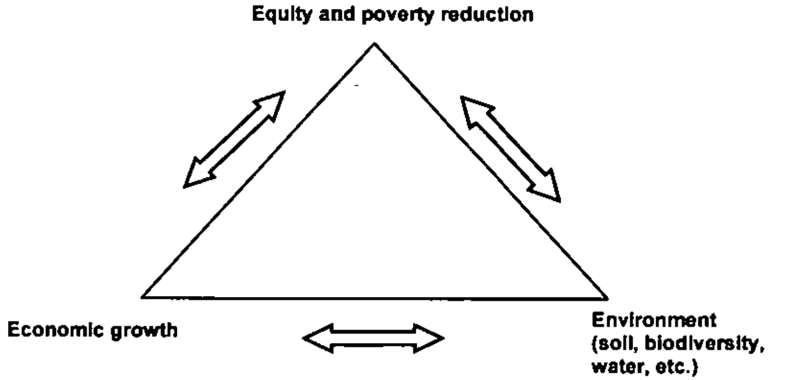

Fig. 1. The critical triangle of sustainable development.

In this paper, we seek to provide an overview of economic and social issues related to sustainable agriculture, and discuss policy strategies that can contribute to achieving a more sustainable agriculture for the benefit of current and future generations. These issues include the increasing scarcity of farmland and water for agriculture, declining biodiversity, and the need to provide more and better quality food for a growing world population while ensuring food security for everyone. These problems will most certainly gain in importance in future in the context of national and international policies. Indeed, it is the political framework that will guide the socio-economic behaviour of farmers, agro-industry, and consumers towards more or less sustainable agricultural and food systems. In addition, future innovations in technology and institutions are required to achieve more sustainable agricultural systems. But here again, policy will have a pivotal role to play in providing the right signals to induce the search for appropriate institutions and technologies that are environmentally and socially more friendly while, at the same time, economizing in and using more efficiently increasingly scarce resources such as land, water and non-renewable energy. As environmental concerns with agriculture and the food and agribusiness system become increasingly international, if not global, policy solutions will also need to be sought at the international level.

The paper, in six sections, first reviews what is meant by sustainable agriculture, or more generally, sustainable development. The next two sections are devoted to economic and social issues related to sustainable agriculture, respectively. Implicit in these sections is the treatment of environmental issues, although we do not systematize the latter. The next two sections review the role of policies and the role of technologies for sustainable agriculture, while the sixth and final section presents some concluding remarks.

Definitions of sustainability

As defined by the economist Sir John Hicks, sustainable income is the maximum value that a person or society can consume during a specific period of time and still expect to be as well off at the end of the period as at the beginning (Hicks, 1946). Although sustainability concepts have a long history, as this definition exemplifies, the most famous and politically relevant definition has been given in the 1987 Brundtland Report *Our Common Future*, which defines sustainable development as "development that meets the needs of the present generation, without compromising the ability of future generations to meet their own needs". The key idea of the report is that of intergenerational equity which should be achieved by finding a balance between the trade-offs of the three main components of sustainable development which are environmental protection, economic growth and social equity. Nevertheless, this definition is still broad and has led to widely differing interpretations.

One common characteristic of any definition of sustainability, however, is that "continuity through time" plays a major role, referring to continuity of economic, ecological and social issues in an ongoing *dynamic process* of development. Therefore, rather than having a well-defined meaning, sustainability refers more to a principle that gets a specific meaning only at a given point of time and according to *context-dependent* human expectations about future opportunities (Cornelissen *et al.*, 2001). It is therefore sensitive to changes in the analytic and value context.

Consequently, there is no optimum strategy of sustainable (agricultural) development once and for all (Giampietro, 1997).

When concentrating the focus on *agricultural sustainability* in its social and economic dimension (leaving aside the ecological dimension for the moment), among the context-dependent criteria that have to be considered, are cultural identity, sociopolitical organization, institutional context, macro-economic framework, knowledge (e.g. on ecological processes and micro-economic variables) and economic criteria such as land and labour productivity that relate resource availability to demographic and socio-economic development (Giampietro, 1997).

Already the characteristics of the natural resource base, e.g. land, and the demographic development differ widely from region to region and result in very different conditions for agricultural productivity. Taking into account the additional country-specific infrastructural, technological, socioeconomic and cultural characteristics of agriculture, it is possible to understand why sustainability priorities and strategies differ between and within countries. Thus, something defined as sustainable on one level, on one space-time scale and seen from the perspective of one social group, becomes unsustainable when viewed from another level, on a different time scale and seen from the perspective of another social group (Lefroy *et al.*, 2000; Giampietro, 1997).

If we consider the definition of *sustainable land management* given by Lefroy *et al.* (2000) as the "long-term preservation of the resource base to allow adequate food production in a manner that is socially acceptable, economically viable and environmentally sound", the question arises as to how strictly should the "preservation of the resource base" be understood and how many of the existing resources should be used now, and how many should be left for future generations (McIntosh & Edwards-Jones, 2000).

Here, a general distinction must be made between *(very) weak and (very) strong sustainability concepts*. It is based on the contribution of Pearce *et al.* (1989) (cited in McIntosh & Edwards-Jones, 2000) who classified all resources into three classes of capital: natural capital (including the planet itself, all minerals, all species, water, soil and air), man-made capital (including all non-natural material items like roads, cars and buildings), and human capital (referring to knowledge, experience and culture).

Differences arise depending on whether substitution between the different types of capital assets is permitted and if so, to what degree or not at all. With *weak sustainability*, substitution of different forms of capital is allowed, but the total value of the capital must remain intact or increase. This approach calls for cost-benefit analysis (CBA) to evaluate potential benefits and the costs of action and related environmental externalities (van der Voet *et al.*, 2001). As private economic agents and markets fail to account for these externalities, various policies such as subsidies, taxes or permits are applied to enhance positive externalities such as cultural landscape created by farmers or to reduce negative externalities such as nitrate leaching. Applying this concept, an agricultural system can be said to be sustainable if the amount of income extracted for consumption each year can be sustained over time. This requires that the value of the capital stock will not be depleted over time; hence sufficient income must be set aside or otherwise forgone to replenish any capital depreciation or losses incurred in the production process. For this purpose, capital is defined to include all natural resources, human, and man-made capital assets. In its extreme version, called *very weak sustainability*, this concept allows perfect substitution of natural by man-made capital as proclaimed by neoclassical economists like Solow (see e.g. Solow, 1991) while in the more moderate concept of weak sustainability the aim is to preserve at least a "critical stock of natural capital" that should not be substituted. In the more appropriate concept of weak sustainability (see e.g. Pearce *et al.*, 1989; Pearce & Atkinson, 1993), full environmental costs should be included in economic decision making based on CBA, with equal weight with other factors. In a similar approach, Serageldin (1996) has suggested a compromise definition called "sensible sustainability". It allows for capital transformations - that is, of natural capital into human capital (through education) or into man-made capital - but it also recognizes that critical levels of each type of capital may exist beyond which concerns about substitutability can arise. Since the exact boundaries of the critical limits for each type of capital are not known or are a question of political choice, "it behooves the sensible person to err on the side of caution in depleting resources (especially natural capital)" (Serageldin, 1996). Unfortunately, there is little evidence in the policies in developed as well as in developing countries to suggest that policy makers act sensible. Short-term horizons seem to favour environmentally extractive rather than environmentally conserving policies.

In contrast, in the *strong sustainability* concept, the substitution of different forms of capital is not allowed. Thus, the stock of each form of capital needs to be sustained, including the value of natural resources (Pearce *et al.*, 1989). Therefore, evaluations follow the approach of finding least-cost solutions and use optimization models where environmental conditions are treated as external constraints (van der Voet *et al.*, 2001). In the concept of *very strong sustainability*, even zero-growth is proclaimed because it is thought that the critical limits of natural capital substitution have been be reached and current economic activity is assumed to harm the rights of non-human species. In this approach, as presented by Daly and Cobb (1989), important policy instruments are environmental standards and regulations. Of course, if the (very) strong sustainability definition is applied, little of agricultural, rural and overall economic development in the past decades can be called sustainable.

"Weak" (or "sensible") definitions of sustainability have the advantage that they do not suggest freezing or preserving all natural resources at existing levels. They permit trade-offs between growth and environmental objectives: resources can be degraded or depleted to increase production, *if* compensatory investments are made in other forms of capital to sustain the stream of consumable income over time. Decisions about the degradation or depletion of natural resources should, therefore, depend on whether the social benefits accruing to the users are greater or smaller than the social costs (Turner, 1993). For example, because some resources are renewable (trees, soil nutrients) or have adequate substitutes (agro-forestry can replace woodlands for fuelwood), they need not all be preserved at current levels or at all points in time. In cases of critical habitats for conservation of biodiversity and unique ecosystems, however, the costs of degradation are likely to be so high (mainly their uncertain discounted value derived by our future generations) that conversion to agriculture or other land uses is not a socially optimal decision. Because of this, many nature reserves and natural protection zones have been implemented by most national governments. However, the quality of protection varies greatly in practice.

Economic issues

Meeting fast-growing demand for food with declining per-capita land and water resources

In recent decades, dramatic changes in food production, processing, and trade provided - in principle - enough food to meet the basic needs of each and every person in the world. Doubling grain production and tripling livestock production since the early 1960s has made available about 2700 calories per person per day. Today, approximately 800 million people still suffer from chronic food insecurity, most of them living in developing countries (FAO, 1999). Due to major advances in agricultural research and related use of improved seeds and fertilizer in recent decades, food poverty has in the past not been a problem of low production, but in distribution. Thus, the challenge for the future is not only to grow more food, but also to enable the poor either to produce enough food for themselves or to earn enough income to satisfy food and other basic needs.

Results from a global food model, the International Model for Policy Analysis of Commodities and Trade (IMPACT), suggest that under the most likely scenario global demand for cereals will increase by 39% between 1995 and 2020 to reach 2466 million tonnes (Mt); demand for meat will increase by 58% to reach 313 Mt; and demand for roots and tubers will increase by 37% to reach 864 Mt. These large increases in food demand will result, despite the already declining rate of population growth, from income growth, urbanization and associated changes in lifestyles and food preferences (Pinstrup-Andersen *et al.*, 1999). As people move from rural to urban areas, they tend to adopt more diverse diets, shifting away from coarse grains such as sorghum and millet to rice or wheat. They also tend to consume more livestock products, fruits, vegetables, and processed foods. The United Nations expect that much of the population growth will take place in the cities of the developing world. While its rural population is expected to increase by less than 300 million between 1995 and 2020, the developing world's urban population is projected to double from 1.7 billion to reach 3.4 billion in 2020 (UN, 1996). By 2020, about 52% of the developing world's population will be living in urban areas, up from 38% in 1995.

Many developing countries have achieved impressive growth rates in agriculture in recent decades. India, for example, which was threatened by hunger and mass starvation in the 1960s, is now self-sufficient in staple foods even though the population has more than doubled. Yet, in spite of this success, serious concerns remain. First, hunger and malnutrition persist in many countries, often because past patterns of agricultural growth failed to benefit the poor adequately. Second, agricultural demand will grow along with population growth and rising per capita incomes, and this will require continuing increases in agricultural productivity. Yet growth in yields appears to be slowing while the prospects for expanding cropped and irrigated areas become very limited. Third, if not checked, environmental problems associated with agriculture could threaten future levels of agricultural productivity as well as the health and well-being of rural as well as urban people.

Two basic types of environmental problems are associated with agriculture (Hazell & Lutz, 1999). Most of the successful breakthroughs in productivity have occurred in more-favoured agroecological zones and have been based on intensive use of irrigation water, fertilizers, pesticides, and other modern inputs. Agriculture based on intensive use of these inputs can be prone to mismanagement and can lead to environmental degradation particularly when the system of incentives is inappropriate. However, where governments have neglected to intensify agricultural production through the use of modern technology, population growth has worsened poverty and hunger, driving rural people to expand cultivation into less-favoured, often environmentally fragile areas, such as forests, hillsides, and wetlands, and to reduce fallow periods to the point of depressing soil fertility. Especially in forest areas like the Amazon region, policy makers are forced to manage the trade-offs between the conservation of biodiversity and natural forests on the one hand and infrastructual and technological improvement to reduce poverty on the other hand (Vosti, 1992).

More efficient use of non-renewable resources in agriculture

While the so-called Green Revolution technologies enabled an impressive growth in food production during past decades and contributed to rural development and poverty reduction, the use of mineral fertilizers and pesticides, as well as increased mechanization and food processing, caused a dramatic increase in energy use, from non-renewable fossil reserves, in agriculture and additionally led to the release of large amounts of carbon dioxide (CO_2) into the atmosphere (Hülsbergen *et al.*, 2001).

Some forms of intensive agriculture and horticulture have negative energy balances when all system inputs and outputs are accounted for in an eco-balance framework. Modern crop production is characterized by high direct (fuel and electricity) and indirect inputs (fertilizers, plant protection agents, and machines) of fossil energy of more than 30 GJ ha^{-1} in Western Europe whereas in low-input cropping in Africa less than 1 GJ ha^{-1} are used (Hülsbergen *et al.*, 2001). Most of the energy use in agriculture is due to nitrogen (N) fertilization and fuel (Hülsbergen *et al.*, 2001), less to other fertilizers and pesticides. Hence, it is quite obvious that the present "modern" agriculture in developed countries will be unsustainable in the long-term when non-renewable energy resources such as gas and oil are used up. Future agricultural research will therefore need to find technologies that are not only economizing on land and water, but also on energy.

The *energy input* with N fertilization is due to the high energy costs in production, manufacturing, transportation, and spreading of mineral N fertilizers. But are organic fertilizers a more energy-efficient source of nitrogen? In a long-term fertilizer trial on fertile soils in central Germany, the application of farmyard manure resulted in even higher energy costs (for machines) due to the lower concentration of N in farmyard manure and the related higher energy costs in transporting and spreading manure (Hülsbergen *et al.*, 2001).

Considering that fossil energy and land are both limited and considering that soil nutrients need to be replenished to secure future harvests, more important than energy inputs are the parameters *energy output* and *net energy output* of agriculture. In the German long-term fertilizer trial mentioned above, the moderate use of both farmyard manure and mineral N produced the greatest rotational net energy output, especially with sugar beet, whereas fertilizer N alone had the highest output/input ratio when compared to manure alone or the combination of manure and mineral N. Under the conditions of the study, the general energetic parameters of the manure plus mineral N treatment improved considerably over time, although considerable differences between crops were found. Unfortunately, differences between the treatments in soil nutrient supplies at the end of the experiment were not considered (Hülsbergen *et al.*, 2001) so that the findings on (net) energy output need to be adjusted to allow for replenishing soil nutrients.

Policy interventions that accelerate price increases for fossil fuel resources on the one side, and on the other give economic incentives favouring renewable energy resources could induce systems with a higher energy efficiency and/or lower energy input. They could also steer agricultural and other research towards more energy-efficient technologies and improved cycling and use-efficiency of plant nutrients.

Costs and availability of fertilizer

Soils can be seen as storehouses of plant nutrients, the principal capital of all agricultural activity. Therefore, for agriculture to be sustainable, it is necessary to maintain soil fertility by substituting extracted nutrients and organic matter through internal or external inputs. Sustainable nutrient management must further aim to optimize nutrient cycling, minimize the use of external inputs, and maximize input use efficiency (Gruhn *et al.*, 2000).

In conditions with limited and insecure access to fertilizer and credit markets and poor infrastructure which results in high transaction costs and/or high fertilizer and low output prices at the farm-gate level - as experienced in many rural areas of developing countries - it continues to be difficult for smallholder farmers to obtain external agricultural inputs. Under these conditions, under-application of fertilizers and thus over-exploitation of land and declining soil fertility is a widespread phenomena. Lower yields in the short term and soil mining and erosion in the long term are the consequences (Gruhn *et al.*, 2000). This clearly contrasts with the problems associated with overuse of N inputs, often resulting from organic manure in areas with high livestock densities, in developed countries.

Hence, under these conditions, system sustainability can only be achieved by two alternatives. First, policy and technology development can aim to recycle and use nutrients more efficiently but farmers will have to accept lower yields when N, P, or K nutrients become the constraining growth factor. One hundred percent nutrient recycling is simply not possible for each and every farm, partly because of system losses and even more so because the centers of consumption of feed and food are regionally or internationally dispersed so that transportation costs back to the farm become prohibitive. Second, one can improve rural infrastructure so as to improve farmers' access to external inputs that complement organic fertilizer. In the following sections these alternatives are discussed further but they should not be seen as mutually exclusive, but rather as alternatives that should be pursued simultaneously by appropriate policies and technology development.

The first alternative includes the adoption of soil-conservation practices and nitrogen-fixing species and inoculants. These technologies are part of the concept of *low-external-input and sustainable agriculture* (LEISA) in which the use of such inputs like mineral fertilizers, pesticides and hybrid seeds is not excluded but seen as complementary to the use of local resources. However, these features are also part of integrated nutrient and pest management (IPNM) so that LEISA is not clearly distinguishable from integrated crop management (UNDP, 1992). The following two examples are from Zambia. In Zambia, farmers and consumers faced higher input and food (maize) prices after market liberalization and the related removal of subsidies for mineral fertilizer. Under the conditions of limited access to input markets for fertilizer and improved maize seed prevailing in the rural areas, pasture legumes as green manure were introduced to supplement mineral fertilizer N through fixation of atmospheric N and to improve microbiological soil activity while open-pollinating varieties enabled the farmers to multiply maize seed by themselves. The integration of leguminous plants or of pasture legumes as green manure into maize cropping was successfully adopted in a farmers' research approach (Steinmaier, 2001). The second example of how on-farm agricultural research can support nutrient management is the introduction of leguminous trees supported by the International Center for Research in Agroforestry (ICRAF). ICRAF began on-farm experimentation in 1992/93, and by 1996/97 roughly 3,000 Zambian farmers spontaneously tested the technology. Keil *et al.* (2002) showed that 75% of testers have adopted the technology which demonstrates that improved fallows are a suitable practice under conditions of lack of access to input and credit markets and relatively low population density, as found in large parts of southern Africa.

The integration of livestock into farming systems is also part of the first alternative of enhancing nutrient cycling and nutrient use efficiency. Compared to pure cropping, mixed livestock-cropping systems can increase total farm output per hectare while saving on fossil resources as found by Schiere *et al.* (2002). They offer opportunities for waste and nutrient recycling and increase the efficient use of nutrients. Eltun *et al.* (2002) showed from an experimental comparison of different cropping systems in Norway that, at least in large parts of Northern European agriculture, it is easier to maintain yield levels in mixed farming systems than in arable farming systems without livestock. They associate mixed farming with lower risk of N losses and better protection against soil erosion, thus reducing nutrient losses and improving soil conditions. These positive environmental effects are due to the fact that animal manure is favourable for biological soil parameters like microbial and earthworm biomass (Eltun *et al.*, 2002) and additionally includes the secondary nutrients and micro-nutrients which are necessary to sustain yields over time with larger applications of the macro-nutrients N, phosphorus (P), and potassium (K) (Gruhn *et al.*, 2000).

However, the data of Steinmaier & Ngoliya (2001) suggest that it is difficult to ensure a balanced P and K supply with leguminous crops because only part of the harvest can be recycled. This holds true also for mixed-cropping livestock systems as manure cannot fully replenish P and K because of system losses as well as the sale of animal products. Thus, in view of the finiteness of many reserves, especially of P, efficiency in the use of P will need to improve with increasing scarcity. Also N is not used efficiently in agriculture. According to Gruhn *et al.* (2000), "often less than 50% of applied nitrogen is found in the harvest crop" because of nutrient loss due to leaching, runoff and volatilization. Freney (in Gruhn *et al.*, 2000) reports N losses by volatilization between 20 and 80% in flooded rice. Therefore, to improve the efficiency of fertilizer use, further improvements in the reduction of nutrient losses are required, for example by applying appropriate fertilization techniques including depth of placement, use of inhibitors and timing of the application as well as other factors like timing of ploughing and harrowing, type of crop rotation and type and amount of organic and mineral fertilizer (Gruhn *et al.*, 2000; Eltun *et al.*, 2002).

The first alternative can be greatly supported by long-term research on cropping and livestock systems and their impact on soil quality and nutrient balances, as well as by research aiming to breed plants that more efficiently use soil nutrients and water, the latter becoming an increasingly scarce resource. The development of such technologies, in turn, can be accelerated with appropriate policy frameworks.

With respect to the second alternative, a number of policy options exist to improve farmers' access to fertilizer markets and related farming technology. Public investment in transport and communication infrastructure is necessary to develop efficient markets, especially in remote areas. The farmers' need for fertilizers is not necessarily translated into effective demand because of lack of access to capital (Diagne and Zeller, 2001), high input and/or low output prices, high transaction costs, insecurity of input supplies, and risk aversion strategies (Zeller *et al.*, 1998). Insufficient infrastructure and market failures often lead to excessively high fertilizer prices at the farm gate in developing countries (Gruhn *et al.*, 2000). For these reasons, especially in developing countries, it was thought that public intervention in agricultural input markets would improve their functioning but too often, it was the intervention itself that worsened inefficiencies, in rent increases, excessive distribution costs and stagnation in the agricultural sector (Goletti & Alfano, 1995). Additionally, the recent experiences with the liberalization of agricultural input and output markets and privatization of parastatals has not produced the hoped-for supply response in many developing countries because the underlying structural constraints of poor market integration, such as insufficient infrastructure, lack of market information, weak legal systems, and so on have not been addressed appropriately by state interventions.

Worldwide, but particularly in developing countries, the *price-cost-ratio* (of cereal prices and fertilizer costs) has tended to decline. This development is likely to continue in the future as fertilizer prices are expected to increase (Gruhn *et al.*, 2000), and get even larger at the farm-gate where they are already large in developing countries. Perz (2001) showed that small price-cost-ratios, resulting from high prices for inputs, high transaction costs and/or low prices for agricultural outputs, are key factors limiting "productive conservation" strategies of sustainable development in the Brazilian Amazon.

Social issues

Food security

The essential issue and main global challenge of all agricultural activity, especially under conditions of poverty, population growth and environmental degradation, is *food security* all over the world, but especially in Asia where most of the world's poor live (Tiongco and Dawe, 2002). Food security is both an economic as well as social issue as it is concerned with both the production and distribution of food.

To achieve food security, three aspects have to be taken into account: Food availability or adequate food production, economic access to available food, and nutritional security which depends on non-food resources like child and health care, clean water and sanitation (Quisumbing *et al.*, 1995). Thus food security can be defined as the "availability of, access to and appropriate utilization of food for every person to lead a healthy and active life" (McCalla, 1999), and it can be measured at different time horizons (short-, medium- and long-term) and different aggregation levels such as household, nation or global.

While in the short-term, food security - although with support of local and national governments - has to be solved primarily at the household or farm level through access to food or productive resources, for social safety nets and health services, in the medium term (5-15 years) the focus must be at the national level through pro-poor rural development, including expansion of the non-farm sector, and investments in agricultural research and extension fostering sustainable agribusiness systems. In contrast, for long-term food security - which obviously is the only truely "sustainable" type - involvement is necessary at all aggregation levels in a broad-based approach of local poverty alleviation and social infrastructure, overall national development strategies, and the especially important potential of fair global trading systems, international research and availability of technology. At this level, population and income growth in developing countries become a challenge for the future demand for food while at the same time the question of a functioning fair trading system becomes extremely important to guarantee food flows from areas of surplus to those of deficit (McCalla, 1999).

Human health and food safety

As stated by Haddad (2000), "productive activities in any sector run the risk of having negative impacts on health. Agriculture is no difference". This does not only concern those directly involved with agriculture (e.g. farm workers and farm households) but also society as a whole via the food chain. Therefore, the health implication of agriculture is not only restricted to the farm/household level but also to the regional, national and international level. For example, nitrate from agricultural sources is being detected above the appropriate limits in some US drinking water wells (Kim *et al.*, 1999). In the Aral Sea area, in Kazakhstan, the infant mortality is five times higher than in the western part of the country as a result of the extensive cotton and paddy rice fields cultivated in other countries of Central Asia (Koch, 2000).

With regard to occupational hygiene, agriculture is among the most hazardous sectors. In the United States, the mortality rate during the 1980s was estimated to be of 22.9 per 100,000 agricultural workers, ranking agriculture as the third most dangerous employment sector (Arcury and Quandt, 1998).

A well publicized and controversial aspect of agriculture with particular reference to health is the use of agrochemicals. They include pesticides such as insecticides, herbicides, and fungicides. The health consequences of agrochemicals include a range of diseases for farm workers (Perry and Bloom, 1998). Despite these harmful effects (not to mention concerns about food residues), the use of pesticides between 1948 and 1993 grew at an average rate of 6.1% annually (Kim *et al.*, 1999). Growing concerns about pesticides within the agricultural industry, scientists, governments and the general public has lead to the adoption of a range of techniques or practices among which are integrated pest and nutrient management, production of more effective but less harmful chemicals, biological pest control, conservation tillage, genetic improvement of crops, and organic agriculture.

High quality agricultural inputs and labeling of their contents, is a prerequisite for their responsible and safe use. Even in Europe, published data on the chemical properties of pesticides often show large differences or are even lacking, especially on formulated products, adjuvants and metabolites of pesticides (Reus *et al.*, 2002). How much worse might be the situation in developing countries with less quality standards and institutions for control? According to WHO (2001), 30% of pesticides sold in developing countries do not meet internationally accepted standards and this is blamed on weak quality control. Not only the correct formulation and declaration of chemical and biological products but also the information and advice given to the users in oral and written form deserve more attention. To achieve environmental and food safety and human health for producers and consumers, a joint effort by the chemical industry and government in developing countries is necessary because market forces themselves are not able to control the current misuse of chemical products and to take future social benefits and negative external effects into account.

Gender and intra-household issues

Although there has been progress in the improvement of women's human capital concerning increased life expectancy, declining fertility rates, and better education in many countries in recent decades, there continue to persist serious gender gaps, especially in assuring *women's rights to natural and physical capital.* Under conditions of gender-biased rights to make decisions and to have access to credit, women's productivity is extremely limited in many parts of the world. This contrasts with the intergenerational pay-offs of investing in women's human and physical capital which shows that, for example, women's health and nutrition positively influence the nutritional status of the next generation. Therefore, in the discussion of social issues of sustainable agriculture, gender-sensitive agricultural policies are one of the central aspects not only with respect to human rights but also to food security. This is because women play very important roles in food security as well as in the management of natural resources (Quisumbing and Meinzen-Dick, 2001).

Worldwide, millions of women work as farmers and farm workers accounting for more than half of the labour required to produce the food consumed in the developing world while facing unequal access to land, inputs and information. In addition, mainly in Africa, but also in Latin America, women have a substantial share in the work of food crop processing, provision of water and fuelwood, food storage and transport, hoeing, weeding, harvesting and marketing. Therefore, improving women's access to productive resources, could have a great impact on increased agricultural productivity because constrained access to inputs and information as well as insecurity of land tenure reduce women's readiness to invest time and resources in land and to adopt environmentally sustainable farming practices such as tree planting and soil conservation (Quisumbing *et al.*, 1995).

Reforms of the legal and institutional frameworks provide the basis for women's claims to all types of assets (Quisumbing and Meinzen-Dick, 2001). Yet, direct intervention in gender-based property rights, e.g. of land, has proven to be extremely difficult (Quisumbing *et al.*, 2001) because, even if formal tenure systems exist, in practise customary rights have often strengthened land rights of senior, male household heads so that only a few women hold land certificates or titles and are generally limited to user or usufruct rights derived from their relationship to men (Crowley, 2001). In the same way, land reform programs, agricultural extension services, and credit programs often do not recognize women as potential beneficiaries. As a consequence, under-investing in their human and physical capital and ignoring their experience and indigenous knowledge pose strong barriers to women's increased productivity, thus creating high opportunity costs to society in terms of forgone output and income (Quisumbing *et al.*, 1995).

With respect to the social criteria of sustainability and considering the fact that nutritional status is cumulative over time and influences the nutritional status of the next generation (Quisumbing and Meinzen-Dick, 2001), long-term sustainability cannot be achieved if agriculture only contributes to increasing food production in general without institutional improvements towards women's education and rights to decide over the household's productive resources and outcomes.

Distribution and security of land tenure

In countries where agriculture is the dominant sector, ownership of land is directly associated with (political) power and indirectly facilitates access to agricultural support services (Crowley, 2001). The distribution of land is very unequal in many developing countries, particularly in Latin America.

According to Crowley (2001), *security of land tenure* consists of three components. These are the clear definition of duration and content of rights, the independent control over the land, and the ability to defend and enforce the land right. Yet, certain social groups, mostly women and poor people in developing countries, do not have the political connections, information, money or physical proximity needed to secure or even receive land rights. Therefore, efforts should be made to reduce the administrative transaction costs and barriers faced by poorer groups and women to acquire land.

Why is it so important with respect to sustainable agriculture that improvements in land tenure security can be achieved? Several authors indicate the connection between secure land tenure and environmentally and economically beneficial long-term investment in agriculture: Security of land tenure is an extremely important factor for sustained and high-level investments in land-based innovations, like terracing, as the most prominent type of investment in land quality (Zaal and Oostendorp, 2002), improvements in soil fertility (FAO, 1998), intensification of fertilizer use and successful promotion of integrated plant nutrient management systems (Gruhn *et al.*, 2000). As improved management will take place when there is a closer match between those who control and those who use resources (Quisumbing *et al.*, 2001), without the official recognition of land ownership in the form of land titles, there is less incentive for farmers to improve land productivity and invest in long-term methods that will bring them income in the future (or even in the next generations) rather than immediate rewards (FAO, 1998).

The same applies to the introduction of agroforestry systems. As shown by Quisuming *et al.* (2001), "agroforestry depends on people's rights to plant and use trees. ... Without clear property rights, there are few incentives to preserve natural resources (in the form of longer fallow periods) and to invest in trees because future benefits would not accrue to those who manage them."

Interestingly, the authors argue that formal land titling programs will only become successful and sustainable in areas of high market and property rights development, where communal land tenure institutions have become sufficiently individualized and where the importance of credit and purchased inputs increase due to intensified land use. If these conditions are not fulfilled, land titling programs are at risk to be costly undertakings that include the danger that the rich and political elite will seize large areas of titled land (Quisumbing *et al.*, 2001). Additionally, land titling programs and land reforms in general have another critical aspect when analysed from different perspectives: Although they have proved to improve landholding patterns, poverty, and inequality in many countries, in Latin America they overproportionally recognized men as beneficiaries thus increasing gender gaps in access to productive resources, thus leading to greater inequality in the intra-household distribution of assets (Crowley, 2001). However, if women get recognized in land redistribution in an adequate way, land reforms are one of the most important aspects in achieving multidimensional sustainability in agriculture.

The role of policies

In the preceding two sections, the discussion of economic and social issues emphasized that the policy framework providing economic incentives, regulations and penalties are important in guiding the development of technologies and institutions and thus steering agricultural and rural development on more or less sustainable pathways.

Policy and institutional framework

To achieve agricultural sustainability, Hazell and Lutz (1999) pointed to three issues. First, at what level of society are environmental costs and benefits to be measured? Because resource degradation often has spillover or externality costs for nonusers (for example when the degradation of watershed protection areas leads to the silting of irrigation systems downstream or when water pollution causes health problems throughout river basin systems), the more aggregated the concept of society that is used, the greater the total environmental costs. Thus, levels of environmental degradation that may be considered acceptable to farmers or rural communities may be unacceptable at national or international levels if the externality costs are significant. The reverse can also be true: resources that generate environmental benefits may be undervalued at farmer or community levels because their benefits are captured at broader national or international levels. The conservation of the cultural landscape or of traditional land races of maize may serve as examples for the latter. Clearly, assessing sustainability at the farm or community level is not sufficient if there are important externalities, and regional and national assessments are needed to guide policy decisions. International or global assessments are required if and when important international externalities are concerned such as the impacts of agriculture on global climate change.

The second issue concerns methods of valuing environmental costs and benefits (Hazell and Lutz, 1999). Values can be grouped into direct use values, indirect use values, option values and existence values. Direct use values are associated with food production and consumption, biomass, recreation, and health. Indirect use values are associated, for example, with ecological functions, flood control, and storm protection. Option values are associated with the preservation of resources that have probable but uncertain value in the future, for example, biodiversity conservation. Finally, existence values include the value that people place on the mere existence of resources from which they may never directly or indirectly benefit (from the existence of parks or species, which they may never actually visit or see). As a rule, the more tangible the costs and benefits, the more reliable the estimates that can be produced.

The third issue concerns the design of incentive schemes that induce farmers, communities, cities and governments to factor important externality costs or benefits into their own resource management decisions. As a general finding, undistorted macroeconomic and sectoral policies tend to provide better incentives from an environmental perspective than highly distorted policies (Warford *et al.*, 1997; Lutz and Young, 1992). Subsidies for agricultural inputs tend to be particularly costly in terms of economic efficiency, government budgets, and the environment (World Bank, 1997). However, macroeeonomic and price policies (for example through taxation on the use of non-renewable resources) can have beneficial effects on lowering the use of such resources. Unfortunately, the developed countries, as major users of energy, have very divergent patterns in environmentally motivated taxes (for example the price of energy in the USA compared to the European Union).

Next, European agricultural policies serve as examples to illustrate the impacts of different subsidy types on agricultural sustainability. The structural changes in European agriculture by advances in the fields of mechanization, animal breeding, seed quality, crop protection and trade during recent decades enabled substantial increases in agricultural production and farm labour productivity that partially kept in line with the development of wages in the industrial and service sectors. However, they also led to negative impacts on the environment such as nitrate contamination of water (Billing, 1998; van Huylenbroeck *et al.*, 1999). This mixed development, in particular the enormous surplus production during the 1970s and 1980s, has been partly caused by the European policy strategies of guaranteed prices and export subsidies for agricultural products until 1992. From that year on, the Common Agricultural Policy (CAP) reforms have been introduced. These reforms led to reduced output prices. Moreover, for the first time the policies integrate environmental considerations by giving farmers incentives to employ more conservationist production methods through premiums and subsidies for positive environmental externalities (environmental services) and measures to reduce the agricultural area, fertilizer and pesticide use, livestock density and nitrate leaching (Billing, 1998). The idea is to use financial rather than mandatory methods to compensate farmers for higher costs or lower revenues that result from producing environmental goods and services or from preventing negative agro-environmental externalities (Gatto and Merlo, 1999).

Within the CAP, subsidies still play an important role but the focus of subsidies has gradually changed from price and income support (benefiting larger farmers relatively more than smaller ones) to environmental considerations. The trend towards environmentally motivated support of the farm sector in the EU is likely to continue. In addition, there is pressure from the international trade negotiations on agriculture that demand the opening of EU markets to produce from developing countries. In general, there are three types of agricultural subsidies.

a) Production-based subsidies, like guaranteed prices for agricultural products, or input subsidies that give incentives to increased production like intensification and expansion of agricultural areas. These have been used in the European Community to satisfy self-sufficiency goals since the Second World War.

b) Product-bound subsidies to support products with regional and/or national comparative disadvantages that are of interest for regional rural development goals, including tourism, for example the sheep premium in Ireland and subsidized cheese production in the Alpes based on extensive grazing.

c) Subsidies according to environmental and social goals. This type of subsidy includes premiums for environmental or social services to society like the promotion of organic farming, agricultural extensification by 20-year set-aside for environmental reasons and the conservation of landscape, valuable biotopes and agricultural biodiversity (Billing, 1998) in the European Union, the USA and Japan as well as subsidies for sustainable cropping and pasture land management in developing countries.

The negative environmental effects arising from increased production as a consequence of the first subsidy type have been mentioned above. They are due to the fact that subsidies for agricultural outputs or inputs distort prices and lead to suboptimal over-use of essentially non-renewable resources. As these inputs (e.g. N and P fertilizers and crop protection agents) can have negative external effects, subsidizing them may "artificially boost profitability of activities using these inputs and encourage resource depletion and degradation" (Shiferaw and Holden, 2000) while at the same time those who benefit from fertilizer and credit subsidies are often large farmers (Goletti and Alfano, 1995). Under the conditions of poverty in areas with low soil fertility and without keeping animals (for manure) in developing countries, however, input subsidies can prevent soil mining and enhance household welfare. Shiferaw and Holden (2000) point out that production-based subsidies linked to (soil) conservation requirements (especially of long-term measurements in soil conservation) can protect the environment and household welfare at the same time.

What about the economic and social aspects of sustainability regarding production-based subsidies in Europe? In the case of guaranteed prices and export subsidies in the EU, the corresponding expenditure led to an enormous financial burden that may even increase with the enlargement of the EU towards Eastern Europe as well as to distortions of the world market that earn continuous international criticism with respect to the General Agreement on Tariffs and Trade GATT (Billing, 1998). In the case of the social effects, production-based subsidies were justified by their positive effects of supporting a diversified, small-structured agricultural sector of family farms that is of interest not only for employment reasons but also for cultural traditions and aesthetic landscape values in European rural villages. However, production-based subsidies may actually lead to increasing inequality within the agricultural sector. Since the subsidy is bound to production volumes, benefit increases parallel to the increase in total output. Resource-rich farmers that produce large quantities consequently derive absolutely and relatively greater benefits from guaranteed prices.

The second, product-bound subsidy type in Europe addresses the upkeep of agricultural land use in marginal areas and aims to preserve the semi-natural grazing land where farming is already very extensive and has comparative disadvantages within the European countries (Röhm and Dabbert, 1999).

Depending on the country-specific ecological and economic conditions, the third subsidy type (subsidies according to environmental and social goals) not only includes premiums for extensification and organic farming in developed countries with surplus production, but contrarily could also comprise policy measures to intensify agricultural production as implemented in Mali to change free grazing on common land towards more intensive confinement systems. In this case, these "subsidies to users of substitute techniques to reflect their social benefits" (Dalton and Masters, 1998) in the form of construction-cost subsidies for corrals, however, were highly inferior to direct pasture taxes with regard to their effect on the adoption of the environmentally more friendly technology. According to Dalton and Masters (1998), the recurrent costs of the new technology exceed its benefits for the farmers relative to the continued use of the old technology. In such a case, it can be more successful to tax an unsustainable than to subsidise a sustainable technology.

Hence, the situation-specific decision-parameters of farmers that determine their opportunity costs of labour and capital need careful analysis. And even if the right political measure is found, it influences farmers behaviour in the wanted direction only as long as the payments continue. In Europe, extensification subsidy schemes using financial incentives are characterized by high implementation and transaction costs in comparison to market regulation instruments (van Huylenbroeck *et al.*, 1999). Therefore, because of the risk of a heavy burden for the economies of poor countries, subsidy systems must be designed carefully (Shiferaw and Holden, 2000). In a similar way, premiums that are too small or the combination of different subsidy types with competing aims can inhibit progress towards sustain-ability. As illustrated by Billing (1998), ecologically competing support measures within the EU, like certain livestock premiums of the product-bound type on the one hand, and incentives of the environmental subsidy type to achieve a general reduction of livestock densities on the other hand, as well as different measures within the environmental premiums giving incentives for organic and conventional production at the same time, can lead to reduced efficiency of these policy measures and a waste of funds without beneficial impacts on the environment or society.

We conclude that the first type of unlinked production-based subsidies tends to make agriculture less sustainable, not only from an environmental point of view but also from an economic as well as social one. Product-bound, but, in particular, environmentally or socially motivated subsidies, offer more possibilities to influence agricultural development with all three objectives of sustainable development in mind. However, general policy recommendations cannot be derived because situations differ from country to country. In high-input agricultural systems, small farmers with environmentally and socially sustainable production methods on disadvantaged sites or in ecologically valuable regions could be economically supported by subsidy policies that complement rather than compete with each other and ideally are linked to conservation requirements. In low-input (both external and internal input systems), resource mining such as soil degradation and deforestation could be actually reduced by facilitating farmers' access to fertilizers and other technologies.

Internalization of negative external effects

The growing internationalisation of the agribusiness and food sectors and the increased recognition of agriculture's environmental outputs are two of the most important factors affecting agriculture at the start of the 21st century. While both factors can be expected to lead to improvements in social welfare, there may be trade-offs between environmental protection and trade liberalization, especially if the former is interpreted widely to include the much-cited 'multifunctionality' of agriculture.

Under conditions of perfect markets, the 'world' market prices reflect the social value of productive resources. In reality, transaction costs, imperfect information, incomplete property rights and covariate risk (Shiferaw and Holden, 2000) contribute to market imperfections that distort the true value of resources. Thus, 'world' as well as 'liberalized domestic' market prices can be distorted. The price of energy is an example because it does not include the costs of environmental damage caused by energy use as well as the reduction in the quality of life because of energy use. It is not the user of energy that has to bear these costs of energy use, and they are therefore not considered in the self-regulating market processes (therefore "external effects").

In the case of agriculture, these external effects can be positive (like the creation of wildlife habitats and pleasant cultural landscapes) or negative (like water pollution by pesticides, soil erosion, and waste of energy) (Whittaker, 1998; Gruhn *et al.*, 2000). To avoid the negative and foster the positive externalities, policy-makers have a choice between command-and-control regulations accompanied with penalties for non-compliance for generators of externalities, for example, by setting limit standards of emission or pollution or flexible market-based instruments that give economic incentives to reduce negative externalities by, for example, Pigouvian price changes of agricultural inputs (Shiferaw and Holden, 2000).

Facing the challenges of diminishing global fossil energy reserves, the difficulties in internalizing negative external effects in agriculture require a joint effort of all the stakeholders in the agricultural sector, not only farmers or agribusiness firms. Eventually, the consumer will have to pay either indirectly through higher taxes or directly through higher prices for food.

Why is it so important for achieving sustainable agriculture that the possible negative effects – e.g. of using synthetic pesticides – giving rise to chemical residues in food, fossil energy use and pollution of soil and water, get incorporated into the price-regulated market system at higher aggregation levels? One possible answer would be because otherwise, sustainable and responsible pest control and fertilization in cropping systems and the related research budgets will depend only on the local consumers' willingness to pay due to their ethical conviction while the pure "rational economic behaviour" leads them to buy less sustainably produced items. This is especially true for environmental costs of the indirect value type that do not occur directly at the farm-level or within the time-horizon of the farmers' decision making but which become visible only in the long term (like slowly decreasing microbial soil populations) that will affect mainly the next generation of farmers, or take place due to accumulative effects at the regional level (like weed resistance against herbicides due to their repeated region-wide application).

The role of technologies

Integrated pest and nutrient management

One important issue not only for environmentally sustainable agriculture from an energetic point of view but also for human health is the biological control of weeds, pests and pathogens, for example in form of "native weed pathogens" (Quimby *et* *al.*, 2002). This technology plays a role in Integrated Pest Management (IPM), a mixed strategy of selective use of agrochemicals, biological methods, genetic resistance, and appropriate management practices (UNDP, 1992).

For developing countries and following the example of Integrated Pest Management (IPM), Gruhn *et al.* (2000) propagate the approach of Integrated Nutrient Management (INM). INM focuses on the use of carefully derived combinations of mineral and organic fertilizers in combination with complementary crop practices such as tillage, rotation, and moisture conservation (FAO in UNDP, 1992) in order to meet economic productivity goals without sacrificing future soil productivity.

Integrated pest and nutrient management (IPNM), or integrated crop management, places emphasis on rationalizing the use of chemical and other external inputs as much as possible, and stresses the economic use of internal inputs. It has a considerable potential in meeting all three objectives of sustainable development as it combines features of farming based on locally produced organic inputs with the application of modern technology. Thus, it is a technology that does not *a priori* exclude certain inputs, and can therefore have a production frontier function (see Figure 2) that is farther away from the origin and that offers more possibilities for complementarities between environmental and economic objectives. Organic agriculture, on the other hand, limits the use of external inputs to a great extent. Organic agriculture thereby has a production frontier function theoretically closer to the origin compared to IPNM, reducing farmers' choices in the use of internal as well as external inputs and thus limiting the productivity of the agricultural system.

Organic agriculture

Lampkin (in UNDP, 1992) defines organic agriculture as "a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives" while relying "on crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, and aspects of biological pest control. The concept of the soil as a living system (...) is central to this definition." IFOAM defines organic agriculture as referring to its "Basic Standards for Organic Agriculture and Processing" which serve as a common international framework from which regional regulations (like the EC Reg. 2092/91 and 1804/99 for the EU) and more specific national certifying standards are derived. The main issues of these Basic Standards are long-term soil fertility, exclusion of all synthetic N fertilizers and synthetic pesticides, settings for maximum outdoor and total stocking densities, regulation of animal husbandry aiming at maximizing animal welfare, and the exclusion of synthetic feed additives. But due to climatic and structural differences between countries, already ecological farming within Europe and even more worldwide is characterized by diversity (Stolze *et al.*, 2000). IFOAM's "Principle Aims of Organic Agriculture and Processing" include not only agronomic and environmental issues, but also requirements concerning food production, food quality standards, human rights, health, social impacts and democratic principles which are explicitly expressed (FAO, 1998). Unfortunately, no comparable definition and regulative framework exist for conventional farming (Stolze *et al.*, 2000).

Concerning the current discussion on organic agriculture, there is relatively little attention is paid to its contribution to economic and social sustainability, particularly in developing countries. But even with respect to *environmental contributions*, much of the information on the ecological benefits of organic agriculture is formulated in the form of expectations and ecological reasoning rather than on measurable quantitative comparisons. This might be due to the fact that comparative long-term analysis of whole farming systems is methodologically complicated and time-consuming (UNDP, 1992).

Stolze *et al.* (2000) recently analysed the environmental impacts of organic agriculture in Europe comparing it to conventional farming on the basis of OECD environmental indicators for agriculture. Their main findings include that, with respect to *ecosystem and soil fertility indicators*, ecological farming unambiguously shows a greater contribution to floral and faunal diversity, significantly greater biological activity and usually a larger soil organic matter content than conventional farming. For soil structure and erosion control, no clear results could be given. With respect to *ground and surface water* indicators, organic farming results in between 57% less and similar nitrate leaching rates per hectare, whereas the rates per output unit were similar or slightly larger due to the lower yields of organically produced crops. Looking at *climate and air indicators*, quantitative research results exist only for CO_2 emissions and they indicate that emissions on a per hectare basis are 40-60% lower than in conventional farming but again they tend to be higher on a per unit output scale. The same applies to nitrous oxide (N_2O) and methane (CH_4) emission estimates. However, referring to *farm input and output* indicators (nutrients and energy), negative balances were found for P and K in organic farming. Energy efficiency was higher than on conventional farms in most cases. With respect to the *quality of food produced*, the risk of pesticide and nitrate contamination as well as antibiotic residuals is assumed to be lower in organic food, especially in animal products, whereas no clear differences in other wanted (vitamins, nutrients, aromatic compounds) and unwanted substances (heavy metals, PCBs, radioactive contamination) in organic and conventional food could be demonstrated.

Other studies confirm many of the above mentioned findings (see Eltun *et al.* 2002; Kumm, 2002). While ecological farming in Europe shows advantages with respect to many environmental indicators investigated, negative nutrient balances (of P and K) may be seen as the main future challenge to long-term productivity in organic farming (Eltun *et al.*, 2002).

With respect to yield, organic farming is inferior to conventional farming. Cereal yields are typically 60-70% of those produced by conventional methods whereas this reduction is less in potatoes and forage crops (Offermann and Nieberg, 2000).

The smaller amounts of plant available nutrients and the time difference between main nutrient uptake and greatest nutrient availability in the soil, can explain this observation (Eltun *et al.*, 2002). *Labour requirements* per ha of utilisable agricultural area (UAA) in European organic farming are on average 10-20% higher on organic farms. Possible reasons are more labour intensive activities (like weed control) and crops (like potatoes), more marketing and on-farm processing activities, and more information requirements (Offermann and Nieberg, 2000). The observed concentration of organic farms in regions of lower production potential (Offermann and Nieberg, 2000) also contributes to the lower productivity of organic as compared to conventional agriculture. These results imply that farm-gate prices of organically produced food need to be higher than conventionally produced food in order to make organic agriculture financially sustainable. All the studies on alternative farming systems conclude that, without economic support that allows for the positive environmental contributions, a greater movement in the direction of more ecological mixed farming in Europe cannot be expected.

It is important to consider that in economic terms, the environment can be considered as an income elastic good that becomes more valuable to consumers as income rises (van Huylenbroeck *et al.*, 1999). Therefore, as soon as there are trade-offs between economic goals and environmental interests, policy intervention is necessary. In Europe, organic farming is part of an agro-environmental policy scheme that aims at extensification, combined with decreasing yields and lower stocking rates per hectare, while keeping agricultural land in production and avoiding negative externalities (Röhm and Dabbert, 1999).

Transferring these observations to developing countries often leads to discussions on their low purchasing power and poor economies and to the question of how the environmentally more sustainable alternatives for agriculture can be made economically sustainable and contribute to their food security. This argument, however, overlooks the different stage of agricultural development in those countries and the possible synergies that result from positive complementarities between growth in production and the creation of positive externalities. According to the FAO, already, today, successful organic farms can be found worldwide.

Unfortunately, quantitative research results are not yet available to broadly assess the economic viability of organic farms under specific political support conditions in different developing countries. Nevertheless, a UNDP study (UNDP, 1992) gives an overview in the form of a comparison of 21 organic farms in Asia, Africa and Latin America. The results show that despite the overall variation in yield level, yields on organic farms in dry African regions are reported to be more stable in dry years than those on conventional farms. As labour requirements are generally higher than in conventional farming and constitute the main input, production costs depend on the prices and opportunity costs of labour. Large labour requirements due to specific organic production techniques are of advantage for poor farmers and can principally be considered as one of the main attractive aspects of organic farming for rural employment in developing countries whereas they can be the major impediment to organic agriculture in developed countries (FAO, 1998). One important characteristic is that the beneficial effects of organic farming for the farmers appear slowly so that, especially for poor people with shorter time horizons, accompanying "quick-yielding" effects may be needed for long-term adoption of organic farming (UNDP, 1992). This may be particularly true for many countries where conventional yield-increasing inputs like fertilizers and pesticides are subsidized and thus under-valued with respect to their environmental and health costs (FAO, 1998).

Nevertheless, Gatto and Merlo (1999) presented an interesting theoretical framework which shows that there are stages of agricultural development, similar to those in most developing countries, where complementary effects rather than trade-offs between economic and environmental goals are to be expected (see Fig. 2). Based on the concept of a production possibility function, the figure illustrates that agriculture, while producing food and fibre, can either produce positive or negative externalities at the same time. In an initial stage of agricultural development based on traditional practices (A-B), any improvement in countryship stewardship in the form of agro-environmental technologies, like drainage, erosion control, path and road construction and maintenance, crop rotation and the introduction of N-fixing crops, is very likely to increase production efficiencies at the same time and may result in maximum complementarity between food and fibre production and environmental goods and services in developing countries.

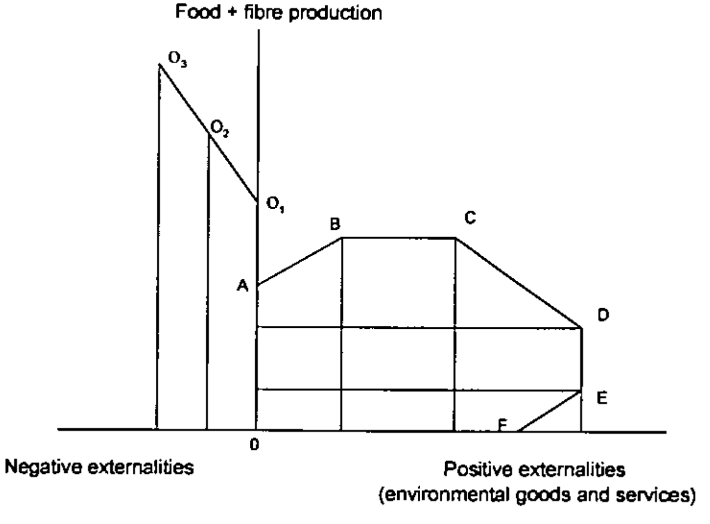

Fig. 2. Hypothetical production possibility function for food and fibre and the production of positive or negative externalities (adapted from Gatto and Merlo, 1999).

In remote areas with low access to external inputs that need good transport infrastructure (like fertilizer bags), organic agriculture (or any future variation of this theme) can offer a potential if there is access to other mainly non-material inputs that are essential for organic farming like ecosystem knowledge and extension services and provided that local or international demand for higher-priced organic produce exists.

However, to resolve the food challenge of the 21st century, i.e. to produce more food at prices affordable for the poor, it is unclear whether organic farming can make more than a niche-type contribution as it may pose the social risk of not producing enough food if greatly expanded at the cost of conventional agriculture. More comparative research of organic versus conventional or integrated farming systems is required, in particular in the tropics and subtropics.

Biotechnology and genetic engineering

Increased investment in agricultural research, making use of ***biotechnology*** and adapted agroecological approaches, as well as investment in rural development in general, offer tremendous potential to resolve the food challenge in the 21st century (Pinstrup-Andersen *et al.*, 2000).

Qaim and Virchow (2000) argue that biotechnology is not a panacea for solving the food challenge. They assert, however, that biotechnology, and genetic engineering in particular, offer outstanding potential to increase the speed and cost efficiency for improving the yield and quality of crops. At the same time, such technologies potentially reduce the use of water, pesticides, N fertilizers, and other conventional crop production inputs as well as agricultural area expansion into ecologically fragile environments thus bringing about substantial positive environmental effects. In two selected case studies from Kenya and Mexico, the authors demonstrate that transgenic crops can be beneficial for farmers and consumers alike in developing countries. Biotechnology offers the possibility to increase rural incomes of smallholder farmers while reducing food prices in developing countries. Both effects are crucial for solving the food challenge as about 60 to 70% of the world's poor currently reside in rural areas and depend either directly or indirectly on agriculture. According to Qaim and Virchow (2000) the private sector can and should play an important role in providing developing countries with access to biotechnology. However, there are a number of technology areas – in particular in semi-subsistence crops such as tubers, or crops that need to be adapted to marginal agroecological environments - that will not be tackled by private research owing to market risks. The public sector (or public-private partnerships) will have to address these market risks if biotechnology is to contribute to poverty reduction. Thus, while biotechnology and genetic engineering have a lot of potential in addressing the objectives of sustainable agriculture, there are also important risks to be considered mainly from the environmental and social point of view. Qaim and Virchow (2000) point out "that profound and pro-poor institutional adjustments in research and regulatory frameworks are essential to ensure that biotechnology does not bypass those who need it most." As with any new technology, its risks must not be neglected and must be carefully assessed. Among the environmental risks are the loss of land races and other biodiversity if (as with the Green Revolution), transgenic crops are too successful and the risk that transgenes escape into the wild through cross-pollination. Other risks include detrimental effects on natural food chains and the emergence of more aggressive pathogen populations. Health risks include the possible occurrence of undesirable toxic by-products in the food, the transmission of antibiotic resistances (used as marker genes) to microorganisms in the human digestion tract and unknown allergic reactions by food consumers.

Therefore, a responsible management of biotechnology is a prerequisite for considering this technology as a possible contribution to sustainable agricultural development. It requires establishing effective regulations for biosafety and food safety wherever transgenic crops are developed and released and that intellectual property rights schemes are developed that provide technology potential for the developing world and recognize the rights of poor countries to their own genetic resources. Responsible technology management, therefore, remains a challenging task for future policies, but must not be confined to the risk side only. Risks should always be juxtaposed with the potential benefits case by case, and certain residual risks appear tolerable if they are offset by much higher benefit prospects.

Hence, Serageldin (1996) and Kendall *et al.* (1997) concluded that - under conditions of responsible technology management - biotechnology could increase global agricultural output in the future while potentially promoting more environmentally friendly agricultural production patterns. However, as responsible technology management requires regulation and their effective enforcement by governments and therefore cannot be taken for granted, and since the risks as well as benefits of biotechnology, as perceived by producers and consumers, vary with the agro-ecological system and the state of economic development, biotechnology and genetic engineering in agriculture is no blueprint solution.

Concluding remarks

Continued agricultural growth and advances in agricultural research and the related use of modern technologies will be a necessity, not an option, for achieving more sustainable agriculture in all its three dimensions. Further, the required increase in agricultural production must not jeopardize the underlying base of natural resources, and it must be equitable if it is to contribute to the alleviation of poverty and food security. Thus, profitability and growth in agriculture will not solve the problems alone as long as the monetary costs and non-monetary obstacles to invest in conservation are not addressed (Vosti, 1992). Government policies, institutional development, agricultural research, and projects at local, regional, and national levels need to be designed and implemented with these objectives in mind.

A number of technologies have the potential to address the challenges of future sustainable agriculture. Among them are integrated pest management, integrated livestock-farming systems, organic agriculture and biotechnology. While each of these technologies may only serve market niches or certain aspects contributing to the overall objective, they nonetheless all deserve to be explored and exploited more. In essence, there are no blueprints for success. Policies as well as technologies need to be designed and context-specific as the importance of the environmental, economic and social objectives and the underlying agricultural systems and socio-economic conditions change from country to country.

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The regulatory framework for a profitable agriculture

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It is a pleasure for me to participate in this Golden Jubilee Congress of the International Potash Institute. The Institute can be proud of the contribution it and the industry it represents has made over the last 50 years to increasing crop yields in farmers' fields and improving world food security. However, farmers and the industry still have a lot of work to do together to meet the food needs of a growing world population, and at the same time protect the natural resource base.

The International Federation of Agricultural Producers (IFAP) is a global forum for farmers from throughout the world to come together to exchange ideas and experiences, and promote common policies and actions at the international level. IFAP has in membership 100 national family farmers' organisation in 71 countries. Altogether the Federation represents about 500 million farm families worldwide. Most member organisations are from developing countries.

Given the correct regulatory environment, farmers can assure the food security of each nation, manage the natural environment sustainably and protect precious soil resources, and help to maintain the vitality of rural communities with their culture and traditions.

IFAP believes that a correct regulatory framework for a profitable agriculture should have two main objectives.

- The first should be to promote a competitive, market-oriented agricultural system that is capable of surviving on more open markets, and can deliver a fair income to the farmer.
- The second should be to provide a framework in which to meet the many expectations that consumers and the general public have for their agriculture.

In striving to meet these two objectives, farmers, the industry and governments have to deal with two important challenges. These are:

- the challenge of globalisation, and
- the challenge of sustainability.

A regulatory framework for globalisation

Globalisation is being driven by spectacular progress in transportation technology and, more recently, in information and communications technology. Government policies have also facilitated economic integration through liberalisation of trade and financial markets. However, the benefits of globalisation have not been shared equally. Many developing countries are being left behind. Yet over 90% of the growth in the world's population is occurring in the developing countries.

The poverty gap between rich and poor countries is widening, particularly in the rural areas. There are about 2 billion farmers in the world but only 5-10% of them are connected with the global agri-food economy. There are over 1 billion people living in absolute poverty and most of them are farmers. This is an unacceptable and unsustainable situation.

Better sharing of the benefits of globalisation

The concern that developing countries must share more in the benefits of global economic growth is now driving the agenda at the international level. There is wide recognition that the global regulatory environment must be improved in order to allow developing countries to become better integrated into the global economic and financial system. Reducing poverty has become the key objective of international institutions. Since 70% of the poverty is in the rural areas, this policy will impact most strongly on agriculture.

There are two main lines of action being taken to improve the international regulatory framework. The first is to create a more 'level playing field' in the WTO for trade in products of export interest to developing countries. The second is to increase the priority given to agriculture, particularly in terms of increased investment and technical assistance, to enable farmers to better exploit market opportunities as they become available.

For IFAP, trade preferences for developing countries are not privileges. They are simply a way for developing countries to participate in world trade along with much stronger partners in the industrialized countries. However, IFAP insists that any trade preferences given to developing countries must actually benefit the farmers in those countries. This means that in return for trade preferences, developing country governments would be required to put in place anti-poverty programs, if they have not already done so.

Stabilising the farm economy

As farmers are more exposed to the volatility of world markets, it is important for them to have access to suitable income safety-net programs, including crop insurance schemes, revenue insurance programs and other risk management tools. The instruments used should be cost-effective in helping to stabilize farmers' incomes, while at the same time not distorting production or trade.

Farmers' organisations would like government regulators to be more active in exploring new options in this area. It should be remembered that farming is first and foremost an economic activity. Without remunerative prices and a reasonable level of income, farmers will not be able to invest in the best agricultural methods, and provide the contribution that society expects of it.

Making markets work

If farmers are to benefit from the new opportunities opened up by globalisation, it is critical that markets function properly. A few large firms now dominate the agri-food chain. There is genuine concern in the farming community that world markets are not functioning correctly, and that world market prices are not reflecting true economic conditions. Attention has correctly been called to the distortions that certain types of government policies can have on the functioning of markets. However, little attention has been given to the market distortions caused by the high level of concentration of commercial companies in the agri-food system.

One of the main themes of the last IFAP World Farmers' Congress was "Industrial Concentration in the Agri-Food Chain". In its policy statement on this subject, the Congress called for a regulatory framework to control oligopolies and monopolies in the agro-food sector.

As one response to the problem of increasing industrial concentration in the agri-food sector, IFAP would like to see more national initiatives to strengthen the position of the farmer in the food chain. Such initiatives would include:

- Effective regulatory frameworks to allow farmers to organise themselves and to consolidate their economic power, through means such as farmer co-operatives, producer groups or direct marketing;
- Inter-professional agreements among producers, manufacturers and distributors of food and agricultural products;
- Production and marketing contracts between farmers and their food chain partners that are based on a fair sharing of the risks, the value-added and the guarantees, while avoiding the integration of farmers into industry structures.

International harmonisation of standards

With globalisation, it is increasingly necessary for national farm policies to be adjusted relative to one another. Otherwise producers who face stricter regulations in their country can be placed at an unfair competitive disadvantage.

One area where this is critical is sanitary and phytosanitary measures. Supplying consumers with safe food is an essential goal for all countries. However, sanitary and phytosanitary measures must be fully transparent so that they are not used as a form of protectionism from imports. The SPS Agreement of the WTO encourages members to use international standards, guidelines and recommendations where they exist. However, members can also set higher standards based on appropriate assessment of risks, so long as the approach is consistent, non-discriminatory and scientific. These conditions are important.

A regulatory framework for sustainability

'Sustainability' is a complex challenge. It covers the multiple functions that agriculture can provide to society, including food security, managing natural

resources such as land and water, preserving rural traditions, culture and landscapes, and contributing to the socio-economic viability of rural communities. In today's environment of more open global markets and increased competition, market forces will not be able to deliver many of these multiple functions expected by society from agriculture. It is therefore an issue for public policy.
The concept of sustainability in a policy context differs from country to country. In the developing countries, the priority is to achieve food security and create jobs in the rural areas. In the industrialized countries, sustainability is viewed more in terms of food safety and quality, countryside management, and maintaining rural culture and traditions.
The regulatory framework for sustainability will obviously not be the same in each case.

Regulatory frameworks for food security and rural development

In order to escape from poverty, farmers in developing countries need equitable access to land, water and other resources. Having access to land is the best possible incentive for individual farmers to preserve and improve soil fertility.
The regulatory framework in developing countries therefore needs to provide secure land tenure to farmers, secure water rights, access to credit at affordable prices, and access to genetic resources such as improved seeds and livestock. Women, who constitute the majority of farmers in developing countries, also need to have legal rights to land and other resources.

Regulatory frameworks for food safety and quality

Farmers are under intense pressure from consumers on food safety and quality issues. Consumers want to know more about how and where their food is produced, and they are increasingly concerned about the healthiness of what they eat. The recent BSE crisis fundamentally changed the attitudes of consumers to farm policy in Europe. Now, food safety is at the top of the agenda. As a result, new demands are placed on farmers, and regulation of farming and food production is increasing.
IFAP adopted a policy statement on "Food Safety and Quality" at its World Farmers' Conference earlier this year. The statement makes a distinction between food safety and food quality.

- Food safety means fitness for consumption. This must be assured by governments through food safety standards.
- Food quality, on the other hand, is related to the special characteristics of a product as a result of regional culture, or special efforts by farmers in their production practices. These can be controlled by producer quality assurance programs, or through certification schemes for the whole product chain that guarantee quality from the seed to the table. Examples include the "little red tractor" British farming standard, or "agriculture raisonnée" in France (FARRE).

Regulatory frameworks for the management of natural resources

At the same time as consumers are putting pressure on farmers and the food chain on food safety and quality issues, the general public is putting pressure on farmers concerning environmental issues.

Farmers are responsible for the management of about 70% of the cultivable land and 70% of the freshwater supplies of the planet, so that it is not surprising that governments are interested in regulating how these natural resources are being managed. In Austria, for example, the Law on Forests lays down strict rules for the correct maintenance, management and protection of woodland. In several Northern European countries, strict rules have been introduced concerning the storage and spreading of animal manure.

In the industrialised countries, there are many examples of government programs to protect the environment. These include: measures to reduce the use of pesticides and the loss of soil nutrients, rewarding farmers for stewardship or environmental services, promoting organic agriculture, maintaining biodiversity, and the development of protected areas.

Farmers strive to use the best farming methods resulting from technological and scientific progress, and manage their farms in a sustainable manner. Many farmers' organizations are working with their colleagues in industry to promote good practices. For example, the fertilizer industry in New Zealand in conjunction with Federated Farmers has developed a Code of Practice for Fertilizer Use. French farmers' organisations established in 1991 voluntary actions for the integrated use of fertilizers ("Ferti-Mieux") and plant protection agents ("Phyto-Mieux"). There are many such examples.

Farmers' organisations have also been active in stewardship and environmental awareness programs. Starting in the early 1990's farm organizations in Canada devised Environmental Farm Plan (EFP) workbooks in order to help farmers to become more aware of their impact on the environment. The Landcare program in Australia is a good example of a community-based approach to sustainable land and water management, promoted by the National Farmers' Federation and the Australian Conservation Foundation in the early 1990s. In 1996, the Swedish Farmers' Federation (LRF) decided to establish workgroups of farmers and rural residents within watershed catchment areas to work out locally adapted plans to reduce plant nutrition leakage.

Due to the dynamic processes occurring in agriculture, it will be difficult for regulators to come up with a rigid and permanently accepted definition of "good agricultural practice". Agricultural practices have to be adapted to local soil and climatic conditions. The best farmers are continually seeking to improve the sustainability of their farms, and can develop best practice more rapidly than governments can document it.

However, where farmers are required by government to follow rules that go beyond normal considerations of what constitutes good farming practice, then government should compensate farmers for the extra costs involved. This concerns the whole area of providing "environmental services", such as protection of wildlife habitat, protection of biodiversity, protection of landscape, etc.

Conclusions

Any regulatory framework for a profitable agriculture must protect people, animals and nature, and it must also provide farmers with a level playing field on which to work. This means that it should ensure:

- sustainable livelihoods to farmers
- food safety for consumers,
- labour standards for workers
- animal welfare for livestock
- conservation of the natural environment for future generations.

Further, with increasing globalization, national regulatory frameworks for agriculture need to be harmonized internationally in order to ensure faimess in competition. However, international rules – particularly trade rules - need to accommodate the diverse situations of agriculture in different countries. And they need to accommodate the diverse aspirations of the people of those countries for their agriculture.

Globalization and fertilizer use: Policy and efficiency issues

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Abstract

Under the Uruguay Round Agreement of Agriculture (URAA), World Trade Organization (WTO) members agreed to decrease tariffs and quotas and reduce export subsidies and domestic support to agriculture to promote the globalization of agricultural markets. It was expected that these changes, especially by the developed countries, would open markets and increase the demand for agricultural exports from developing countries and, therefore, have a positive impact on fertilizer demand. However, these expectations were belied because developed countries implemented their commitments on tariff and subsidy reductions in such a way that it had little impact on agricultural trade, and transitional and developing economies made limited progress on non-liberalization policies, which continued to keep fertilizer demand low. Global fertilizer use showed little increase during the 1990s. In fact, during the first half of the 1990s, global fertilizer use decreased from 145 million tonnes (Mt) of nutrient, i.e. $N+P_2O_5+K_2O$ in 1988/9 to 120 Mt in 1993/4 whereas during the second half it slowly recovered to 141 Mt in 1999/2000. Although the drastic decline in global fertilizer use was caused by the collapse of fertilizer markets in transitional economies, recovery was mainly fueled by increased use in Asian economies. Fertilizer use registered a modest increase in developed economies and stagnated in transitional economies.

Although fertilizer use did not increase during the 1990s, the pattern of trade in fertilizer products changed drastically with transitional economies becoming net exporters because the more than 70% decline in domestic use created large surpluses for exports. This change had a depressing impact on global fertilizer prices and forced further restructuring of the fertilizer industry in developed economies.

Although there is a need to increase fertilizer use to confront the food security challenge, there is also a concern that fertilizer use efficiency remains low in many countries. Average fertilizer use efficiency is estimated to be 20%-50% for nitrogen (N), phosphorus (P), and potassium (K) fertilizers. Proper timing and placement of fertilizer products and use of precision technologies can help to enhance fertilizer use efficiency and thereby create a win-win situation of productivity growth and environmental protection by reducing losses.

Introduction

Globalization is a process by which national markets are integrated with global markets. Since the 1950s, the General Agreement on Tariff and Trade (GATT), has been trying to promote free trade among developed and developing countries by reducing tariffs, quotas, and export subsidies. However, trade in agricultural goods was exempted from these agreements. Grain surpluses of the mid-1980s, mounting burdens of export and production subsidies, and demands from developing countries to improve market access to the developed country markets forced the GATT Secretariat to include agricultural trade for negotiation and discipline. Agriculture was thus included in the last round of GATT negotiations held in Uruguay and completed in 1994. The agreement reached in this round is known as the URAA. Under the URAA, both developed and developing countries agreed to decrease tariffs and quotas and reduce export subsidies and domestic support to agriculture to promote free and fairer trade in agricultural goods. Thus, the URAA initiated the process of globalization of agricultural markets. The distinct characteristics of the Uruguay Round are succinctly summarized by the Organization for Economic Cooperation and Development (OECD, 1993) as follows:

> The Uruguay Round is the most comprehensive and hence complex round of GATT negotiations ever undertaken. The Round seeks to advance trade liberalization in traditional areas, extend the liberalization process to areas not covered at present by the GATT, and tighten up multilateral rules and dispute settlement procedures and enforcement mechanisms. In short, it aims to make the world trading system fairer and more transparent.

It was expected that the implementation of the URAA commitments by various countries will reduce protection by phasing out import tariffs and export subsidies, promote free trade, and lead to an increase in crop prices and production. Increased crop prices and production would provide incentives to farmers to grow more food and non-food crops for export and domestic consumption and thereby increase demand for fertilizers.

This paper attempts to analyze the impact of the globalization process initiated by the URAA on fertilizer use and trade. As a background to the URAA impact analysis, trends in fertilizer use and trade during the period from 1979/80 to 2000/1 are analyzed in the next section. Important policies affecting these trends are also identified. The URAA and its impact on the global fertilizer outlook and related policy and efficiency issues are discussed in the following sections. The last section provides a summary and conclusions.

Trends in fertilizer use and trade

Fertilizer use

Global fertilizer use increased from 112.5 Mt in 1979/80 to 145.6 Mt in 1988/9. After 1988/9, global fertilizer use decreased continuously until 1993/4 when it reached 120.8 Mt (Fig. 1). The drastic reduction in fertilizer use in transitional markets[1] was the main cause for this declining trend. Although fertilizer use reached a plateau in transitional markets and started a declining trend in developed markets, the growth in fertilizer use in developing markets reversed the declining trend in global fertilizer use after 1993/4. With a modest increase in 1994/5, global fertilizer use gradually recovered to 140.5 Mt in 1999/2000. Yet, this amount was still less than that in 1988/9.

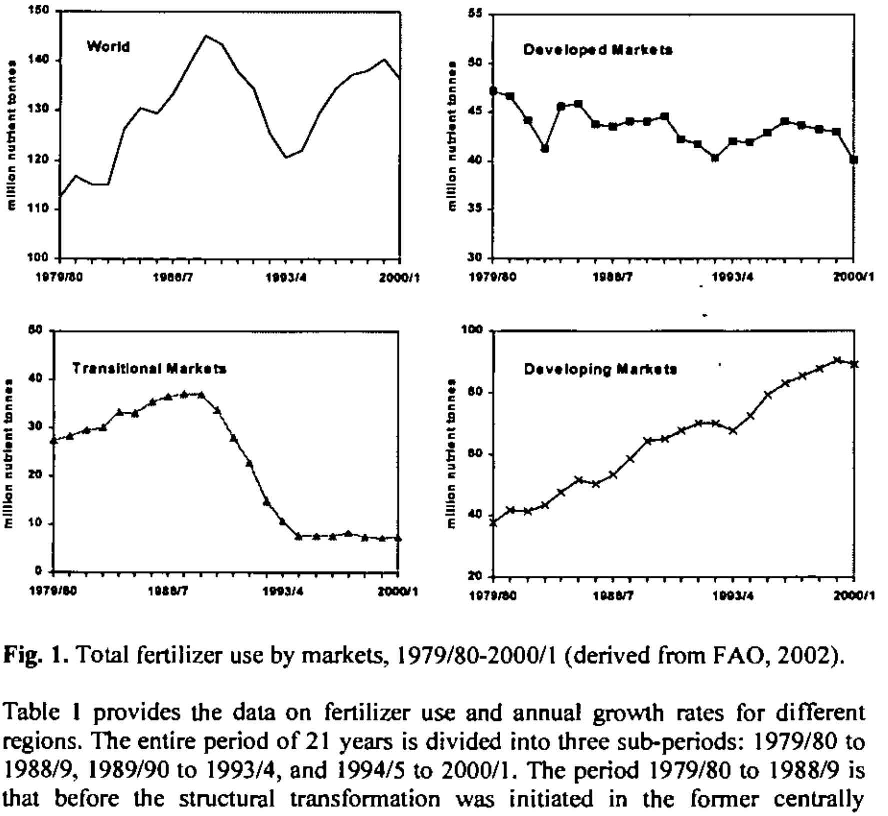

Fig. 1. Total fertilizer use by markets, 1979/80-2000/1 (derived from FAO, 2002).

Table 1 provides the data on fertilizer use and annual growth rates for different regions. The entire period of 21 years is divided into three sub-periods: 1979/80 to 1988/9, 1989/90 to 1993/4, and 1994/5 to 2000/1. The period 1979/80 to 1988/9 is that before the structural transformation was initiated in the former centrally planned economies (CPEs). Also, global fertilizer use peaked at the end of this period, i.e., in 1988/9. During the 1988/9-1993/4 period, significant economic and political changes occurred in Eastern Europe and Eurasia, and fertilizer sectors disintegrated in these regions. The last period, namely 1994/5-2000/1, covers the developments dealing with the implementation of the URAA and therefore is referred to as the post-URAA period.

[1] See Appendix and Bumb and Berry (2002) for details on regional and market classification.

Table 1. World fertilizer use by regions and markets, 1979/80-2000/1 (derived from FAO, 2002).

Region/market	1979/80	1988/9	1993/4	2000/1	Annual growth		
					1980-1989	1989-1994	1994-2001
	(Mt)				(%)		
Developed markets	**47.2**	**44.0**	**42.1**	**40.1**	**-0.8**	**-0.9**	**-0.7**
North America	22.7	19.9	22.7	21.0	-1.5	2.6	-1.1
Western Europe	22.7	22.4	17.2	16.0	-0.1	-5.3	-1.0
Oceania	1.8	1.7	2.2	3.1	-0.6	5.2	4.9
Transitional markets	**27.5**	**37.0**	**10.7**	**7.4**	**3.3**	**-24.8**	**-5.3**
Eastern Europe	10.1	9.8	3.1	3.5	-0.3	-23.0	1.7
Eurasia	17.4	27.2	7.7	3.9	5.0	-25.2	-9.7
Developing markets	**37.8**	**64.2**	**67.7**	**88.9**	**5.9**	**1.1**	**3.9**
Africa	2.8	3.7	3.8	3.9	3.1	0.5	0.4
Latin America	6.7	8.7	8.7	13.1	2.9	0.0	5.8
Asia	28.3	51.7	55.2	71.9	6.7	1.3	3.8
World	**112.5**	**145.2**	**120.5**	**136.4**	**2.8**	**-3.7**	**1.8**

There was little growth in fertilizer use in North America, Western Europe, and Oceania during the first period 1979/80-1988/9. Depressed crop prices, acreage reduction programs, and related policy changes created little incentive to increase fertilizer use. In Eastern Europe, fertilizer use was stable at approximately 10 Mt. On the other hand, strong policy support through subsidies and foreign exchange commitment made fertilizer use grow at 5%/year in Eurasia. A big push for food security supported these developments. In both Africa and Latin America, fertilizer use grew at approximately 3%/year.

Asia continued to experience significant growth in fertilizer use - both in absolute and relative terms. Fertilizer use increased by 85%, from 28.3 Mt in 1979/80 to 51.7 Mt in 1988/9. Most of the Asian countries, including Bangladesh, China, India, Indonesia, and Malaysia, continued to provide a stable policy environment conducive for promoting growth in fertilizer use for food security reasons. No "reform shocks" were introduced. Most of the countries maintained reasonable stability in exchange rate, kept fertilizer prices low and affordable to farmers, made credit available to farmers at reasonable interest rates, and ensured adequate and timely supply of fertilizers through imports and investment in domestic production. The growth in fertilizer use in Asia contributed over 70% to the growth in global fertilizer use during the 1979/80-1988/9 period.

During the second period 1988/9-1993/4, there was a drastic reduction in fertilizer use in Eastern Europe and Eurasia caused by political and economic reforms. Both the nature and scope of these economic reforms and the manner in which they were introduced contributed to the drastic reduction in fertilizer use. The devaluation of domestic currency and removal of subsidies in a "big bang" manner led to astronomical increases in fertilizer prices. The sudden withdrawal of the government from fertilizer marketing and distribution made the situation change from bad to worse. The disintegration of the USSR created fragmented and dysfunctional fertilizer markets. The lack of management skills and credit for dealers and farmers and underdeveloped crop markets have kept recovery in fertilizer use either slow or minimal. During the first 5 years of economic and political reforms, the size of the domestic fertilizer market was reduced by over 70% in Eastern Europe and Eurasia. The decline in fertilizer use in these regions was so large that it exceeded the greater than 7% growth in fertilizer use in Asia and, in consequence, the global trend in fertilizer use was downward. In addition, decline in fertilizer use in Western Europe also contributed to a decrease in global fertilizer use. Macroeconomic instability in Latin America and reforms of the common agricultural policy (reduced support for commodity programs) and environmental regulations in Western Europe were other significant policy measures that affected fertilizer use adversely in the early 1990s.

During the post-URAA period, fertilizer use decreased in both North America and Western Europe. Policy changes related to production and export subsidies, and environmental measures seem to have impacted fertilizer use in these regions. In Eastern Europe, there was a modest recovery (from 3.2 Mt to 3.5 Mt), whereas in

Eurasia it continued to decrease mainly because of exchange rate instability (the crash of the ruble in 1998) and fragmented input supply systems. The lack of conducive policy environments and poor marketing infrastructures created a near stagnation in fertilizer use in Africa, especially in Sub-Saharan Africa (Fig. 2). Such stagnation is a matter of great concern because this region is suffering from chronic food insecurity problems. Increased crop prices of the 1995-1998 period created incentives for farmers in Oceania and South America to increase fertilizer use. In both regions, fertilizer use increased by over 5%/year. In Asia also, fertilizer use increased by 3.8%/year. However, in absolute amounts, Asia's fertilizer use increased by 12 Mt and thereby accounted for over 80% of the growth in global fertilizer use. Thus, during the last two decades, the global fertilizer story has become an Asian fertilizer story. A strong commitment to promote food security and maintenance of a conducive policy environment created such an impressive growth in Asian markets. It is interesting to note that unlike South America and Eurasia, East Asia maintained a strong growth in fertilizer use in spite of currency crises of the late 1990s. A detailed analysis of the policy environment in East Asian countries will be desirable to develop a policy agenda for promoting growth in fertilizer use in Eurasia and Africa.

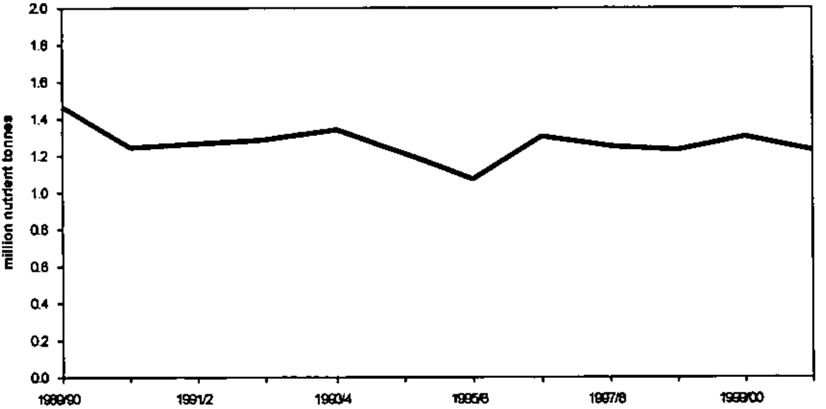

Fig. 2. Sub-Saharan Africa: fertilizer use, 1989/90-2000/1 (derived from FAO, 2002).

Fertilizer trade

Global fertilizer imports increased from 34 Mt in 1979/80 to 48.3 Mt in 1988/9 (Table 2). During the period 1988/9 and 1993/4, global fertilizer imports stagnated at an annual average rate of 48.5 Mt mainly due to reduction in fertilizer imports in the transitional markets, which offset the increase in fertilizer imports in the developing markets.

Table 2. World imports and exports of fertilizer, 1979/80-2000/1 (derived from FAO, 2002).

Fertilizer	1979/80	1988/9	1993/4	2000/1
	(Mt)			
Imports				
N	12.6	19.7	20.7	28.1
P_2O_5	5.8	9.4	10.5	12.1
K_2O	15.5	19.2	17.4	23.5
Total	**34.0**	**48.3**	**48.5**	**63.7**
Ratio of imports to fertilizer use (%)	30.2	33.3	40.2	46.7
Exports				
N	11.9	19.2	20.0	24.7
P_2O_5	6.8	10.1	11.1	12.1
K_2O	15.6	20.5	17.1	23.4
Total	**34.1**	**49.8**	**48.2**	**60.2**
Ratio of exports to production (%)	29.0	31.6	31.4	42.4

Note: Totals may not add due to rounding.

The drastic reduction in domestic fertilizer use not only led to reduced imports by transitional markets but also made these regions net exporters of fertilizers. For example, before the fall of the Berlin Wall in 1989, Eastern Europe was a net importer of fertilizers, but in 1994/5, it became a net exporter (Table 3). Likewise, Eurasia increased its exports significantly and changed its position from a net importer to a net exporter of phosphate fertilizers. The slow growth in fertilizer use and macroeconomic difficulties in Africa and Latin America also contributed to stagnation in global trade. However, after 1993/4, global trade in fertilizers increased at an annual rate of 3.9%. By 2000/1, global fertilizer imports reached 63.7 Mt. The ratio of imports to consumption increased from 30% in 1979/80 to 47% in 2000/01 - signifying the increasing role of trade in meeting fertilizer requirements.

Global fertilizer trade increased at a faster pace than global fertilizer use during the 1979/80-2000/1 period. The main reason for this growth in fertilizer trade is that the developing regions as a group are net importers of fertilizers, and Asia is also a significant importer. In contrast, both developed and transitional regions are net exporters. Thus, continued growth in fertilizer use in Asia provided the necessary stimulus for growth in fertilizer trade. In part, this is because Asia and other developing countries have limited resources to produce all the fertilizers required. Among developing regions, only Central America, North Africa, and West Asia are significant exporters of fertilizers while all other developing regions, including East Asia, South Asia, South America, and Sub-Saharan Africa, are net importers. These are also the regions where fertilizer use is expected to increase to meet the challenges of food security and environmental protection.

Table 3. Net fertilizer imports by region, 1979/80-1994/5 (derived from FAO, 2002).

Region		1979/80	1988/9	1994/5
			(Mt)	
I.	**Developed markets**			
	North America	(6.7)	(8.1)	(9.2)
	Western Europe	(3.0)	(1.2)	2.3
	Oceania	0.3	0.7	1.5
II.	**Transitional markets**			
	Eastern Europe	1.5	1.2	(1.5)
	Eurasia	(3.0)	(6.0)	(9.1)
III.	**Developing markets**			
	Africa	**0.9**	**(0.8)**	**(1.0)**
	North	0.2	(1.5)	(2.1)
	Sub-Saharan	0.6	0.8	1.0
	South	0.1	(0.0)	-[a]
	Latin America	**3.6**	**3.8**	**4.8**
	Central	1.0	0.8	0.7[b]
	South	2.7	2.9	4.2
	Asia	**6.0**	**10.6**	**12.2**
	East	3.2	10.5	11.3
	South	3.1	2.5	4.1
	West	(0.4)	(2.4)	(3.2)

a. Amount less than 50,000 tonnes.

b. Central America is a net exporter of N fertilizers.

Notes: Net is imports minus exports. Numbers in parentheses are net exports.
Totals may not add due to rounding.

Most developing regions do not have adequate resources to become self-sufficient in fertilizer production. Although natural gas is widely available in different regions, potash ore and phosphate rock are mainly in North America, Eurasia, and North Africa. Hence, other developing countries have to depend on imports. Even in those countries where natural gas is available for the production of N fertilizers, unremunerative and lower prices in the mid-1980s and early 1990s discouraged investment in domestic production and encouraged reliance on imports. Noteworthy examples of this phenomenon are India and China, which slowed investment in domestic production and relied increasingly on imports. Moreover, under the structural adjustment programs (SAPs), many developing countries had already liberalized their fertilizer markets during the 1980s and early 1990s.

Impact of globalization on fertilizer use

The URAA

As explained earlier, the globalization of agricultural markets started with the implementation of the URAA in 1995. Under this agreement, various countries made commitments to decrease import tariffs and convert quotas into tariff bounds through tariffication, reduce export subsidies, and minimize trade-distorting support to agriculture (Matrix A). Under these commitments, developed countries were required to reduce average tariffs by 36% (with a minimum of 15% for each tariff line) during the 1995-2000 period and developing countries by 24% (with a minimum of 10% for each tariff line) during the 1995-2004 period. Likewise, export subsidies and domestic support to agriculture were to be reduced by different rates in developed and developing countries. It should be noted that developing countries were given a longer period to reduce tariffs by a smaller percentage. This was done to recognize the fact that developing countries still had a long way to go and needed additional time for development. There was also recognition that the degree of protection and export subsidies were higher in the developed countries than in developing countries and, therefore, it was the former who needed to open their markets to imports from the latter. Moreover, all countries were allowed exemption under the Green Box and Blue Box measures (FAO, 1998; WTO, 1995). Although countries agreed to reduce tariffs and export subsidies, several lacunae and exemptions compromised the potential impact of the agreement (Hathaway and Ingco, 1996; Valdes and McCalla, 1996). Nevertheless, the URAA developed a framework and set the stage for future negotiations to liberalize trade in agricultural commodities. The Seattle Round of 2000 was a debacle, but the Doha Round of 2001 re-ignited the process of negotiations about market access, export subsidies, and domestic support to agriculture so that new commitments about these issues could be finalized by the end of 2004 for the new round of trade liberalization. Overall, the main beneficiaries of the URAA and future liberalization efforts will be the consumers in the OECD countries because removal of tariffs and quotas will lead to lower prices and more choice of agricultural products. The farmers in food-exporting countries will also benefit whereas consumers in the food-importing countries may experience a small loss in welfare due to higher food prices. Recent estimates by the International Monetary Fund (IMF, 2002) indicate that industrial countries could reap benefits worth $100 billion from liberalization, and global benefits could reach $128 billion.

The effective implementation of the URAA was expected to result in increased crop prices and output in the global market.

Matrix A

Uruguay Round Agreement on Agriculture (URAA): Basic provisions			
Provisions	Developed Countries (DDCs)	Developing Countries (DVCs)	Least Developed Countries (LDCs)
I. Market access commitments			
1. Convert all NTBs (non-tariff barriers) into tariff-tariffication	Yes	Yes	Yes
2. Bind all tariffs	Yes	Yes	Yes
3. Reduce all tariffs (existing and NTB-related)	average 36% over 1995-2000 with a minimum of 15% for each tariff line	average 24% over 1995-2004 with a minimum of 10% for each tariff line	Exempt
4. Increase share of imports in domestic consumption (1986-88 base)	3%-5% (1995-2000)	3%-5% (1995-2004)	3%-5% (1995-2004)
5. Special Safe Guards (SSG)	Yes	Yes	Yes
II. Export subsidies			
1. Ban on new export subsidies and increase in existing subsidies	Yes	Yes	Yes
2. Reduce volume of subsidized exports (base: 1986-90)	21% (1995-2000)	14% (1995-2004)	Exempt
3. Reduced expenditure on export subsidies (base: 1986-90)	36% (1995-2000)	24%[a] (1995-2004)	Exempt
III. Domestic support Reduce aggregate measure of support (AMS) (base: 1986-88)	20% (1995-2000)	13.3%[b] (1995-2004)	Freeze at 1986-88 level
IV. Green Box Provisions	Applicable	Applicable	Applicable
V. Blue Box Provisions	Applicable	Applicable	Applicable

a. Subsidies on marketing and transportation costs are excluded.
b. Input subsidy for poor farmers, investment subsidies, and diversification subsidies are exempt.
Source: WTO (1995).

Expected price and output increases are summarized in Tables 4 and 5.

Table 4. Expected changes in world prices between 1987-89 and 2000 (derived from FAO, 1995).

Item	Baseline	Uruguay Round (UR) (%)	Total[a]
Wheat	-3	+7	+4
Rice	+7	+7	+15
Maize	+3	+4	+7
Millet and sorghum	+6	+4	+10
Other coarse grains	-3	+7	+5
Fats and oils	-4	+4	0
Oil meals	+3	0	+3
Bovine meat	+6	+8	+14
Pig meat	+3	+10	+13
Sheep meat	+13	+10	+24
Poultry	+5	+8	+14
Milk	+32	+7	+41

a. Total does not necessarily equal the sum of two effects.

Note: "Baseline" refers to projected changes in the absence of the UR, while "UR" takes its effect into account.

Table 5. Growth in production from 1987-89 average to 2000 (calculated from FAO, 1995).

	Regions/ countries	Wheat		Rice		Other grains		Oil-meal proteins	
		Base	UR	Base	UR	Base	UR	Base	UR
		(% per year)							
I.	**Regions**								
	World	1.7	1.6	1.8	1.8	1.6	1.7	3.0	3.0
	Developing	2.7	2.9	1.9	1.9	2.9	2.9	4.0	4.2
	Developed	0.8	0.6	0.7	0.2	0.8	0.9	1.8	1.8
II.	**Countries**								
	Argentina	1.4	1.9	6.3	6.2	3.5	3.8	6.0	6.2
	Mexico	1.0	1.3	1.9	2.0	2.2	2.3	1.8	1.8
	China	2.8	2.9	1.5	1.5	3.1	3.0	2.6	2.5
	India	2.9	3.1	2.0	2.0	0.3	0.4	5.6	5.7
	Pakistan	2.8	3.3	1.2	1.3	2.5	2.8	3.9	3.9
	United States	2.4	2.1	2.2	2.3	2.1	2.3	1.6	1.6
	EU-12	-0.5	-0.9	2.1	-0.8	0.2	-0.3	2.4	2.5
	Australia	2.0	2.7	2.2	2.4	1.4	2.3	6.0	6.0

Note: "Baseline" refers to projected growth rates in the absence of the UR, while "UR" takes its effect into account.

The results indicate that due to URAA, agricultural prices were projected to increase from 4% for wheat to 41% for milk. Prices of other cereals could increase from 5% (coarse grains excluding maize) to 15% (rice). Surprisingly, these increases in global grain prices seem to have a marginal impact on global grain production, mainly because of production shifts from OECD countries to developing countries and Oceania. Maize is the only crop for which production is expected to increase in the United States, mainly for export of feed grains (FAO, 1995).

The increased prices were expected to create two counter-balancing effects. First, farmers in the food-exporting countries (Argentina, Brazil, and Thailand in the developing markets and Australia, Canada, and New Zealand in the developed markets) would have an incentive to grow more food products for export. Besides, farmers in the food-importing countries will have an incentive to increase food production because increased prices in the global market will make domestic food relatively cheaper. This could lead to a higher level of food self-sufficiency in food-importing countries. Both of these effects were expected to have a positive impact on fertilizer use. Similarly, a reduction in tariffs on fertilizer imports would contribute to an increased demand for fertilizers in fertilizer-importing countries. However, these positive effects could be counterbalanced by a likely decrease in grain production resulting from the reduction in import tariffs and export subsidies in the OECD and other countries. Increased prices would also have a dampening effect on demand for food in food-importing countries. The studies conducted by FAO, OECD, and other organizations indicate that the net impact of these two contradictory forces could be a small gain in global grain production but relatively large gains in some countries and regions (FAO, 1995). These changes may create a modest impact on fertilizer use.

Generally, increased grain prices lead to an increase in fertilizer use by making fertilizer use relatively more profitable, but increased grain prices also lead to increased fertilizer prices. The removal of subsidies on fertilizer exports under the UR agreements may also lead to increased fertilizer prices. Naturally, increased fertilizer prices may have a negative impact on fertilizer use and imports unless these increases are compensated by other measures such as subsidies. However, because many countries have eliminated fertilizer subsidies under SAPs and economic reforms, fertilizer subsidies are unlikely to be available. Macroeconomic reforms leading to devaluation of domestic currency and instability in exchange rate can have a significant negative impact on fertilizer use by making fertilizer prices increase substantially, as happened in Ghana, Poland, Russia, and other reforming countries (Narayan and Bumb, 1995). As developing and transitional regions reform their macroeconomy through changes in exchange and interest rates and reduction in budget deficits through removal of subsidies, fertilizer use may continue to be adversely affected. In fact, the negative impact of these reform measures may outweigh the positive impact of the URAA on fertilizer use.

FAO (1997) estimated the impact of the URAA on fertilizer demand. The study uses the projected increase in crop production to estimate a likely increase in fertilizer use by using the fertilizer elasticity of crop production in different developing regions. For the developed regions and China, the study uses projections of area harvested to estimate the impact of the URAA on fertilizer use. Overall, global fertilizer use is estimated to increase by less than 1% primarily due to the URAA impact on crop production in the year 2000 (Table 6). In the developing countries, fertilizer use will be higher by 1% and in the developed countries by 0.1%. Because the liberalization of agricultural trade is expected to help agricultural exporting countries relatively more, fertilizer use is expected to be higher by 3% in South and Central America. In South and East Asia, fertilizer use is projected to be higher by 0.7% (1.7% if China is excluded).

Table 6. Global and regional impact of the UR on the use of fertilizer, 2000 (FAO, 1997).

Item	Nitrogen	Phosphate	Potash	Total
	(%)			
World	0.6	0.8	0.8	0.7
Developing countries	0.9	1.1	1.6	1.0
Near East	1.3	1.5	0.8	1.4
Latin America	2.3	3.6	3.9	3.2
South and East Asia	0.7	0.6	0.4	0.7
South and East Asia (excluding China)	1.8	1.6	1.2	1.7
Developed countries	0.0	0.1	0.2	0.1

The positive impact of the URAA on fertilizer demand would also have a positive effect on fertilizer trade because the fertilizer industry has become a demand-driven industry. As explained earlier, global trade in fertilizers had been growing even before the URAA. The URAA could further strengthen the on-going trends in fertilizer trade by a modest margin.

The implementation experience of the 1995-2000 period indicates that many countries, especially developed countries, implemented their commitments on import tariffs and export subsidy reduction in such a way that it created only a modest impact (OECD, 2001; WTO, 2001). Domestic support to agriculture has also been reduced by a minimal amount, although a large proportion has been moved from price-based support to Green Box measures. Recent estimates by OECD, as reported in IMF (2002), indicate that about 33% of the farm income in OECD countries was in the form of subsidies totalling over $300 billion and amounting to six times the overseas development assistance. Moreover, the new US Farm Bill 2002 has reintroduced price-based support to farming. All these developments indicate that the implementation of the URAA has generated only small benefits, if any, for global agriculture. A recent study (OECD, 2001) concluded that "the overall effects have been moderate". Even crop prices have been lower during the post-URAA period. If the impact of URAA is moderate on world agriculture, can it be significant on global fertilizer use and trade?

Impact of the URAA on fertilizer use and trade

To analyze the impact of the URAA on fertilizer use and trade, annual growth in fertilizer use and trade during the 1994/5-2000/1 period (post-URAA period) is compared with the performance of the fertilizer sector during the 1979/80-1988/9 period (referred to as pre-URAA period) because structural changes in transitional markets disrupted the global and regional trends in fertilizer quantities during the 1989-1994 period. Thus, if the annual growth in fertilizer use and trade during the post-URAA period was greater than that during the pre-URAA period, it may indicate that the globalization resulting from the implementation of the URAA had a positive impact on fertilizer use and trade. If the growth rate is less during the former period than that during the latter period, then the conclusion is obvious that the URAA had little impact. However, such a conclusion may have to be qualified to ensure that other factors did not compromise the URAA impact.

During the post-URAA period, global fertilizer use increased from 120.5 Mt in 1993/4 to 136.4 Mt in 2000/1, an annual rate of 1.8%. In contrast, global fertilizer use increased at an annual rate of 2.8% during the pre-URAA period. From this comparison, it is obvious that the implementation of the URAA did not have a significant impact on global fertilizer use. At the regional level, globalization seems to have had different impacts (see Table 1 for details). In Latin America and Oceania, fertilizer use grew at higher rates during the post-URAA period than during the pre-URAA period, whereas in Africa, Asia, Eurasia, North America, and Western Europe, the situation was reversed. In Eastern Europe, fertilizer use increased at 1.7% per annum during the post-URAA period. However, it should be noted that this growth started from a base that was only one-third of the level that prevailed during the pre-URAA period. In North America and Western Europe, decline in use was attributable to both policy changes and environmental concerns.

Likewise, the impact of the URAA on global trade in fertilizers is also minimal (Table 7). Global fertilizer imports increased at an annual rate of 3.9% during the pre-URAA period and in the post-URAA period. At the regional level, the picture is mixed. In all three market groups, fertilizer trade grew at a lower annual rate during the post-URAA period[2] than during the pre-URAA period. Fertilizer imports have increased at a higher rate in North America and Latin America during the post-URAA period. However, it should be noted that these two regions had fewer tariffs on fertilizer products even before the URAA. In Western Europe, as fertilizer use decreased, fertilizer trade also shrank. Moreover, Western Europe used anti-dumping measures to restrict imports from Eastern Europe and Eurasia (IFDC, 2000).

[2] The practice of differential subsidies on domestically produced and imported fertilizer products in some countries including India may have slowed the growth in fertilizer trade.

Table 7. World fertilizer imports by regions and markets, 1979/80-2000/1 (derived from FAO, 2002).

Region/market	1979/80	1988/9	1993/4	2000/1	1980-1989	1989-1994	1994-2001
	(Mt)				Annual growth (%)		
Developed markets	**16.1**	**21.1**	**22.5**	**29.3**	**3.9**	**1.3**	**3.8**
North America	7.8	8.1	10.0	14.7	0.4	4.2	5.5
Western Europe	7.9	12.2	11.2	12.7	4.8	-1.7	1.8
Oceania	0.3	0.8	1.4	2.0	10.9	11.2	5.1
Transitional markets	**3.4**	**4.5**	**1.8**	**2**	**3.1**	**-18.3**	**1.5**
Eastern Europe	3.3	4.3	0.7	1.7	2.9	-36.3	12.7
Eurasia	0.1	0.2	1.1	0.3	7.7	34.1	-18.6
Developing markets	**14.5**	**22.8**	**24.3**	**32.4**	**5.0**	**1.3**	**4.1**
Africa	1.3	1.6	1.6	2.1	2.3	0.0	3.9
Latin America	3.9	4.3	5	9.8	1.1	3.0	9.6
Asia	9.2	17	17.6	20.5	6.8	0.7	2.2
World	**34.0**	**48.3**	**48.6**	**63.7**	**3.9**	**0.1**	**3.9**

Why has globalization had little impact on global fertilizer use and trade? There are several possible explanations. First, progress on the implementation of the URAA commitments was slow and crop prices did not increase as much as expected. Consequently, there was little price incentive for farmers to increase fertilizer use. Second, little reduction in tariffs on fertilizer imports was realized because tariffs on fertilizer imports were already low but more significantly, in anticipation of import surges, several countries introduced higher tariff bounds to protect their domestic industry (Table 8). Third, non-liberalization policy changes, such as exchange rate depreciation, debt crises (East Asia, Latin America, and Eurasia), environmental regulation (North America and Western Europe), and fragmented markets, especially in Sub-Saharan Africa, Eastern Europe, and Eurasia, constrained the growth in fertilizer use and trade.

Table 8. Tariffs on fertilizers in selected countries (GATT, 1994).

	Tariffs on fertilizers	
	Pre-URAA	Post-URAA[a]
	(%)	
Developed countries		
Canada	0	0
United States	0	0
Australia	0-2	10
European Union	0-8	0-6.5
Poland	10	6.5
Developing countries		
China	5-6	20
South Korea	20	6.5
India	0-5	5
Pakistan	16	40
Bangladesh	0	0-50

a. Bound rates.

Policy and efficiency issues

Policy issues affecting fertilizer use and trade

While analyzing the trends in fertilizer use and trade, several policy developments were mentioned. However, developments in three areas, namely, currency devaluation, subsidy removal, and privatization, need special attention because developments in these areas seem to have had a profound impact on fertilizer use and trade.

Currency devaluation: Devaluation of domestic currencies during the structural transformation of the CPEs and SAPs in developing countries has affected fertilizer use in several countries. Depreciation of domestic currency adds to the cost of inputs for farmers and risk and uncertainty in the import business. This latter effect discourages investment in input imports and thereby increases input prices, which reduces profitability of input use. Stability in exchange rate is essential to promote growth in fertilizer use. Inflation and high interest rates resulting from devaluation create a credit squeeze for both farmers and dealers and discourage fertilizer use. Exchange rate stability is essential for both input use and food production.

Subsidy removal: After the energy crises of the 1970s, many developing countries introduced fertilizer subsidies to keep fertilizer prices low and affordable to farmers. Likewise, former CPEs also heavily subsidized inputs. In some countries, the level of fertilizer subsidy was over 80%. When these subsidies were suddenly removed under economic reforms and SAPs, fertilizer prices increased several fold and reduced fertilizer use drastically. Devaluation of currency increased the negative impact of subsidy removal on fertilizer use. For example, nominal fertilizer prices increased by over 12,000% in Ghana during the 1982-1990 period, when the value of cedi depreciated and fertilizer subsidy was removed (Bumb *et al.*, 1994). During that period, fertilizer use decreased by two-thirds. Likewise, during the 1988-1993 period, with currency devaluation and subsidy removal, fertilizer use decreased by over 70% in Eastern Europe and Eurasia.

Privatization: Both in developing countries and transitional economies, fertilizer production and distribution was mostly a public sector monopoly. When these monopolies were abolished during economic reforms, input supply channels disintegrated because the private sector was not ready to accept this responsibility. As a result, many farmers could not access inputs easily. To avoid the misunderstanding that privatization *per se* is bad, it should be stressed that the manner in which public sector monopolies were dismantled created an organizational vacuum. A well-phased program of privatization can improve input supply and reduce prices; this type of situation occurred in Bangladesh (Ahmed, 1999). However, in many countries in Africa and Eurasia, input markets remain fragmented and dysfunctional. There is a need to build private sector capacity to create well-functioning input markets in these regions.

Fertilizer efficiency issues

Large farm yields are needed to increase rural incomes and confront food security challenges, and balanced, adequate fertilizer use is a necessary component. However, there is a concern that fertilizer use efficiency remains low in many countries. Average fertilizer use efficiency is 20%-50% for the primary nutrients - N, P, and K. The crop use efficiency of micronutrients is even lower (5%-10%). Nutrient use efficiency, based on grain harvest, is 33% for N, 10%-20% for P (including residual effects), and 17%-30% for K.

The efficiency of fertilizer use is dependent on the synchrony between plant demand and nutrient release or supply. During the early period of plant growth, nutrient supply from soils and mineral fertilizers exceed plant demand; therefore, nutrients may be at risk to loss or retention in the soil in forms not immediately available to plant. If mechanisms could be developed to more nearly match plant demand with nutrient supply, then nutrient use efficiency could be increased and losses minimized.

The imbalance between nutrient supply and crop nutrient demand can be minimized to a large extent by:

1. Proper placement of fertilizers as in deep placement of large briquettes (N, P, or K) or banding of P fertilizers in highly P-fixing soils.
2. Precision application of fertilizers as dictated by source (most effective for N fertilizers), season, cultivar, climate, water management, soil type, and cropping pattern. A site-specific fertilizer recommendation based on both the supply and demand of nutrients takes into account indigenous nutrient supply, yield target, and nutrient demand as a function of the interactions between N, P, and K. Precision timing is implemented as per site- and season-specific rules and field-specific monitoring (tissue analyses, chlorophyll reading).
3. Controlled-release fertilizers (CRFs) that supply nutrients at controlled and predictable rates as determined by the type and thickness of coating, soil moisture content, and temperature. Based on crop growth duration and environmental conditions, CRFs provide an excellent match between crop nutrient demand and nutrient release.
4. "Smart" innovative fertilizers that combine above synchrony with crop protection measures and improved water harvesting.
5. Crop rotations and intercropping with legumes and pastures can boost nutrient supply to cereal crops. Synchronization of supply of nutrients from such cropping systems/organic sources with plant demand is more difficult because decomposition is dependent on soil properties, moisture, temperature, cultural practices, and type of organic material. Perhaps a more beneficial effect of cropping systems and organic residues is the improved nutrient use efficiency of applied fertilizers due to better soil health, root formation, and water content.

Finally, conventionally bred and genetically engineered varieties are being released for higher nutrient use efficiency resulting from (1) better nutrient acquisition by roots, (2) higher production per unit fertilizer applied, (3) rhizospheric modification for increased nutrient concentration, and (4) better tolerance and resistance to abiotic and biotic stresses. Balanced use of potassium fertilizers could reduce biotic and abiotic stresses.

Summary and conclusion

The Uruguay Round is one of the most comprehensive, complex, and unique rounds being the first round in which negotiations about reducing tariffs, quotas, and trade-distorting export subsidies on agricultural products were undertaken, and the final agreement on agriculture (URAA) was reached in 1994. Under these agreements, developed and developing countries agreed to reduce import tariffs, export subsidies, and trade-distorting support to agriculture. However, many countries, especially developed countries, implemented their commitments in such a way that it produced minimal impact on agricultural trade. In some cases, countries have introduced more subsidies. Consequently, the impact of URAA has been minimal on world agriculture and insignificant on global fertilizer trade and use. Both global fertilizer use and trade grew at a relatively faster pace during the pre-URAA period than during the post-URAA period. Several non-liberalization policy developments also compromised URAA impact on global fertilizer use. However, some regions seem to have benefited from the globalization process.

Global fertilizer use remains below the level achieved in 1988/9. To meet the food security challenge of feeding over 8 billion people in 2025, fertilizer use must be increased in an environmentally sound way. A conducive and stable policy environment is essential to promote growth in fertilizer use. However, fertilizer use efficiency remains low in many countries and therefore efforts are also needed to promote efficient fertilizer use. Improved efficiency will create a win-win situation by promoting productivity growth and environmental protection through reduced nutrient losses.

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Agro-economic benefits of balanced fertilization

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Abstract

Balanced fertilization is part of integrated soil and crop management and balance must be sought between the nutrient requirements of crops, their response to nutrient inputs and the socio-economic setting within which farming takes place. Nutrient audits can capture the scale of the problem of nutrient depletion in world soils and the trends are particularly serious in Africa. Low-input sustainable agriculture will be unable to meet the 3-5% projected growth in food demand in Africa unless a high external-inputs agriculture is practised.
With stagnating fertilizer use, per capita food production/availability will fall if productivity increases do not match population increases. Balanced fertilization can promote sustainable agricultural development in which increases in crop yield lead to improved food security, affordable consumer food prices, increased agricultural employment and improvements in the rural economy. Benefits of balanced fertilization are transmitted to the wider rural economy through prices and markets; multiplier effects and institutional changes can spread them even further. Access to livestock, labour, credit and markets are important in explaining which farmers are best able to maintain and improve soil fertility.
The optimum combination of the nutrients nitrogen (N), phosphorus (P), and potassium (K) depends on their separate and combined contributions to plant yield and also on their relative prices. Compound fertilizers should be made available to farmers with nutrient contents and at prices which enable them to satisfy their individual soil-crop requirements at minimum cost. Lack of available nutrients in appropriate amounts and ratios and at unrealistic prices prevents farmers choosing balanced fertilization in many parts of the world. Despite the benefits of balanced fertilization, there are many constraints to its widespread adoption. Key results from soil science must be integrated with tractable models of small-scale farming and rural livelihoods if we are to achieve improved fertilization.

Introduction

Balanced fertilization is an important component of integrated soil and crop management that includes improved soil moisture storage, use of organic and inorganic fertilizers and other soil amendments. Balance must be sought not just with regard to the nutrient requirements of crops and soils but also with respect to the socio-economic setting within which farming takes place. Integrated soil management practices are crucial to arresting soil degradation and increasing farm productivity and household incomes but often structural difficulties and unfavourable market price relations and economic returns have impeded implementation. The optimum combination of the nutrients nitrogen (N), phosphorus (P), and potassium (K) depends not just on their separate and combined contributions to soil fertility and crop yield but also on their relative prices. Soil nutrient depletion is widespread particularly in Africa. The depletion of K is particularly severe and could ultimately lead to a serious loss of crop productivity in many countries. Inorganic fertilizers hold considerable potential for nutrient replenishment but are often applied at rates well below recommended levels, or not at all. This paper looks at some of the economic issues and benefits of the balanced use of fertilizers.

Fertilizer nutrient audits

Sheldrick *et al.* (2002) carried out national, regional and worldwide soil nutrient audits using a mass balance model which measures nutrient imports into the soil and nutrient exports from the soil in crop and livestock products. The model uses an FAO database for 197 countries for the period 1961 to 1996. The results show:

- World food production is, currently, on average, depleting nutrients in the soil.
- In 1996 average world soil depletion was 12.1 kg N ha^{-1}, 4.5 kg P ha^{-1} and 20.2 kg K ha^{-1} and between 1990 and 1996 depletion rates increased sharply.
- Negative balances for N, P and K exist in rice production systems in Bangladesh, Indonesia, Myanmar, Philippines, Thailand, and Vietnam.
- There are some surplus balances in West Europe, Japan and Malaysia.
- Very high nutrient depletion rates are widespread in Africa where, over decades, small-scale farmers have removed large quantities of nutrients from their soils without using sufficient quantities of manure, fertilizer or crop residues to replenish the nutrients removed.
- As a percentage of total soil nutrient inputs, manure accounts for 14% N, 25% P and 20% K. The worldwide contribution made by manure relative to fertilizers plus manure is declining. Since 1961 the percentages have decreased; for N from 60 to 25, for P from 50 to 38 and for K from 75 to 57 (Sheldrick *et al.*, 2003) Put simply, there are not enough livestock, manure and crop residues to feed the world. Organic food production will fulfill a small, important, niche role in both developed and developing country agriculture but mineral or inorganic fertilizers have a key role to play in maintaining soil fertility and the productivity of world food production systems.
- Soil K depletion now seriously threatens soil reserves and world food security.

The nutrient flows for K are shown in Table 1. Crop residues are particularly important for K but a large amount of the K in crop residues is not actually returned to the soil.

Table 1. Potassium nutrient flows in world farming in 1996.

Potassium					
IN	Mt K	% total	OUT	Mt K	% total
Fertilizer	15.3	14.9	Arable crops	23.6	22.9
Crop residues	36.8	35.7	Crop residues	61.3	59.5
Manure	20.2	19.6	Losses	18.1	17.6
Sewage	0.1	0.1			
From soil	30.6	29.7			
Total	103.0	100.0	Total	103.0	100.0

Source: Sheldrick *et al.* (2002).

We should however be careful in interpreting these results; nutrient budgets do not give an indication of the overall stocks of nutrients available and, in some cases, nutrient depletion may well be occurring in settings where considerable stocks exist and no immediate concern for productivity is apparent. In such cases nutrient depletion may be a sensible short-term option particularly if, under changed economic and social circumstances, investment in soil improvement and recapitalisation then takes place (Scoones, 2001).

The benefits of balanced fertilization

To feed the world's growing population will require gains in output that are only possible with a plentiful and assured supply of plant nutrients to sustain the needed increases in crop yields. A high external-input agriculture is required to ensure world food security. Fertilizer contributes to increased crop production in several ways (Bumb and Baanante, 1996):

(i) First, by replenishing nutrients it helps to maintain and enhance soil fertility and thereby sustains crop production.

(ii) Second, fertilizer enables modern high-yielding varieties (MVs) which can potentially increase cereal yields several fold to be grown. Without a plentiful supply of nutrients through fertilizers and other inputs, such varieties are unlikely to achieve their potential yield. Early studies of the impact of the green revolution on rice production increases in Asia attributed 27 Mt to high yielding varieties, 34 Mt to irrigation and 29 Mt to fertilizers (Pinstrup-Andersen and Hazell, 1985). Between 1950-70, fertilizer and varieties combined contributed some 44%, irrigation 26%, labour 12% and capital 16% towards output growth of rice in highly irrigated areas in South Korea, Pakistan and Indonesia (Barker *et al.*, 1985).

(iii) Third, in nutrient-poor soils of the tropics, fertilizer use can increase both yields and biomass; additional biomass can be ploughed back to augment the supply of organic matter which improves moisture retention, nutrient use efficiency and soil productivity. Used as a vegetative cover, crop residues also help to reduce soil erosion. Well managed and balanced fertilizer use can thus create a 'win-win' situation by increasing food production and reducing soil degradation in nutrient-poor, fragile soils.

(iv) Fertilizer use is generally labour-intensive and should increase rural employment both in terms of fertilizer application, crop-care activities and harvesting the additional yield which the fertilizer nutrients generate. In this way it contributes to sustaining rural wages and employment but this effect can be double-edged. Increasing numbers of farm households in Africa are currently losing their working age members to disease and migration to urban areas and cannot afford to hire in any labour. (Omamo *et al.*, 2002). In such cases the increased labour requirements from fertilizer using acts as a constraint to its uptake and adoption.

(v) Finally, fertilizer can make an important contribution to sustainability and inter-generational equity by preserving and conserving the natural resource capital in the soil. In other words, fertilizer is required for both food security and resource conservation.

Putting the benefits together – a Philippine case study

It is difficult to identify and isolate the benefits of fertilizers from many other influences in rural development. Diffusion of modern technologies, of which fertilization is a part, has taken place within a setting of population pressures, land reform, public infrastructure investment, growing urban influences and globalisation of world agriculture. Hayami and Kikuchi (2000) chart long-term developments in a Philippine village in which frequent rounds of detailed survey data has been collected since the 1960s. Fertilizer nutrient applications grew from 15 kg/ha in 1966 to 132 kg/ha in 1995 ($N+P_2O_5+K_2O$) which in association with public sector irrigation development and growing high yielding varieties increased average village rice yields from 1.9 to 4.5 t/ha. This allowed the village to feed itself and, in addition, generate agricultural marketed surpluses to counter the rapid and sustained population growth and in-migration which took place in the 1970s.

Subsequently, land reform combined with population growth to change the class structure of the village from dominant farmer households to landless labour households. The labour-intensive technology of unmechanised land preparation, fertilizer and agrochemical applications and harvesting and threshing the larger crops provided employment for tasks formerly carried out by family labour. In the 1990s with farm mechanisation and a privatised irrigation system, village livelihoods became increasingly dependent on non-farm employment opportunities particularly for women who became small village shopkeepers, rice traders and food vendors. Diversified livelihood sources and pluri-activity prevented per capita incomes from declining. The rural village has since become more connected to wider urban economic activities via output, input and labour markets. Income is being repatriated to the village from migrant workers in the Middle East, new urban-style housing has been constructed, the village road was paved in 1994, housing density has risen and there are fewer trees. A creeping process of 'village urbanization' is taking place and there has been some loss of rurality. Small farmers have now diversified livelihood sources and are active, competitive traders in rice and other markets. Cottage industries are beginning to emerge in the village tied by sub-contracting arrangements with large manufacturers and traders in metro Manila.

In economic terms, 'endogenous growth' (internally generated) is now taking place. As incomes rise, so do savings and investment, investment in human capital (education) is increasing and imperfections in rural markets and infrastructure are being gradually reduced. The main benefits of balanced fertilizer use in this case have been in helping villagers to 'kick-start' rice production to overcome structural handicaps and reach the 'take-off' stage for economic development. Once soil and natural capital has been formed and agricultural marketed surpluses generated, sustained soil management can make further investment more productive and allow diversification. Such a process should eventually be possible in parts of Africa (Koning *et al.*, 2001).

Balanced fertilization and economics

Profit maximising, efficient farmers should aim to produce a given level of crop output (say a yield of 1 t/ha) at minimum cost. This implies combining the various nutrient inputs such that the marginal productivity per $ spent is the same across all nutrient inputs.

That is,

$$\frac{MP_N}{P_N} = \frac{MP_P}{P_P} = \frac{MP_K}{P_K} \qquad (1)$$

where the MPs are the marginal productivities of the various nutrients (the contribution to yield of the last 10 kg unit applied) and the Ps are the relative prices (for 10 kg of N, P and K, respectively). If the price of a nutrient falls, ceteris paribus, we should use more of that nutrient and substitute it for another nutrient and vice-versa for a rise in the price of a nutrient. Nutrient complementarities should also be optimised. A major issue is the inter-relationship of K with N. If K is limiting, then N use efficiency is often impaired and the economic response of N applications reduced. Remedial K inputs may yield significant benefits indirectly in improving the response to N; this situation is thought to prevail in many parts of China where the economic returns to K inputs could be large (Syers, personal communication). In this way we determine the optimal combination of nutrient inputs; only when equation (1) is satisfied do we have the least-cost combination or balance of nutrient ingredients. This relationship should also hold for all other farm inputs such as labour, pesticides, mechanisation, irrigation, etc.

In addition we should apply the individual nutrients up to the points where:

$$P_N = MP_N \times P_{OUTPUT}$$
$$P_P = MP_P \times P_{OUTPUT}$$
$$P_K = MP_K \times P_{OUTPUT} \qquad (2)$$

That is, for profit maximisation, we apply nutrient inputs up to the point where the cost of the last 10 kg of nutrient is just balanced by the additional value of crop output that the last 10 kg of nutrient input generates. This is the familiar marginal cost equals marginal revenue relationship. Balanced fertilization thus depends upon nutrient input prices, crop output price and the underlying crop - nutrient response curves; changes in any of these parameters will, in theory, change any recommended fertilizer application. Such relationships are commonly referred to in production economics and farm management as 'the laws of equi-marginal value returns'. Farmers can purchase straight fertilizers containing only one nutrient such as muriate of potash (0-0-60) or urea (46-0-0) and then apply them to attempt to satisfy equations (1) and (2) and thus to maximise profits.

However, in practice, farmers may be faced with a restricted range of fertilizers in the market possibly of compound or complex fertilizer brands or blends containing various, fixed combinations of the three plant nutrients N, P and K. The one to choose whilst simultaneously matching nutrient inputs to soil and crop requirements and at the same time minimising costs is often a difficult exercise. Table 2 shows a 2001 price list for 21 compound fertilizer brands on sale in the UK with several different N, P and K ratios. The choice of fertilizer is far from obvious but some brands represent better value for money than others.

We may hypothesise that there is a relationship between the price of a blended compound fertilizer and its nutrient contents. i.e. the price is related to the N:P:K ratios. Statistical analysis confirms this. The following regression equation was fitted to the price data in Table 2.

$$\underset{}{\text{PRICE}} = \underset{(3.825)}{44.541} + \underset{(6.453)}{2.310\ \text{NITROGEN}} + \underset{(6.161)}{1.722\ \text{PHOSPHORUS}} + \underset{(5.074)}{1.160\ \text{POTASH}}$$

$$R^2 = 0.723$$

Figures in brackets are t-statistics

Broadly interpreted this equation tells us that there is indeed a linear relationship between compound fertilizer prices and their nutrient contents. The coefficients on the N, P and K variables are all statistically significant at the 99% level and 72.3% of the variation in prices across the 21 fertilizers is explained by their nutrient contents.

We can then use this equation to predict the 'value for money' of the various brands simply by putting their NPK ratios/contents into the equation and comparing their actual list prices with their predicted prices. The difference or residual is an indication of value for money; a negative residual indicating a good buy, a positive residual an overpriced brand. These residuals are shown in Figure 1; brands above the zero deviation line represent poor buys, below good buys or bargains.

Table 2. UK compound fertilizer prices, July 2001.

	Nutrient analysis			Price per tonne
	N	P	K	£
Brand 1	0	24	24	115
Brand 2	0	18	36	115
Brand 3	0	20	30	115
Brand 4	0	30	15	115
Brand 5	0	30	20	115
Brand 6	5	24	24	125
Brand 7	8	24	24	130
Brand 8	10	24	24	130
Brand 9	10	10	30	122.50
Brand 10	12	15	20	120
Brand 11	13	13	20	127.50
Brand 12	15	15	20	132.50
Brand 13	15	15	19	130
Brand 14	17	17	17	132.50
Brand 15	20	4	14	115
Brand 16	20	10	10	120
Brand 17	20	8	12	115
Brand 18	22	11	11	137.50
Brand 19	24	4	4	107.50
Brand 20	25	5	5	115
Brand 21	25	0	16	112.50

Prices are for fertilizer *delivered* in bags; delivery in bulk averages £7/tonne less. Discounts for cash payment approximately £2.50/t. They assume delivery in 20 tonnes lots.

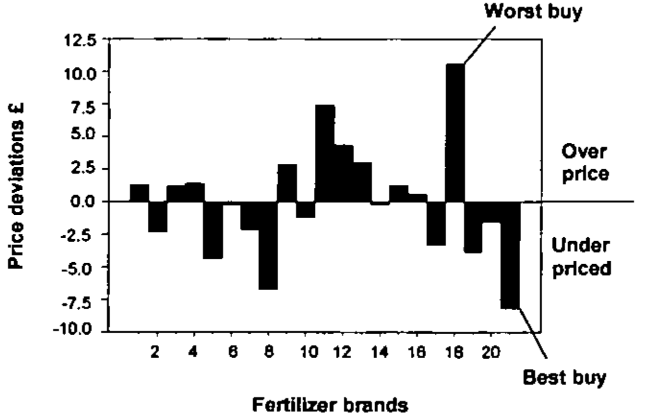

Fig. 1. UK compound fertilizers 2001, best buys/worst buys.

Brand 18 is overpriced by £10.57 whilst brand 21 is a best buy, its price being some £8.20 below what its nutrient contents would justify. Farmers should attempt to purchase fertilizers 'below the line' which match their soil and crop requirements and avoid the over-priced, uncompetitive brands or blends wherever possible. What this simple example illustrates is a further complexity introduced into determining and implementing balanced fertilizer recommendations once market considerations are taken into account. Resource-poor farmers have neither the knowledge, time nor skills to perform such analyses but it is important that they are served by a well-functioning, competitive fertilizer marketing and distribution system if they are to get 'value for money' and apply at recommended rates and nutrient ratios (Omamo and Moses, 2001). Competition in fertilizer markets should eventually eliminate price distortions and excessive pricing.

Conclusions

The benefits of balanced fertilizer use are many but soil fertility depends on a wide range of factors many of which lie outside the purely biophysical domain. It is unlikely that any one single intervention, by itself, such as phosphorus recapitalisation will make a big difference to soil fertility management and livelihoods (Scoones, 2001). There is an urgent need to understand the basic rationale of small farmer livelihoods, their access to the necessary capital for development and the dynamics and diversity of soil nutrient mining. An integrated soil management programme requires considerable investment; for soil and water conservation and organic fertility measures these consist mainly of labour time; for inorganic fertilizer use mainly money and credit. The full benefit of these investments appears only after a considerable time lag. Nutrient depletion is taking place gradually over time. The observed yield effects are small but cumulative and the question arises as to the optimal timing of any recapitalisation measures. There are learning effects as farmers acquire new knowledge and adapt it to local conditions. Nutrient recovery is initially low and soil capital can only be built up over time. The low initial productivity reduces the profitability to farmers particularly if interest rates on borrowed capital are high. Poor farmers unsurprisingly have short time horizons and high discount rates, both of which are not conducive to sustainability. However once enough soil capital has been formed, the improved soil condition will make further investments more remunerative. Access to livestock, labour, credit and markets are important in explaining which farmers are best able to maintain and improve soil fertility

The economic costs and benefits of balanced fertilization is not always readily available and there is a need to combine biophysical nutrient response data with price information in making recommendations. Conditions in fertilizer markets are crucial. Fertilizers in Africa cost 2 to 6 times more than prices in Europe, USA or Asia (Sanchez, 2002) and policies are required to reduce these price disparities. Economic and social analysis is necessary to place the issue of soil fertility management in its wider context. Inter-connections must be made between biophysical processes of nutrient depletion and the socio-economic processes operating at local, regional, national and even international levels. Agro-ecosystems differ immensely in space and time. We must capture their key differences in our analysis if we are to understand and improve them.

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Session 2: Panel Discussion

Economic constraints in achieving sustainable crop production

Role of fertilizers in achieving sustainable crop production in Romania

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Romania is a medium sized country in Central-South Eastern Europe. Physiographically it includes three major, approximately equal size relief units, namely 30% mountains, 37% hills and plateaus and 33% plains. The total area is 23.839 million ha (Mha), of which 14.856 Mha are agricultural land, 6.457 Mha are forests and forest-type vegetation, 0.633 Mha are built on construction, 0.388 Mha are roads and railways, 0.868 Mha are surface water, 0.636 Mha are in other uses. The agricultural area is 62.32% of the total area, with 0.66 ha per inhabitant, while the arable area is 39.35% of the total area, with 0.42 ha per inhabitant. The agricultural area includes 9.381 Mha of arable land, 3.442 Mha of pastures, 1.507 Mha of meadows, 0.272 Mha of vineyards and grape-vine nurseries, 0.255 Mha of orchards and fruit-growing nurseries (Romanian Statistical Yearbook, 2001).

The working population in agriculture and contribution of agriculture to the gross national product

In Romania, agriculture represents one of the largest and most important economic activities. In 2000, 40.8% of the total working population were engaged in agriculture, and in the last 9 years it provided, on average, 16.89% of the gross national product (GNP).

The percentage of the working population engaged in agriculture has been increasing, from 28.2% in 1990 to 33.6% in 1995, 34.6% in 1996, 36.8% in 1997, 37.4% in 1998, 40.6% in 1999 and 40.8% in 2000 (Romanian Statistical Yearbook, 2001). This increasing trend will continue during the next 2-3 years, until the end of the industrial reorganization process, but it will then decrease because the rural population is getting older. The average agricultural contribution of 16.89% to the GNP, compared to 40.8% of the working population, shows the small contribution of agriculture to the GNP, emphasizing the low productivity, the low professional level, the ageing rural population and the material endowment (a large volume of manpower, animal energy use), etc.

With improvements in the Romanian economy, the agricultural contribution to the GNP has decreased in the last 9 years as follows: 18.56% in 1992, 19.58% in 1993, 19.40% in 1994, 19.33% in 1995, 18.78% in 1996, 17.63% in 1997, 14.23% in 1998, 12.91% in 1999 and 10.63% in 2000 (Romanian Statistical Yearbook, 2001).

In the same nine year period, the investment in agriculture has been only a small proportion of national investment, namely 10.19% in 1992, 6.6% in 1993, 18.74% in 1994, 10.73% in 1995, 11.23% in 1996, 6.25% in 1997, 6.47% in 1998, 6.72% in 1999 and 7.5% in 2000 (Romanian Statistical Yearbook, 2001). This is because of the low profitability or frequent losses in agriculture.
The opposite situation exists in the European Community budget where, in 1996, agriculture contributed only 1.7% to GNP but its budget represented 54.8% of the total budget. At the same time, the working population engaged in agriculture is only 5.8% and continues to decrease (Ribbe, 1996). At present, Romania's agriculture is severely affected by a lack of capital, unreliable machinery and poor technical support. In addition, there are very limited economic incentives available for private farmers to invest in agriculture and in environmental improvements.

Size and ownership of farms

By the Law of Land No. 18/1991, the agricultural land was returned to its former owners, and, by 1998, this had resulted in considerable structural change:

592 agricultural commercial societies, mostly with state capital, occupied 1.7156 Mha, with an average area of 2,898 ha/farm unit;

3,864 legal agricultural societies occupied 1.9050 Mha, with an average area of 493 ha/farm unit;

15,107 family farm associations occupied 1.4352 Mha, with an average area of 95 ha/farm unit;

4,206,507 individual farms occupied 9.6750 Mha, with an average area of 2.3 ha/farm unit.

The national rehabilitation and development programme for agriculture, the food industry and forests for 2001-2004 stipulates that there should be:

a decrease in the number of individual farms from 4.2 to 3.6 million;

an increase in the number of legal agricultural societies from 3,864 to 5,400;

an increase in the number of family farm associations as a result of the application of the law concerning agricultural households (Law No. 108/2001). This stipulates that the minimum size of a farming unit should be 110 ha in the plains, 50 ha in the hills, 25 ha for meadows, 2 ha for vegetables, 5 ha for orchards, 5 ha for vineyards, 0.5 ha for glasshouses, etc. The minimum number of animals are 15 cows, 50 steers, 300 sheep, 100 pigs, 2,000 chickens, etc. The land can be divided into a maximum of 4 units;

an increase to 1.6 Mha in the area that is irrigated, 0.4 Mha in 2001, 0.8 Mha in 2002; 1.2 Mha in 2003 and 1.6 Mha in 2004.

To promote these processes for change, the Parliament issued Law No. 31/2001 regarding "the compensation of damages caused by natural calamities in agriculture", and Law No. 73/2002 on "organisation and function of agricultural and food markets in Romania". Additionally, to improve the management of these farms, the Ministry of Agriculture, Food and Forests issued the Order No. 60/2002 to "approve the rules to empower the private persons as leaders and managers of farms".

The state initially will subsidize the application of minimum quantities of fertilizers for winter wheat, maize, soybean, sunflower and textile crops. The professional level of farmers will be increased by technical and economic support and there will be compulsory training courses for farmers and managers farming more than 20 ha, and for agricultural mechanization.

Soil resources

The soils of Romania are complex and highly variable. According to the Romanian Soil Classification System, there are 10 genetical soil classes, 39 genetical soil types, and almost 500 genetical soil sub-types. The dominant soils are Chernozems and Phaeozems (27.6%), Luvisols (22.5%), Cambisols (19.5%) and weakly developed soils (14.5% - Fluvisols, Regosols and Arenosols).

A land capability classification of the agricultural land shows that only 2.8% (410,000 ha) are in the first class with very few limitations, 24.6% (3,656,000 ha) are in the second class with a few limitations, 20.7% (3,083,000 ha) are in the third class with some limitations, 24.4% (3,623,000 ha) are in the fourth class with severe limitations, and 27.5% (4,085,000 ha) are in the fifth class with very severe limitations.

With current demographic and ecological trends, the sustainable development of soil use and soil protection is one of the most pressing current problems. The preservation of soils and their fertility, as well as a stable balance of natural processes within them, are esential prerequisites for the food security of a growing population (Sussmuth, 1998). The rapidly escalating deterioration of the soil in many countries is a danger to the vital natural resource base of 900 million people. According to World Bank estimates, about two-fifths of the productive land in Africa, a third in Asia and a fifth in Latin America, are at risk from desertification.

The data of the Romanian National Soil Quality Monitoring System show that about 12 Mha of agricultural land, of which about 7 Mha are arable land and are more or less affected by one or several limitations (Table 1). These limitations cause a deterioration in soil functions, i.e. they affect soil bio-productivity capacity as well as the yield and crop quality and threaten food security.

During the last 10 years of subsistence agriculture, with very little use of amendments and organic and inorganic fertilizers, the area of moderately and strongly acid soils has increased from 2.369 Mha to 3.424 Mha (a 31% increase), while the area of soils with a small and very small content of humus increased from 4.876 to 7.485 Mha (an increase of 35%). Similarly the area of soils with a small and very small amount of readily plant available P increased from 4.473 to 6.330 Mha (an increase of 29%) while the comparable data for K were an increase from

0.498 to 0.785 Mha (an increase of 37%). The area of soils with little available N increased from 3.348 to 5.110 Mha (a 35% increase).

Table 1. The main factors limiting agricultural soil productive capacity in Romania in 2001[a].

Limitative factors	Agricultural area 1,000 ha	Arable area 1,000 ha
Frequent drought	7,100	
- out of which equipped with irrigation schemes	3,211	
Periodical soil moisture excess	3,781	
- out of which equipped with drainage schemes	3,196	
Water soil erosion	6,300	2,100
- out of which with works of soil erosion control	2,274	
Landslides	702	
Wind soil erosion	378	273
Excessive stoniness at soil surface	300	52
Soil compaction due to irrational cultivation (plough pan)	6,500	6,500
Primary soil compaction		2,060
Crusting	2,300	2,300
Low-extremely low humus content	7,485	5,313
Strong and moderate acidity	3,424	1,878
Strong alkalinity	222	134
Low and very low mobile phosphorus content	6,330	3,327
Low mobile potassium content	787	312
Low nitrogen content	5,110	3,041
Micronutrient deficiency (zinc)	1,500	1,500
Soil disturbance by various excavations	15	
Land covering with solid wastes	18	11
Soil chemical pollution due to different socio/economic activities, out of which:	900	
- excessive pollution	200	
- pollution with oil and brine	50	
- pollution with air-borne substances	147	82

These data confirm the prognoses prepared on the basis of data obtained from the long-term field experiments. These experiments show that after a 9-10 year period, soils can become so acid that liming is essential, that without P fertilizers for 10 years, as now happens in Romania, the soil P supply decreases from 36 mg/kg

[a] The same area can be concomitantly affected by several limitative factors.

(moderate P status) to 16 mg/kg (low P status), or from 10 mg/kg (low P status) to 4 mg/kg (very low P status), and the available K values decrease from 100 to 60 mg/kg (from low to very low K status). The optimum rates of K fertilizers (in order to ensure the economic fertilization efficiency) do not compensate for the K removed by the crops and, therefore, do not prevent a decline in the K_{AL} content in soil. Applying only N and P, decreases the K_{AL} content of the soil to such an extent that, on soils initially with a low and moderate available K status, the efficiency of fertilization with NP only decreases very much. At K_{AL} values <80 mg/kg, the efficiency of fertilization with NP becomes hypothetical (Borlan, 1998).

The rationale for P applications is to maintain the soil just above the critical value. This can be done by replacing the P removed in the harvested crop. Only 15-20% of the total amount of P in the plant comes directly from the P fertilizer applied; the remainder must come from soil reserves. These reserves will be seriously depleted if they are not replaced (Johnston and Steen, 2000).

The risk of a decrease in the humus and nutrient content of soil will be more serious where irrigation is used. With optimum soil moisture, biological activity will be stimulated, and, when organic and mineral fertilizers are not applied, the microorganisms will mineralize soil organic matter thus leading to its rapid decrease. At least where nitrogen is used, sufficient organic and mineral fertilizers should be applied to compensate for the nutrients removed by the crop. Thus, irrigation water utilization indexes could also increase, increasing the economic efficiency of irrigation.

Cropping in Romanian agriculture is dominated by cereals (about 70% winter wheat and maize) and technical and industrial crops (about 15% sunflower, potatoes and sugar beet). But the crops and the rotations still do not meet food security, industrial processing demands, the needs of a diversified market and a sustainable agricultural development. Risks connected with the poor cropping patterns are significantly worsened by the primitive market organization that makes it difficult to reliably quantify the effects of an increase in cash crop production on food prices, or identify new important markets for products. The lack of efficient marketing structures, both at the regional and national levels, excludes local producers from considerable market opportunities.

The reduced performance of the agricultural sector is also due to the fact that, during the first 6 years after the 1989 revolution (1990-1996), the state, in order to obtain social peace, artificially maintained lower prices for agricultural products than for the industrial ones. The price index of agricultural products in 2000, as compared to that in 1990, taken as 100, is 82,841.5, an increase of 828.4 times. For the industrial products required by agriculture the price index in 2000 was 241,651 compared to 1990 taken as 100, an increase of 2,416.5 times (Table 2). For example in 2000, as compared to 1990, the price of tractors increased by a factor of 1,987, that of agricultural machines by 2,145, of spare parts by 2,465, chemical fertilizers by 1,625, fuels and lubricants by 3,760, and electrical power and thermal energy by a factor of 2,576. Generally, these very large increases exceeded those for the whole national economy (Lazar, 2000).

Table 2. Price index of agricultural products and price index of industrial products required by agriculture and their ratio ("price scissors"), in 1990/2000 (Lazar, 2001).

Year	Price index of agricultural products 1990 = 100	Price index of industrial products required by agriculture 1990 = 100	Ratio between prices index of agricultural products and price index of industrial products required by agriculture
1991	642.2	1,702.2	37.7
1992	1,401.2	2,757.1	50.8
1993	4,417.9	6,590.7	67.0
1994	9,842.5	13,428.4	73.3
1995	12,585.0	18,539.2	67.9
1996	19,535.0	32,197.9	60.7
1997	37,163.9	74,211.3	50.1
1998	44,795.1	110,531.4	40.5
1999	53,655.7	142,205.9	37.8
2000	82,841.5	241,651.1	34.3

From Table 3, which shows the changes in the prices of several chemical fertilizers, it can be seen that prices in 1994 were higher than in 2000, while the production technology remained the same. Thus, in the first years after the revolution, fertilizer producers unjustifiably increased prices and this alienated farmers. The return of the urea and ammonium nitrate prices in July 2002 to those in December 2000 did not cause any increase in consumption.

Table 3. Evolution of delivery prices for chemical fertilizers ($/t).

Year	Fertilizer type			
	Urea	Ammonium nitrate	Nitrophosphate	Diammonium phosphate
January 1994	274.8	304.8[a]	451.8	277.7
June 1994	296.5	371.1[a]	444.3	348.6
December 2000	169.2	165.2[b]	266.2	313.4
July 2002	173.4	142.9[a]	271.4	361.8

All the data are from S.C. SOFERT S.A. Bacau, except [a] SC TURNU SA – Turnu Măgurele and [b] SC AZOMUREŞ SA – Târgu Mureş.

The average prices for chemical fertilizers in 1990-2000 given in Table 4, emphasize the very different prices between years and these prices were not related to the cost of production.

Table 4. The change in the average prices of chemical fertilizers during 1990-2000, thousand lei/t.

Year	N	P_2O_5	K_2O
1990	4.8	5.3	2.5
1991	67	131	42
1992	67	131	42
1993	215	310	144
1994	650	800	450
1995	850	1000	700
1996	950	1126	781
1997	1240	2235	1238
1998	4700	4800	2800
1999	5000	5700	8500
2000	7500	8500	5500

The considerable difference between the price index of agricultural and industrial products (Table 2) led to many farmers having large financial losses when they purchased machinery, etc. These losses were further increased due to the large bank interest rates caused by inflation, the import of highly subsidised products with low customs duties and the loss of external markets and of domestic agricultural markets. In addition, there is no law that adequately offers farmers access to credit.

Fertilizer consumption and crop yields

Changes in the use of chemical fertilizer in Romania between 1950 and 2000 are shown in Table 5. The tremendous decrease of fertilizer consumption following the peak in the mid 1980s is mainly due to the following factors:

- decline in production and consumption in the Central and Eastern European countries;
- transition from the state centralized agriculture to private market-oriented agriculture, that affected both the internal and external markets;
- loss of the internal market for agricultural products due to the access of foreign, strongly subsidized agricultural products, with little or no custom duties;
- lower productivity of Romania's agriculture compared to that in the European Union;
- the restoration of private ownership of agricultural land led to the creation of small farms, so that a medium farm is 2.3 ha, and each hectare is divided in 3-4 parcels; these farms can only practice subsistence agriculture;
- poor educational standards of the 40.8% of the population involved in agriculture;
- low efficiency of agricultural extension services;
- poor organization of soil testing services, leading sometimes to a lack of correct recommendations;

- poor organisation of fertilizer stocking, distribution and administration when the old system was destroyed without creating a new one;
- lack of credit for both agricultural and fertilizer production;
- excessive instability of the financial system;
- the bankruptcy of many banks and high interest charges (over 100% most of the time) discouraged farmers from using higher inputs;
- low investment in agriculture with the cessation of soil improvement programs, irrigation schemes and the destruction and loss of orchards, vineyards and vegetable farms;
- the increases in the prices for inputs, including machinery and fertilizers, while maintaining control of agricultural product prices, a situation was reached such that the larger the quantity of crops produced, the larger were the losses;
- lack of an organized market and an adequate information system.

Table 5. Changes in the use of chemical fertilizers in Romanian agriculture.

Year	Chemical fertilizers (tons of active ingredients – a.i.)				$N + P_2O_5 + K_2O$ (kg/ha)	
	N	P_2O_5	K_2O	Total	Arable	Utilised agricultural area
1950	2,564	1,625	1,705	5,921	0.6	0.4
1955	9,467	7,146	5,325	21,938	2.3	1.6
1960	24,690	46,810	2,960	74,460	7.6	5.1
1965	144,469	110,166	11,806	266,391	27.1	18.0
1970	366,918	203,171	24,258	594,347	61.0	39.8
1975	571,867	314,350	42,484	928,701	95.4	62.2
1980	646,315	389,441	77,757	1,113,513	113.6	74.7
1985	674,759	342,031	182,405	1,199,193	120.5	80.1
1986	706,934	387,375	200,990	1,295,299	129.9	86.4
1990	656,094	313,108	133,873	1,103,075	117.0	74.8
1995	305,800	149,600	14,700	470,100	49.7	31.8
1996	268,000	153,000	14,000	435,000	46.6	29.4
1997	262,000	129,000	13,000	404,000	43.3	27.3
1998	254,000	114,000	15,000	383,000	41.0	25.9
1999	225,000	93,000	13,000	331,000	35.4	22.5
2000	239,279	88,258	14,637	342,174	36.4	23.0

All these factors resulted in a continuous decrease of mineral fertilizers use in Romania after the 1989 Revolution, from 86.4 kg/ha utilised agricultural area (UAA) (129.9 kg/ha arable land) in 1986, to 23.0 kg/ha UAA (36.4 kg/ha arable land) in 2000, while the application of organic manures decreased from 2.65 t/ha arable land (1.67 t/ha UAA) in 1990 to 1.68 t/ha arable land (1.07 t/ha UAA) in

2000 (Tables 5 and 6). Even in 1986, the year with the largest consumption of fertilizers, Romania used only 5% more than the average use in the European Community in 1960/1961, namely 12.8 kg/ha.

Table 6. Changes in the use of organic manures in Romanian agriculture (t/ha).

Year	1980	1985	1990	1995	1996	1997	1998	1999	2000
Utilised agricultural area	1.69	2.30	1.67	1.18	1.20	1.11	1.07	1.13	1.07
Arable land	2.67	3.65	2.65	1.86	1.91	1.76	1.69	1.78	1.68

Compared to the numbers of livestock in Romania in 1989, the numbers have decreased (Table 7). If all the wastes from these livestock were applied to the whole agricultural land, the nutrients applied would be 8.8 kg N + 5.1 kg P_2O_5 + 8.5 kg K_2O/ha, the total, 22.4 kg NPK/ha, would be about equal to the amount applied as chemical fertilizers at present. But not all the wastes are applied to the agricultural land and they can be important environmental pollutants.

Table 7. Changes in livestock numbers in 1996-2000 compared to those in 1989 (thousand head).

Year	Cattle	Swine	Sheep	Goats	Horses	Poultry
1989	6,416	14,351	16,210	1,078	702	127,561
1996	3,496	7,960	10,381	705	806	80,524
1997	3,435	8,235	9,661	654	816	78,478
1998	3,235	7,097	8,937	610	822	66,620
1999	3,143	7,194	8,409	585	839	69,479
2000	3,051	5,648	8,121	558	858	69,143

Romania has never used enough fertilizers. Considering only the quantity of NPK taken up by the total production of winter wheat, maize, beans, potatoes sunflower, and sugar beet, the amount is 1,203,805 t NPK per year compared to the total application to these crops of only 426,271 t NPK, a three-fold difference. A nutrient balance sheet for 1999 estimated a total deficit of 865,050 t, consisting of 284,470 t N, 156,870 t P_2O_5, and 423,710 t K_2O. This equates to an average deficient of 92.7 kg NPK/ha arable land (30.5 kg N, 16.9 kg P_2O_5 and 45.3 kg K_2O) or 58.6 kg NPK/ha UAA (19.2 kg N, 10.7 kg P_2O_5 and 28.7 kg K_2O). The very large K deficit is almost equal to the sum of that for P and N. The calculation of the balance sheet took into account the input of nutrients from manure and leguminous plants, while the outputs were calculated for cereals, industrial crops, fodder crops, vegetables, and fruits. The compensation index was 48% for N, 28% for P, and only 2% for K, as compared to the nutrient quantity removed by crops in 1999. The calculated optimum requirement for chemical fertilizers for Romanian agriculture in 1999 pointed to a total requirement of 1,952,919 tons, made up with 991,165 t N, 540,878 t P_2O_5 and 417,886 t K_2O.

OECD (2000) recommends maintaining the balance between nutrient inputs by fertilization and nutrient outputs with the crops. Taking, for example, the N balance sheet, where the inputs include the N introduced by fertilizers, manure and other organic wastes, symbiotic fixation of atmospheric N, seeds, and the outputs consist of the main yield, secondary yield and weeds in the crop, OECD concludes that the Romanian N balance for agriculture is negative leading to unreasonable use of soil N resources and to the impossibility of sustainable use of the soil (OECD, 2000).

As long as a "soil nutrient mining" type of agriculture is practised, where the quantities of nutrients removed by the crops is much larger than those applied with fertilizers and manures, the tendency will be to decrease soil fertility, even if the soil degradation rate is reduced as a result of the lower and lower yields. For example, in Romania, the average yield in 1991/2000, compared to that in 1980/1990, has declined by 2.4% for maize, 15% for winter wheat, 26.2% for barley, 10% for sugar beet, 26% for sunflower, and 18.1% for potatoes. Current yields in Romania are much less than those in Western Europe. For example, in 1993/1995 in France, Spain, Germany, Great Britain and Italy, the average yields were 5.2 t/ha cereals, 30.13 t/ha potatoes and 51.8 t/ha sugar beet, while in Romania they were 2.83 t/ha cereals, 12.94 t/ha potatoes and 21.74 t/ha sugar beet (Uebel, 1999).

FAO data (FAO, 2001) show that much of this decline in agricultural production levels in 1997-1999, compared to 1989-1991 in Romania, as in other Eastern Europe and FSU countries is due to the declining use of fertilizers.

While, in Romania, there were large areas with orchards, vineyards, vegetables, potatoes, sugar beet, tobacco and other crops which require more K than that needed by cereals, a large proportion of the soils cultivated with such crops had a low and very low content of available K and fertilizer application was always unbalanced. As a result, on such soils, the yield of these crops decreased and the quality was poor.

FAO data (FAO, 2001) show that there are large differences in the number of animals per hectare in the countries in Central and Eastern Europe in 1991-1999. The largest numbers are in those countries (Slovenia, Czech Republic, Poland) where most mineral fertilizers are applied. The requirement for fertilizers is presumably to grow sufficient cattle feed but it also means an increase in the amount of manure per hectare and the maintenance of the soil humus content.

During the period of the centralized economy, the pricing policy for agricultural products paid very little attention to their quality, so the farmer's view was only to increase yields. In this context, P and K fertilization was frequently neglected, because the yield increase per 1 kg of P and K was less than that of 1 kg N. For example, on average, the increased yield of winter wheat was 13.2 kg for 1 kg N, 11.2 kg for 1 kg P_2O_5, 6.7 kg for 1 kg K_2O and 9.7 kg for 1 kg NPK (Dumitru *et al.*, 1998).

To benefit from the large yield potential of new crop varieties, it is necessary to increase the use of fertilizers. The new crop varieties are very responsive to N, indeed they need generous N fertilization in order to achieve the potential crop production level. At present, the fertilization rates generally used by farmers are much higher than they were a few years ago, but still a less than those in Western Europe.

Forecast of fertilizer use

The strategy for Romanian agriculture in 2000-2012 has in view the following measures concerning the use of the chemical fertilizers:

- the supply of nutrients needed by crops, especially from the natural resurces and supplemented by chemical fertilization, should be at the optimum economic rate;
- the integration of soil mineral nutrition with foliar fertilization;
- the introduction of the biological fertilizers in agricultural systems;
- the economical use of chemical fertilizers to achieve maximum output, with a rational system of fertilization, respecting all the crop and soil management requirements.

To achieve the planned yields for the 2001-2012 period, the total demand for chemical fertilizers is estimated at 2.03 to 2.50 Mt $N+P_2O_5+K_2O$ consisting of 1.25 to 1.50 Mt N, 0.53 to 0.70 Mt P_2O_5 and 0.25 to 0.30 Mt K_2O.

These are the provisions in the development strategy, but the day by day reality is not the same. It is suspected that this strategy will not be achieved because:

- in 2001 and 2002, no increase in fertilizers or organic manure use was observed;
- there are more and more ecological restrictions regarding the use of fertilizers (Nitrate Directive, Water Directive, etc.);
- the economic restrictions will not be greatly reduced because the number of working people in agriculture is excessively high, their incomes are very low, and the government will use a part of its budget to help them survive;
- large areas of agricultural land will be afforested to mitigate or combat their degradation;
- important agricultural land areas will be used as protected areas;
- agriculture will use only about 7.5 Mha of arable land and fertilizer consumption will increase 3-4 times on about 3 Mha with modern management often under the control of foreign companies;
- there are more and more external pressures to practice an ecological agriculture;
- the irrigated land area will not exceed (even in the most optimist case) 1.6 Mha and there is no guarantee that this area will receive optimum fertilization because the available credits will not be sufficient to practice an efficient irrigated agriculture. Usually, the funds are mostly used for irrigation developments but not for a very efficient management of the present irrigation schemes;

- the living standards of small farmers will continuously deteriorate due to the pressure of highly subsidized agricultural commodities in the European Community;
- in Romania, there is a strong tendency for aridization to occur which increases the risk of investments;
- the present legislative background does not offer protection for agricultural investments;
- the market organisation is changing only very slowly;
- many fertilizer producers are likely to cease production;
- technical assistance to agriculture has been decreased;
- economic globalization will marginalize more and more poor countries;
- livestock numbers will show little increase, so the increased demand for fodder cereals on the internal market will be small;
- other production sectors (industry, transport, etc.) are not sufficiently developed to generate a surplus of capital that could be directed towards agriculture; on the contrary, they will mostly exert a pressure on the state budget;
- social pressures are more visible and dangerous in cities, therefore the government will pay particular attention to urban people and not to those who patiently wait in villages, etc.

Taking all these factors into account, it is considered that in Romania in the next 10 years, the average use of fertilizers will increase 2-3 times, from 23 kg NPK/ha agricultural land to 50-70 kg/ha and this will be mostly due to multinational companies farming very large areas of agricutural land in the most suitable regions. It is expected that, as inflation decreases and import restrictions are abolished, the prices of chemical fertilizers will stabilize at levels close to the international ones.

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The economics of potassium use in Asian rice systems

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Introduction

On-farm experiments in intensive rice-growing areas of Asia have SHOWN widespread negative potassium (K) balances in many different countries, implying that farmers are mining soil K reserves. Dobermann *et al.* (2002) report the results of experiments on 179 farms spread across several Asian countries, and found that K balances were negative in about 80% of cases with an average balance of -20 kg K ha^{-1}. Syers *et al.* (2001) reported that for the period 1961-1998, six Asian countries (China, Indonesia, Malaysia, Philippines, Thailand, Vietnam) indicated an overall annual potassium deficit of about 11Mt K, which is 250% more than the current K fertilizer use. For China, the annual K deficit in 1998 was estimated at 8 Mt K (62 kg ha^{-1}); for Indonesia, 1.2 Mt K (41 kg ha^{-1}). Such a large deficit in China and Indonesia is creating a serious nutrient imbalance with major implications for food production. It has the potential to adversely affect food security in Asia, home to 70% of the world's poor. This paper provides a brief overview of the economics of K fertilizer use in Asia[1] , with a specific focus on the region's most important crop, rice, and discusses related policy implications for improving productivity and food security.

Characteristics of the world potash market

Potassium fertilizers are produced in only a few countries but are consumed in more than 80 countries. The four largest producers of potash fertilizers, with their corresponding shares of world production from 1995-1999 in parentheses, are: Canada (34%), Germany (14%), the Russian Federation (13%) and Belarus (13%). These countries are also the world's four largest exporters, as shown in Table 1. Among Asian countries, China is beginning to develop some export capacity: from 1995-99, it was the world's fifth largest exporter in value terms, although this amounted to just 3% of the world total (China was just the tenth largest in volume terms). However, China's imports far exceed its exports, and it is still a substantial net importer.

[1] The "rice-producing" Asia referred to in this paper includes only countries where rice is the principal agricultural crop, viz., Bangladesh, Cambodia, China, India, Indonesia, Japan, South Korea, North Korea, Laos, Malaysia, Myanmar, Nepal, Philippines, Sri Lanka, Thailand, and Vietnam. Pakistan is also included because it is a major world exporter of rice and is immediately adjacent to this region.

Table 1. World's major potash fertilizer exporters.

Country	Average value of exports, 1995-99 (Million US$)	Share of world total (%)	Average volume of exports, 1995-99 (10^3 ton K_2O)	Share of world total (%)
Canada	1287	48	8242	38
Belarus	418	23	2427	11
Russian Fed.	380	15	2637	12
Germany	246	14	2693	12

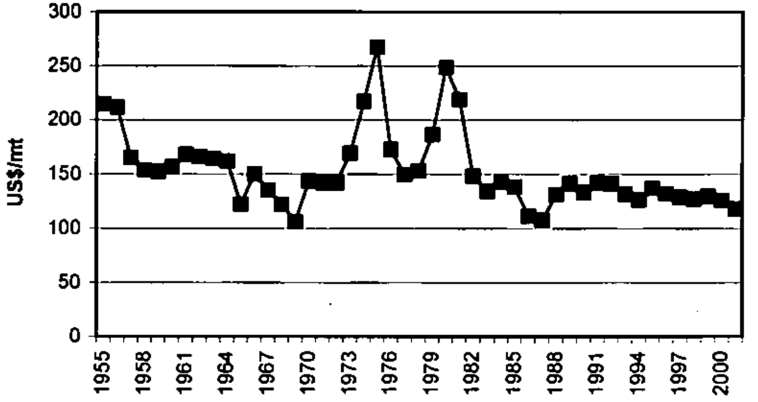
None of the important Asian rice growing countries is a major producer of potash. As a result, half of the top ten importers of potash on the world market are from Asia. China accounts for 15% of world imports, with India, Japan, Malaysia, and the Republic of Korea collectively accounting for another 16% (see Table 2). However, the share of K imports in total economy-wide imports is very small in Asian countries, ranging from 0.002% to 0.64%. Coupled with the fact that most currencies in the region are freely convertible on foreign exchange markets, it implies that foreign exchange constraints are not likely to be a problem in increasing future K imports if that proves necessary.

Table 2. World's ten leading importers (value terms) of potash fertilizers.

Country	Average value of imports, 1995-99 (Million US$)	Share of world total (%)	Average volume of imports, 1995-99 (10^3 ton K_2O)	Share of world total (%)
USA	748	18	5191	24
China	652	15	3392	15
Brazil	446	11	1883	9
India	241	6	1372	6
France	216	5	1414	6
Japan	213	5	409	2
Belgium-Luxembourg	162	4	345	2
Malaysia	141	3	714	3
Korea, Republic of	93	2	361	2
Italy	86	2	438	2

Price trends on the world market

Figure 1 shows that the inflation-adjusted price of muriate of potash (MOP) is about 20% lower today compared with 40 years ago. This price decline has occurred because supply increased faster than demand, due to technological developments in the production of K fertilizers. The price decline for potash has not been as large as that for urea, for which real world prices have declined by about 80% over the same interval. Prices of triple super phosphate (TSP) have also declined by more than prices of MOP. Nevertheless, MOP is more widely available and much cheaper today than ever before.



Source of raw data: International Monetary Fund (2002).

Fig. 1. Long-term trends in inflation-adjusted price of potassium chloride (MOP).

Consumption of potassium fertilizers in Asia

In 1999, rice-producing Asia accounted for 35% of the world's K fertilizer consumption (despite accounting for less than 1% of world production). The largest K consuming countries in Asia are China, India, and Malaysia, which rank as the world's second, fourth and sixth largest consumers, respectively (see Table 3). On a per hectare basis, the most intensive user is Malaysia (131 kg K ha^{-1}), followed by Japan (96 kg K ha^{-1}) and the Republic of Korea (91 kg K ha^{-1}).

Table 3 shows clearly that consumption of potash fertilizers in developing Asia has increased steadily and substantially since the start of the Green Revolution, increasing dramatically from an average of 0.6 kg K ha^{-1} in 1965 to 13.9 kg K ha^{-1} in 1999, corresponding to average annual growth of nearly 10% per year. Growth has been rapid in nearly all countries, with the main exceptions being countries like Japan and Sri Lanka where K use was already at relatively high levels in 1965. This implies that Asian farmers have acquired much knowledge of the importance of K to their crops during the past 35 years. China's growth in K use started primarily in 1978, due to the economic reforms instituted at that time (see Fig. 2). The drop in K use in India by about 1/3 in 1992 was due to the reduction of a fertilizer subsidy that increased the farm gate prices of potash and potassic fertilizers (see Fig. 3) (Krauss, 2001).

Table 3. Potash consumption and crop area harvested in selected Asian countries, all crops.

	1965			1999			Average annual growth rate (%)		
	K cons. ('000 Mt element)	Area harvested ('000 ha)	K used (kg K/ha)	K cons. ('000 Mt element)	Area harvested ('000 ha)	K used (kg K/ha)	K cons. ('000 Mt element)	Area harvested ('000 ha)	K used (kg K/ha)
Malaysia	13	2580	5.0	659	5008	131.5	12.3	2.0	10.1
Japan	509	6634	76.7	323	3349	96.4	-1.3	-2.0	0.7
Korea Rep	33	3323	10.0	193	2116	91.4	5.3	-1.3	6.7
Viet Nam	16	6531	2.4	315	11613	27.2	9.2	1.7	7.4
Sri Lanka	29	1691	16.9	51	2087	24.5	1.7	0.6	1.1
China	39	136694	0.3	2815	158207	17.8	13.4	0.4	12.9
Thailand	4	9411	0.4	229	18198	12.6	12.8	2.0	10.7
Indonesia	2	17766	0.1	332	29911	11.1	16.5	1.5	14.7
Philippines	25	8883	2.8	100	12341	8.1	4.2	1.0	3.2
India	64	154293	0.4	1438	184874	7.8	9.6	0.5	9.0
Bangladesh	2	11914	0.1	110	14217	7.7	13.1	0.5	12.5
Asia	735	359720	2.0	6565	441920	14.9	6.7	0.6	6.0
Developing Asia	193	349763	0.6	6049	436454	13.9	10.7	0.7	9.9

Notes: Countries are ordered in terms of K use per hectare in 1999. Data for Vietnam in the first three columns refer to 1967. Asia refers to only those countries shown in the Table, not all those shown in Footnote 1. For the countries included in Footnote 1 but not shown here, K use per hectare is very small. Developing Asia is Asia minus Japan and Republic of Korea.

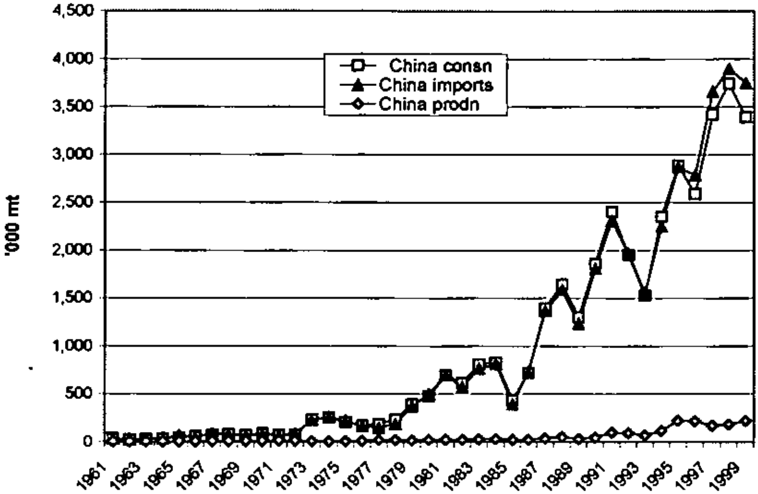


Fig. 2. Consumption, imports and production of potash in China, 1961-1999.

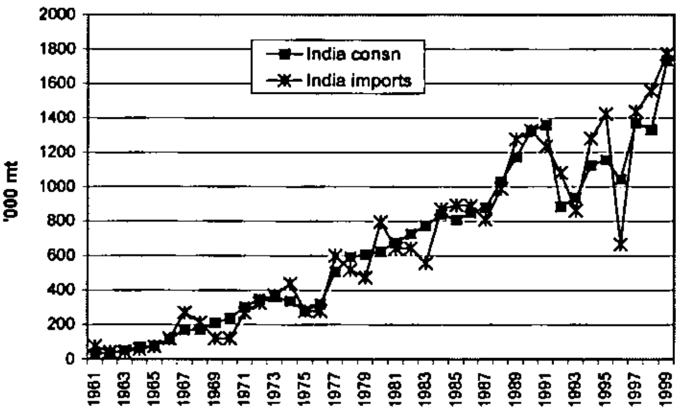


Fig. 3. Consumption and imports of potash in India, 1961-1999.

Unfortunately, the data reported in Table 3 are aggregate data for all crops, making it more difficult to understand trends over time for specific crops. One of the few sets of long-term time-series data on farm-level K use on rice in Asia is the Loop survey conducted by the Social Sciences Division of the International Rice Research Institute (IRRI). This survey is conducted in Central Luzon (Philippines) approximately every four years on a highway loop through some of the country's most important rice growing areas and surveys all aspects of inputs and outputs on rice farms. These data, presented in Figure 4, show that K use has increased over time, consistent with the data in Table 3. Farm level use of K in Central Luzon in the wet season increased from 4 kg K ha^{-1} at the start of the Green Revolution to 22 kg K ha^{-1} in 1999.

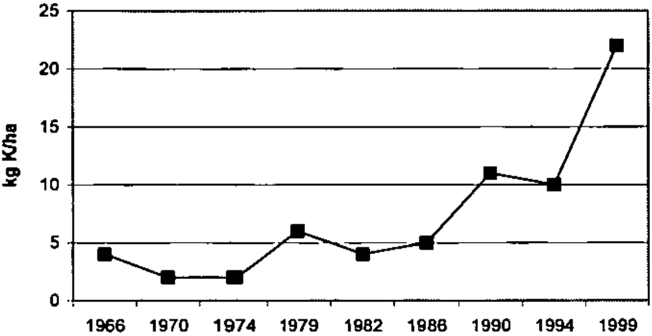


Fig. 4. Trend in average potassium use on rice in Central Luzon, Philippines (wet season).

Potassium use on rice and other crops

The share of K use on rice to total K use on all crops ranges widely among various rice growing Asian countries, from less than 5% in Malaysia to more than 60% in the Philippines (Fig. 5).

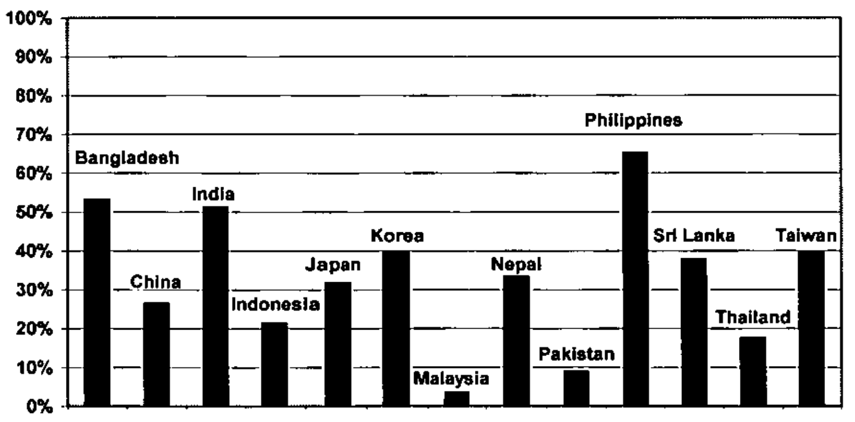


Fig. 5. Share of potassium use on rice to total potassium use in selected Asian countries.

In most countries, it is the most important single crop in terms of K use. The exceptions are countries where rice is a relatively minor crop in terms of area (e.g. Pakistan) or countries where export crops such as oil palm and rubber are important, because these crops tend to use much higher quantities of K ha^{-1} (e.g. oil palm in Malaysia and Indonesia, rubber in Thailand). Other important users of K in Asia include vegetables and potatoes in East Asian countries, tea in Sri Lanka, and oil palm and pineapple in Thailand.

Current levels of K use on rice vary substantially across Asian countries, with K use being substantially higher on a per hectare basis in East Asia (Japan, Korea, China-Taipei and to some extent mainland China) than in South and Southeast Asia (Fig. 6).

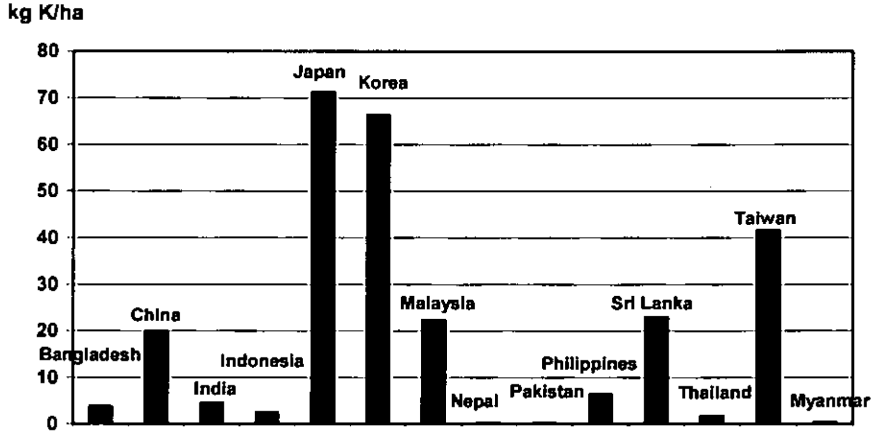


Fig. 6. Potassium use on rice in selected Asian countries (kg K/ha).

Potash fertilizer accounts for a relatively small share of gross returns and total production costs in irrigated Asian rice production, ranging from 0.1-2.6% of gross returns and 0.2-6.0% of total production costs (Table 4). This is not because of widespread subsidies on K, but because of relatively low K use at many sites and the greater importance of other inputs such as labor and nitrogen fertilizer even at sites with relatively high K use. This suggests that most farmers in irrigated areas will be able to afford additional K fertilizer if they are convinced that it is a profitable investment.

Among the sites listed in Table 4, farmers from the Red River Delta in Vietnam and Zhejiang in China applied significantly higher amounts of K fertilizer (about 60 kg K ha^{-1} per crop) compared to the farmers at the other RTDP sites. This may be the result of government information campaigns promoting balanced fertilization that were effective within a system of central planning.

Table 4. Share of potassium in gross returns and total production costs, RTDP* sites, 1999.

Site	Gross returns	Total production posts	Total fertilizer costs	Total K costs	Share of K in gross returns	Share of K in total production costs
	US dollars per hectare per year				%	
Central Luzon, Philippines	2083	888	139	16	0.8	1.8
Central Plain, Thailand	1302	636	125	1	0.1	0.2
Mekong Delta, Vietnam	1160	683	95	8	0.7	1.2
West Java, Indonesia	1490	670	73	8	0.5	1.2
Tamil Nadu, India	1375	698	90	12	0.9	1.7
Red River Delta, Vietnam	1834	1068	145	36	2.0	3.4
Zhejiang, China	1718	731	203	44	2.6	6.0

* Source: Moya *et al.* (2002) and raw data from Reversing Trends of Declining Productivity (RTDP) project, IRRI.

Other than insufficient knowledge, another factor that may hinder K use by farmers in some locations is limited availability of MOP and high K prices from alternative sources. For example, in Central Luzon in the Philippines, for many years the most common source of K was complex fertilizers (14-14-14 and 17-0-17). Unfortunately for farmers, the imputed price of K from these fertilizers (calculated by valuing the N content at the price of urea and the P content at the price of 18-46-0) was much higher than for K obtained from MOP. Often, the imputed price of K was as much as 50% higher for K obtained from 14-14-14 and 250% higher for K obtained from 17-0-17 (Fig. 7).

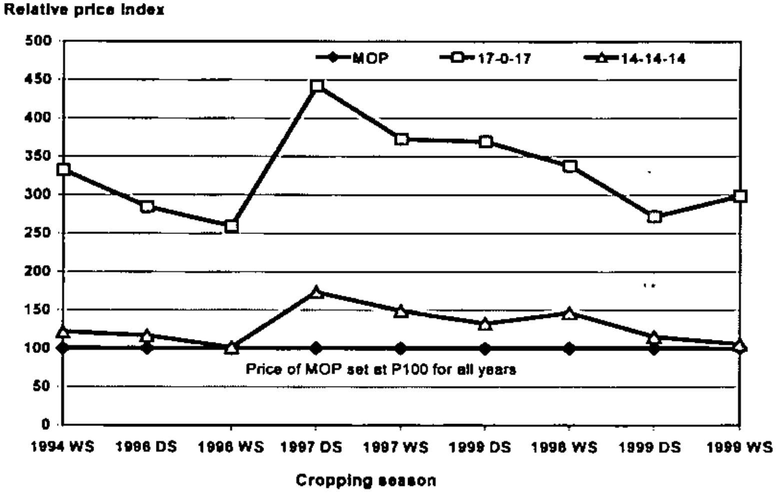


Fig. 7. Relative price index of potassium from various sources, Central Luzon, Philippines.

Potassium fertilizer as a long-term investment

Potassium fertilizer is different from nitrogen (N) fertilizer in important ways. For N, most of the applied fertilizer is used by the current crop or is lost to the surrounding water and atmosphere. Little is carried over to future crops. Thus, N fertilizer is essentially an annual input in the production process. Potassium, however, can be stored in the soil and increase the yield of more than one crop. So the impact of an increased application in one year may not result in increased production immediately. Thus, applying K fertilizer is more akin to an investment with possible future benefit than an input for immediate effect. Evidence from Indonesia suggests that farmers understand this difference and act accordingly.

In the event of price increases for P and K that are perceived by farmers to be possibly temporary, it is rational to postpone purchases of these fertilizers, and that is how the farmers in West Java, Indonesia behaved. The prices of N, P, and K fertilizers all rose substantially in a short period of time due to currency devaluation, from 50% to 75% in nominal terms (i.e., not adjusted for inflation). But N use declined just 13%, whereas P and K use declined 56% and 80%, respectively (Moya *et al.*, 2002).

However, an important question is how long P and K use can remain low before yields are adversely affected. There were many reports that insufficient use of K fertilizers in the Indonesian food sector reduced the physiological ability of plants to resist pest attacks and also affected grain formation, thus reducing crop yields. It is not clear to what extent these effects were due to reduced K use during the economic crisis or were in fact problems that pre-dated the crisis.

Policy implications

While there are indications of negative K balances in irrigated rice fields in Asia, it is not necessarily easy to draw policy implications from this observation. One reason for negative K balances in many fields is the removal of straw, which is rich in K. Thus, a possible policy option might be to encourage incorporation of straw where this does not already occur. Using data from some long-term experiments, Dawe *et al.* (2002) show that straw incorporation can be profitable. However, this recommendation will only be applicable to certain sites. For example, incorporation may cause negative effects on rice growth during the early vegetative stage in some soils with low buffering capacity due to increased soil reduction, N immobilization, and Fe and sulfide toxicity. In some rice-wheat systems of the Indo-Gangetic Plain where rice is harvested by combine, most farmers burn rice straw because the short period of time between rice harvest and establishment of the wheat crop is not long enough for decomposition of the straw. If incorporated during normal ploughing operations, this straw would inhibit emergence of the subsequent wheat crop. Finally, in other cases, straw has alternative uses as a fuel. Thus, incorporation will not be a viable alternative in all situations.

If straw incorporation is not profitable, then additional applications of inorganic K fertilizer offer another alternative. However, just because K balances are negative does not necessarily imply that farmer's use of K is sub-optimal, as some degree of soil mining may be economically rational. In this regard, it is important to remember that farmers are indeed aware of K fertilizers – as discussed in earlier parts of the paper - and farmers do use K, and use has increased substantially since the beginning of the Green Revolution. In an informal survey of 20 farmers in Central Luzon in the Philippines, nearly half were aware of at least some of the benefits of K – fuller and heavier grains, longer panicles, stronger plant structure and increased plant resistance to drought, pests and diseases.

Table 5. Grain yield and fertilizer use in on-farm experiments at SWMRI, Thanjavur and TNRRI, Aduthurai, Tamil Nadu, India, 2001 Kuruvai season (n = 15 in Thanjavur, n=14 in Aduthurai).

	SSNM2				SSNM1				FFP			
	Yield	N	P	K	Yield	N	P	K	Yield	N	P	K
	kg/ha	kg element/ha			kg/ha	kg element/ha			kg/ha	kg element/ha		
SWMRI	6933	118	15	77	6657	118	15	38	6256	103	15	35
TNRRI	6386	118	10	50	6230	118	10	30	5802	111	18	21

Source: Unpublished experimental data from trip report by Christian Witt, IRRI.

Despite these considerations, it is also true that many farmers are ignorant of the benefits of K fertilizer. If farmers do not have full information, perhaps the best solution is to provide concrete demonstrations of the positive marginal effects of K, i.e. a response to K (either in yield or in milling quality). This response must be in comparison with current farmers' practice, not a zero K control. Two examples of such experimental demonstrations were conducted recently in Tamil Nadu (India) at the Soil and Water Management Research Institute (SWMRI) in Thanjavur and the Tamil Nadu Rice Research Institute (TNRRI) in Aduthurai. The data from these experiments are shown in Table 5. Due to higher applications of K, yields in the SSNM2 treatment were higher than in the SSNM1 treatment by 276 and 169 kg ha^{-1}, respectively. Based on prevailing prices of rice and fertilizer in this area, these increased applications of K are profitable to farmers (data not shown). However, the increases in profit are not very large, as they are less than $25 ha^{-1}, which represents an increase in farmers' profits of 2%-4%. Clearly, the more visible the benefits, the easier it will be to convince farmers to increase applications of K.

Temporary subsidies on K fertilizer might be an additional policy option to increase K use, but the advantages of this strategy must be weighed against the possible political difficulties of removing the subsidies in the future. Such subsidies would also have to be consistent with WTO commitments, although this is not likely to be an important practical consideration due to fact that agricultural subsidies are still allowed under the WTO as long as they do not get too large, and potash fertilizer subsidies are unlikely to increase total agricultural subsidies by a substantial amount.

Credit subsidies are not likely to be a good solution. First, K costs are so small compared to gross revenues and total costs of production that it is unlikely that large numbers of farmers are constrained from applying K because of inadequate financing even though they know application of K would be beneficial. Second, credit subsidies are often allocated to the relatively "well-to-do" instead of reaching the poor whom they are ostensibly intended to help. Third, credit is fungible and can be used for any number of other purposes other than fertilizer. There is a large literature on the failures of subsidized credit that describes such problems in detail (e.g. Von Pischke *et al.*, 1983).

In conclusion, increased use of K fertilizer in intensive rice systems has the potential to increase yields and productivity, but researchers will need to interact with farmers in order to provide concrete demonstrations that higher levels of K use will improve profitability.

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Economic restrictions on agricultural production in Latin America

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Summary

In spite of the very large land resources and access to modern agricultural technology, Latin American farmers have a long road ahead of them before succeeding in agribusiness including the problem of subsidies. Latin America has about 1,850 million hectares (Mha) of productive land not yet developed to enlarge its grain production; Brazil alone has nearly 136 Mha in the Cerrados region. In the northeast of Argentina, 2 Mha have been used for grain production during the last decade, yet this area occupies only 20% of the arable land with fertile soils. Similarly, there are large areas in Paraguay and Bolivia. The changes in the region confirm Latin America's role as a low cost food provider to fast growing regions in countries with a high income per capita.

There are limitations in infrastructure and capital to develop these lands in Latin America in order to decrease transactional costs. Infrastructure development is critical for access to technology, credit and other critical resources, all of which require capital that must now be provided by national markets after the recent defaults and economic turmoil in the main countries in the region have restricted international credit. However, regardless of the origin of the capital, credits should be repaid on the basis of appropriate returns, which many agribusiness projects lack.

Latin America has received some benefit during the last decade from the growth in world commerce due to globalization, the growth of the world economy, increase in per capita income in countries with a low capacity of self sustaining food production, growing sophistication in the diet and partial liberalization of commerce in agriculture products after the Uruguay Round.

However, Latin America participates in the major markets mainly with relatively small volumes of commodities. Due to the trend of declining and considerable variability in the short-term prices for world-market agrifoods, competitivity acquires relevance among countries and farmers. The need to identify products, which show smaller declines, or perhaps positive increases, is growing. Competitivity raises exigencies for quality, services, response to consumer preferences and origin and process certification.

Competitivity not only considers productivity but must incorporate quality, a range of products, logistic development and technological and organizational innovation, with a greater coordination within agricultural chains. The fight against subsidies and other distortions by coordination of policies among nations is also necessary to reverse the tendency of decreasing participation of primary products in the final aggregated value.

Economic constraints on agricultural production in Latin America

Generous land and water resources

Latin America has a potential of several millions hectares (Mha) of land not yet developed to enlarge its grain and fibre production. Table 1 shows all the land available in Latin America. Subtracting the areas cropped with annual or perennial crops leaves several thousands of hectares in almost all of the countries for pastures, forest, scrublands and savannas that can be put to agricultural production with varying degrees of investment. On a per capita basis, Latin America has more arable land either cropped or other agricultural area than other continents even discounting the marginal areas (Fig. 1)[1] . Only Oceania may have a larger area of land per capita.

Table 1. Land distribution for Latin American countries, grouped in economic blocks. Potentially available lands represent land not listed under annual and permanent crops, i.e. pastures, forests and woodland, according to FAO definitions (FAO, 2002).

	Permanent pastures	Permanent crops	Annual crops ha × 1000	Agricult. area	Potentially available
Mercosur[a]+ Chile	375.2	14.7	83.8	473.6	1153.0
Andean Pact[b]	125.2	4.9	12.5	142.6	438.8
Central America & Mexico	93.5	4.4	28.5	128.9	204.3
Caribbean & Guyana's	7.8	2.0	8.7	16.0	62.2
Total Latin America	601.7	25.9	133.5	761.1	1858.4

(a) Argentina, Brazil, Paraguay and Uruguay.
(b) Bolivia, Peru, Ecuador Colombia and Venezuela.

Nearly 200 Mha are covered with agricultural intact scrub in the savanna's Cerrados region in Brazil, which has a potential to expand both arable and intensive pasture land with about a ten-fold increase in the national soybean grain production (Wanken, 1999). This region has registered an impressive expansion of the area cropped with soybean during the last two decades thanks to no-till, fertilizers, liming, and genetic development. About 26% of all Brazilian grain production is produced in the Cerrados region (Maggi, 1999) and is continuously increasing its share of the national production (Fig. 2).

[1] According to FAO definitions, *Cropped area* is the sum of area land under temporary and permanent crops, while *Arable land* also includes the area under permanent pastures.

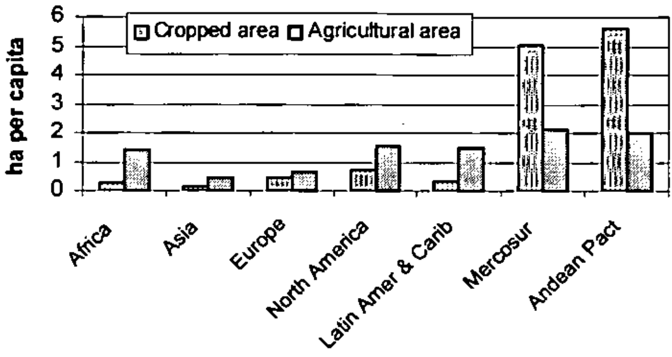


Fig. 1. Arable lands without accounting for marginal areas in hectares per capita (adapted from FAO Ag-stats. www.fao.org).

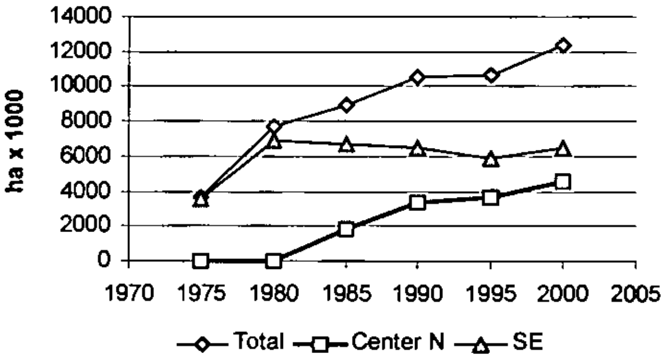


Fig. 2. Expansion of the soybean area in the Cerrados (Center N) (Matto Grosso, Matto Grosso do Sul and Mina Geris) and stagnation in the traditional south (SE) (Rio Grande do Sul, Parana and Santa Catarina), Brazil (adapted from Schnepf *et al.*, 2001).

In northern Argentina, 2 Ma have gone into grain production during the last decade, enlarging the agriculture land at 6% annually, but it still occupies only 35% of the arable land with fertile soils (Table 2). Similar changes have occurred in large areas in the scrublands of the Chaco region in Paraguay and Bolivia. Approximately 600,000 ha of soybean are planted every year in Bolivia near to Santa Cruz yielding 2.3 to 2.7 t/ha. Eastern Paraguay, once covered with a lush forest is now producing annually more than 3 Mt of soybean grain. The soybean output from these four countries, Brazil, Argentina, Paraguay and Bolivia, is now such that world grain traders consider them to match that of the North America, thus contributing to regulate the price of the grain (Schnepf *et al.*, 2001).

Table 2. Available lands for agriculture and expected expansion in 2006 at the Chaco region in Northern Argentina (Melgar *et al.*, 2002).

Province	Total area land classes I – III (a) ha × 1000	Cropped area in 2001 (b) ha × 1000	(% b/a) %	Increase 1991-01 %	Cropped area projected in 2006 (c) ha × 1000	(% c/a) %
Santiago del Estero	2984	747	25	7.2	1273	43
Salta	2707	695	26	4.6	794	29
Tucumán	862	432	50	5.6	390	45
Chaco	1866	1070	57	3.4	1622	87
Total	8419	2944	35	5.1	4078	48

Evolving from agriculture to agribusiness in Latin America

Temperate and subtropical areas in Latin America have been cultivated for the last two centuries but at a very low population pressure up to the last 30 years. Immigrants arriving from Europe in the first decades of the 20th century brought agricultural systems that became the main grain supply to devastated Europe after two world wars. In Argentina, the first colonies settled in Santa Fe province about 1880 and by 1920, production and trade in wheat and maize made the port of Rosario a rival with Buenos Aires in wealth.

Almost contemporarily, coffee and sugar cane production started in Brazil early in the 20th century, with capitalism, landlords, and cheap labour. Well into the 20th century, these two crops and citrus contributed significantly to very well integrated chains with many industrial and trading sectors in the Brazilian economy. It is possible to find several other examples of successful agribusinesses in other countries in the region. For example, temperate deciduous fruit orchards and vineyards in Chile and western Argentina started production a long time ago and nowadays their agribusiness chain provides a significant income in hard currency for each country.

Tropical America has attracted the interest of several research groups, the Tropsoil Program being the most important one (McCracken, 1989). Based in Yurimaguas, in the Peruvian rainforest, a long-term experiment proved that when enough nutrients are provided to cover crops, it is possible to maintain permanent agriculture. This is a good example of what soil science can do as an option to the slash and burnt system that prevailed in the rainforest ecosystem for several generations. However, it would not be enough to support the food needs for a growing population in big mega cities.

Although much of this region has soil fertility limitations like nutrient deficiencies or acidity, (Sanchez and Salinas, 1981), advances like the one achieved by the Tropsoil program in soil science research and management technology make it possible to grow productive crops that support not only the food needs of the farmers, but also produce a surplus to sell bringing cash to the farmers.

Cost of doing business

The example of the soybean production capability of the Latin American countries is an example of their ability to use natural resources to produce food and fibre. Similar possibilities exist for expanding the production of rice, cotton, maize, meat and other outputs originating from agriculture. All Latin American countries base their economies on agriculture. Even Brazil, probably the most industrialized country in the region, gets a large part of its gross national product from crop production and agribusiness.

In spite of there being plenty of land, infrastructure development is crucial for access to technology, credit and other critical resources. A recent comparison of soybean production cost in Brazil, the US and Argentina shows the importance of the infrastructure component in the US. The weighted average transport cost for soybean grain is $ 16/metric tonne, mt/1000 km in the US, while the cost ranges from 26 to 43 in Brazil and to 63 $/mt in Argentina (before devaluation). This large export-related cost combines with other transactional costs, such as congestion at ports during harvest times, improper timing for shipment and long demurrage periods, to add to marketing costs (Schnepf *et al.*, 1999).

Although impressive changes due to investment in infrastructure development during the last decade have reduced much of the transport and marketing cost, the need for capital investment remains significant. Due to the recent default of Argentina and the economic turmoil of the main countries of the region, international credit is restricted and it is likely that future investment will have to be provided by national capital markets.

In dealing with food chain management, the governance of transactions through the food production system is an issue of major importance. The characteristic of local chain food systems is of many individual agents who do not integrate well and who more often compete rather than cooperate. Agents operating in food systems are very often exposed to conflicts in these countries, with high transactional costs resulting from opportunism and a lack of incentives to honour contracts between agents, thereby reducing the efficiency of these organizations (Zylbersztajn and Zuurbier, 1999).

Compared to OECD countries, transactional costs are usually quite large in Latin American food chains, due to poor law enforcement of contracts by courts and related institutions, even when safeguards are provided by contractual clauses. The low quality of organizational and institutional environments is the general rule. An example is the tomato paste case (Zylbersztajn and Zuurbier, 1999), where firms in Brazil decided to reorganize and move the production out of areas where existing contracts were facing problems. The contracts, with contractual safeguards designed to support the transactions, were not effective because the interpretation of law by the local authorities was consistently in favour of the farmers who breached the contract. Thus, the signal to the farmers was that there was no cost in breaking the contracts and the transactions would become too costly to be continued in the region, and it would be safer to import the product, with long-term losses to the local farmers. As a result, new specialized and large-scale suppliers moved to the central states with projects to integrate field production and pre-processing with the aim of replacing imports with the domestically produced paste. These new organizations replaced the contracts between the large food industries and small farmers, with contracts between a small number of large suppliers, who sell unbranded, pre-processed paste.

Another example is the trade policy in the Mercosur for the car makers. A large part of the agricultural sector's income in Argentina is transferred to car manufacturing industry. The regulations allow tax surcharges and tariffs on imports of machinery and farm equipment, that result in higher costs for farmers in the long term, (Medina and Souto, 2000). These authors showed that more than $US 5 billion was annually transferred from the agrifoods business to other sectors of the national economy; of which 3.7 billion went to protectionist commercial policies (import duties, tax on exports and on consumption) and the rest, 1.4 billion, coming from direct taxes on agricultural production went to the State. The sector that benefited most was the car industry sharing 28.3% of the total.

Transforming comparative into competitive advantages

In spite of their enormous capability to produce food, Latin American countries participate in the major markets mainly with relatively small volumes of commodities. Due to the trend of declining and considerable variability in the short-term prices for world-market, agrifoods competitivity acquires relevance among countries and agents of the food chains, including farmers.

Scale is one way to enlarge advantages by decreasing costs. Argentinean producers took this way to remain competitive during the last decade, the number of small farms decreased while the average size increased (White, 2000). Identifying products that show smaller declines or even positive price tendencies, means that countries are focusing on market intelligence, providing qualified commercial information, and focussing on in strategically selected market for exports.

Latin America received some benefits during the last decade from the growth in world commerce due to globalization, the growth of the world economy, increase in per capita income in countries with a low capacity of self sustaining food production, growing sophistication in the diet, and partial liberalization of commerce in agricultural products after the Uruguay Round. In spite of these benefits, income received by the farm sector declined in relative terms, while production increased by 40% (Fig. 3). Figure 4 shows also the changing relationship between decreasing rural credit and the increasing productivity in Brazil. The globalization of finance and trade meant that while the international interest rate was around 5%, the cost of credit to Latin American countries was around 18 to 20%.

A similar situation was seen in Argentina during the last years of the convertibility system, where only the official banking sector participated in credits given to farmers. The modest share of 8% of total credit in 1998 was further reduced at the start of the recession, when bank credit was replaced by credits given by the supply chain, such as: agri-input firms, trading companies and processing industries among others (Cap, 2002).

The recent success of Brazil and Argentina indicates that, in spite of major financial problems, the agricultural sector will continue to gain competitiveness, increase grain production and consequently market share of the main commodities. Trade liberalization and market deregulation will have a major impact on prices in the rural sector (Pessoa and Jank, 2002).

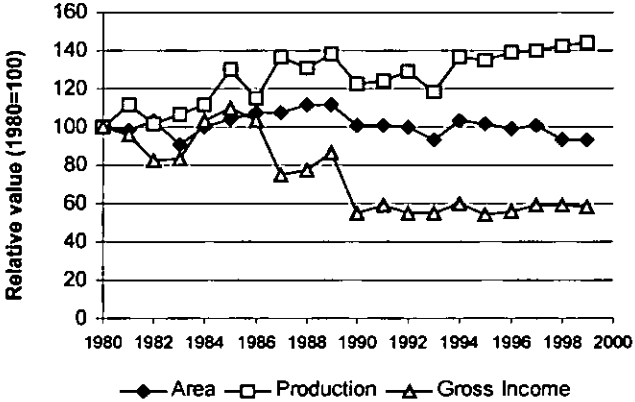


Fig. 3. Evolution of rural income and area under agriculture and agricultural production (França, 2001; FGV/IBREA/CEA cited by Scheid Lopes, 2002).

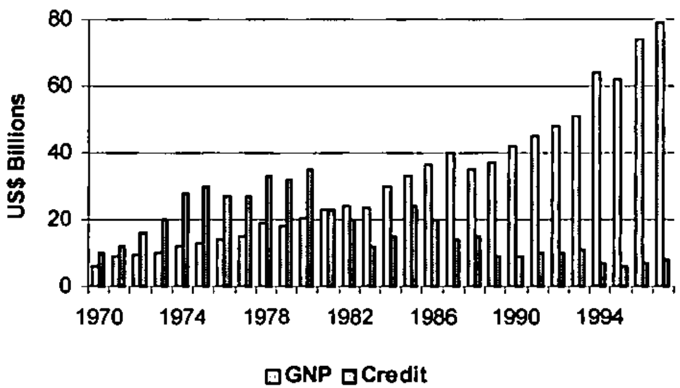


Fig. 4. Evolution of rural credit and Gross National Product in Brazil (Pinazza and Alimandro, 1999, cited by Scheid Lopes, 2002).

How about R & D in the agricultural sector?

Developing countries on average devote 5% or less of government expenditure to agriculture (Cohen, 2002). Chile and Brazil are two countries towards the top of the range, but others, including Argentina, spend less and less, in spite of the large dependency of their economy on agricultural exports.
Countries that have a large portion of their economy rooted in agribusiness should not give up agricultural research. But most Latin American agricultural research institutes receive a smaller budget every year. Instead, increasing millions of dollars are allocated to social expenses (Fig. 5).
There is a need for public agricultural research to increase small farmer productivity, using all appropriate scientific tools and farmers' own knowledge. The expenditure on public agricultural research has stagnated. According to Pardey and Beintema (2001), the amount spent, as a percent of the value of agricultural production, contrasts sharply between developed and developing countries. From 1976 to 1995, the percentage in developing countries went from 0.44 to 0.62%, in developed countries this percentage increased from 1.53 to 2.64%.

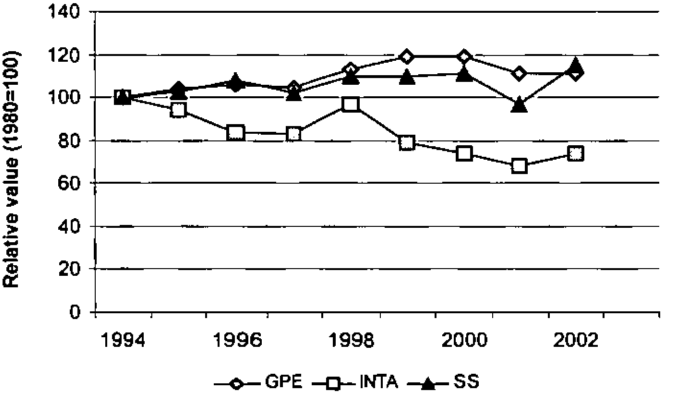


Fig. 5. Changes in the annual budget in Argentina showing a decreasing proportion going to agricultural research and the extension institute (INTA) compared to social (SS) and gross public expenditure (GPE).

Sharp contrasts

There is a big contrast between the agrifoods chains of OECD and Latin American countries. Tariff and non-tariff barriers, scaling protection and subsidies to production and exports, protect agricultural production in developed countries. Institutional and organizational development allows for a friendly environment for business with good risk coverage on safeguards and contracts rather than markets.

Processing of commodities is concentrated into big multinational companies with highly efficient chain coordination that push costs down. It is a characteristic of these economies that strong distribution and logistic development are achieved through alliances and integrations, focusing on business in preference to consumers. There is also a larger proportion of public and private investment in research and development that has led to modernization. As a result through a long period of time, these countries have raised their competitiveness based on different commodities.

The big change of paradigm in modern agricultural business requires an integration of the whole food chain with coordination at all levels. It is of the upmost importance for Latin America countries, and food suppliers of the world, to have successful agribusinesses. Classical economic statistics show the importance of agriculture in terms of percentage of the GNP, i.e. this value in Brazil and Argentina is 7.7% and 4.8%, respectively (World Bank, 2002). However, agriculture is integrated within the whole economy to a much greater extent that reveals the importance of agribusiness to a country's economy. This indicator is 21% in Brazil; with a GNP of US$ 779 billions, US$161 corresponding to agribusiness, of which US$ 7.4 (5%) represents before fences business, US$ 68 (43%) inside fences, or on farm production, and a significant US$ 85 billion (53%) for business carried out after fences, respectively. Similarly, agribusiness in Argentina represents 12% of the total GNP, 25% of the production value; but a much higher proportion (51%) of the total export value of the country, not to mention 43% of the job market (Cap, 2000; Estefanell and Obsschatko, 2000). Equivalent figures in Brazil for 1996 are 25 and 40% of production value and exports, respectively and 37% of jobs.

Latin American countries produce characteristic cash crops that are converted into foods for the NAFTA and other high-income countries. Such crops make a particular contribution in each country, i.e. asparagus from Peru, bananas from Central America, flowers from Costa Rica or Colombia and vegetables from Mexico. Unfortunately coca crops, being the most successful chain in economic terms, are also included in the list. Agribusiness in Chile is so successful that the country markets not only fruit and wines, but also the country as a brand itself. For instance, the fruit industry includes 7,000 farmers on 212,000 ha that support about 423 companies. They export 1.4 billion t of fresh fruit for US$ 1.35 billion value (8.6% of the total). The wine industry has increased at a 15% growth rate, with 80 companies exporting to 90 countries for US$ 0.7 billion value in 2002 (www.agronegocios.cl by Minchel, 2002).

Competitiveness not only considers productivity but also incorporates quality, product differentiation, logistic development and technological and organizational innovations, with greater coordination of the agricultural chains. To slash economic constraints, countries must have advantages that are either comparative or competitive. To be competitive, Latin American countries must have the ability and determination to transform their productivity assets into real competitive qualifications. We can see a few examples of coordinated chains by looking at the average values of agricultural exports (Fig. 6). It is easy to see the contrast between countries, although the massive exports of maize and wheat from countries like the US and Canada may mislead the comparison (Cap, 2000).

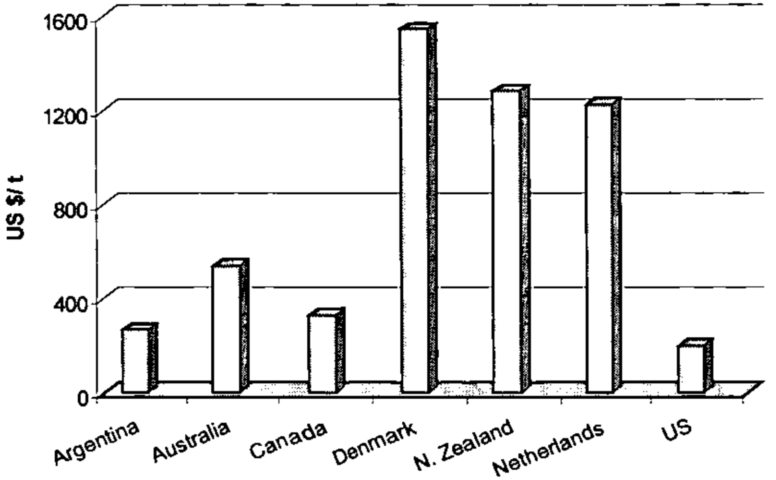
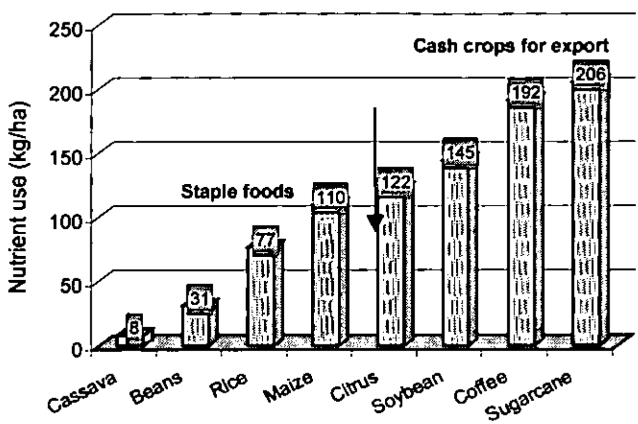


Fig. 6. Average value of food exports by different countries, showing the aggregated value in their chains (Cap, 2000).

Fertilizers, potassium and quality

The International Potash Institute has largely promoted the link between these three terms. It is not surprising then that cash crops for exports receive a large proportion of the fertilizers and potassium used than the food or staple crops in the same country. For example, the cases of Brazil and Colombia are in the Fig. 7. To illustrate the importance of agribusiness in Colombia, the agricultural portion of the GNP in 2000 represented US$ 10.6 billion, of which coffee, bananas and flowers represented 63% exports, and manufactures originated from agriculture 58% of the country's total (Agrocadenas 2002 by Observatorio de Competitividad Agrocadenas, 2002). With different scales on the y axis and crop basket on the x axis, each country's cash crops, receive more fertilizer per ha than the food crops.

A. Brazil



B. Colombia

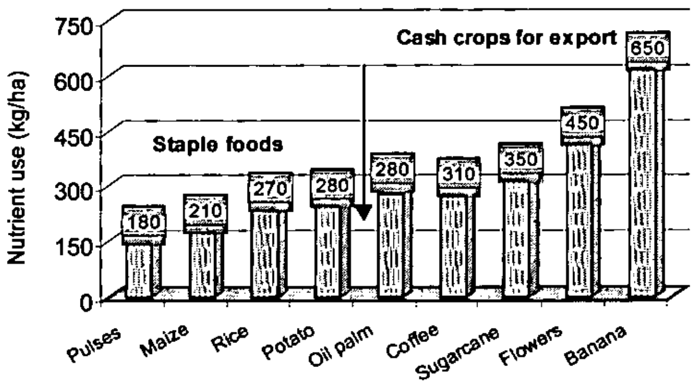


Fig. 7. Differential nutrient ($N + P_2O_5 + K_2O$) use in food and cash crops for export in **A.** Brazil (ANDA, 2002), and **B.** Colombia (IFA, IFDC, IPI, PPI, 2002).

The highest distortion

One of the main issues is that the agro exporting sector in Latin American countries has to work in the international arena where the more developed countries apply subsides to production and exports of foods and agricultural products. The fight against subsidies and other distortions by coordination of policies among nations is also necessary to reverse the tendency of a decreasing participation of primary products in the final aggregated value. The 29 industrialized countries of the OECD applied during 1998 to 1999 more than US$ 366 billion in subsidies, of which EC (142) US (87) and Japan (56) accounted for 78% (US$ 285 billions) (Regúnaga, 2002).

Several speculations have been raised around the withdrawal of subsidies and its impact on Latin American economies (Casaburi and Sánchez, 2002). Research on 25 major importers of soybean oil (40% of world consumption) shows the impact of an increase of soybean oil production in Mercosur after removal of tariff and non-tariff barriers. The annual growth with barriers will be 2.8%, with the removal of these barriers it will be as much as 8.4%. In Argentina, for instance, the removal of tariff and non-tariff barriers would not impact very much on production, but it would have a very large effect on exports. Argentina may increase by 25% its agrifood exports by withdrawing tariffs and eliminating subsidies to exports and production (Table 3) (Regúnaga, 2002).

Table 3. Impact on exports of Argentinean products after elimination of several barriers (Regúnaga, 2002).

	Production			Exports		
	Tariffs	Subsidies to exports	All subsidies	Tariffs	Subsidies to exports	All subsidies
	.... % of increase					
Meat	43	1	55	362	9	421
Dairy	2	7	18	31	133	315
Fruits & vegetables	2	-	2	26	-	25
Cereals	0	4	39	10	10	107
Oil crops	-	-	-	1	-	74
Oil	-	-	12	1	10	18
Sugar	17	-	16	240	3	253

Final considerations

There are many opportunities to come. Introducing China into the WTO would open a market of 1.3 billion of food consumers. The growing economies of Eastern European countries, and the recoveries of Malaysia, South Korea and other emerging countries of Asia, would boost imports of more sophisticated foods.

To gain competitiveness Latin American institutions, firms and governments have to achieve greater coordination of their agricultural chains. Good governance practices are also essential to improve the quality of the organizational environment. To ensure technological innovation on processes and products, investments on research and development, from either the public or private sectors, must increase substantially.

Good agricultural practices, including proper fertilization, are an essential part of any improvement to ensure the quality of products, product differentiation and logistic development. Finally but not least, the fight against subsidies and other distortions by coordination of policies among nations is also necessary to reverse the tendency of decreasing participation of primary products in the final aggregated value of agriculture.

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Session 3

Plant nutrients for sustainable agriculture

Decision support systems in nutrient management

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Sustainable agriculture at a global scale requires that plant nutrients at a local scale be managed efficiently and in a way that optimizes profitability and supports highly efficient use of land. The complexity and inherent uncertainty of managing soil-plant-nutrient systems makes this a daunting task, worthy of the very best that science and technology can offer (Figure 1; Beaufils, 1973). Though the fundamentals of nutrient management have essentially remained unchanged during the 50-year history of the International Potash Institute (IPI), technology, our understanding of how best to apply technology, and the societal context within which we manage nutrients, have changed markedly.

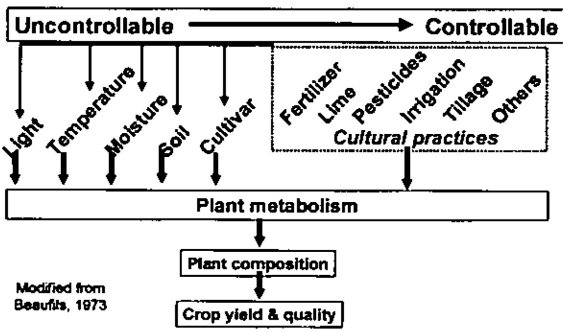


Fig. 1. A complex system involving uncertainty.

Opportunity and need for improved nutrient management

There is a great opportunity for increasing nutrient use efficiency and production capacity through improved application of nutrient management decision aids. For example, studies show that fertilizer nitrogen (N) recovered by crops at a field scale is seldom greater than 50% and often less than 33%. A recent review of N fertilizer recovery in different cropping systems (Cassman *et al.*, 2002) showed average recoveries of 37% for maize in the north central U.S. (Table 1). Recovery in irrigated lowland rice systems of Asia under farmer management was 31%, but increased to 40% under researcher management. Wheat in India during seasons of poor weather conditions averaged 18%, but increased to 49% when weather was favourable for wheat production. These data reveal that while management can substantially improve N use efficiency, weather will always be an uncontrolled factor that can significantly influence system efficiency.

Table 1. Nitrogen fertilizer recovery efficiency using on-farm measurements (Cassman *et al.*, 2002).

Crop	Region	Number of farms	Avg N rate, kg/ha	Recovery, %
Maize	NC USA	56	103	37
Rice	Asia-farmer	179	117	31
	Asia-researcher	179	112	40
Wheat	India-poor weather	23	145	18
	India-good weather	21	123	49

A well-proven practice for improving N efficiency is balanced nutrition. Fifty years ago, *Better Crops with Plant Food* published an article on Illinois research entitled "Big crops require balanced fertility" that showed very little response by maize to application of either N or potassium (K) separately, but a 2.4 t/ha response when applied together (Tyner, 1952). More recently, studies in China have shown dramatic improvements in yield and N efficiency when phosphorus (P) and K needs are met (Table 2; Zhu, 1994; Jin, 2001). Across half a century, the fundamental agronomic need for balanced nutrition has not changed but its importance has, this is because of the environmental need for high N recovery by crop plants.

Table 2. Balanced nutrition - a proven means of increasing nutrient use efficiency.

Crop	Treatment N	NPK	Reference
	N recovery by crop, %		
Barley	28	51	Zhu, 1994
Wheat (11 yrs)	31	70	Jin, 2001
Corn (5 yrs)	35	66	Jin, 2001

Progress has been made in increasing N efficiency, especially over the last couple of decades. Since 1980, N efficiency for maize in the U.S. increased 35% while yields increased 40% (Figure 2; Fixen and West, 2002). This concurrent increase in nutrient use efficiency and yield or land use efficiency is essential for sustainability due to anticipated increases in the demand for food, fiber, and other agricultural products, and the need to limit the expansion of land use for agriculture. Figure 3 (Dibb, 2000) illustrates that one method of increasing nutrient use efficiency is to limit nutrient additions to sub-optimal levels where marginal returns are very high. However, such methods result in low land use efficiency and would require conversion of more land to crop production.

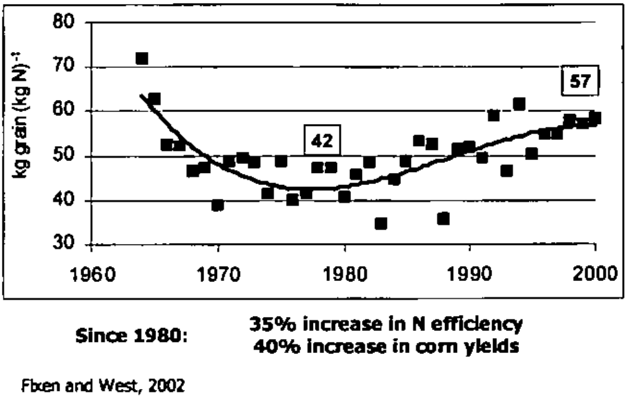


Fig. 2. Corn grain produced in the U.S. per unit of fertilizer N used, 1964-2000.

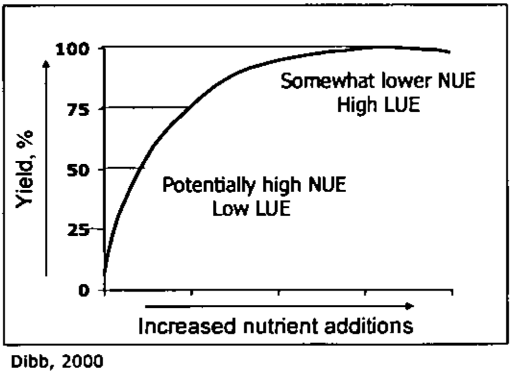


Fig. 3. Nutrient use efficiency (NUE) vs. land use efficiency (LUE).

The best growers in most regions today show us that much higher land use efficiency is possible since they grow yields that are often 50% or more higher than the local average on similar soils. For example, Francis Childs, an eastern Iowa farmer, has exceeded 24 t/ha of maize grain for the last three years with the third year (2001) setting a new world record of 25.7 t/ha. That indicates the genetic potential exists for higher yields through improved crop management.

Nutrient management decision support as part of ecological intensification

A relatively new term coined to describe the simultaneous pursuit of high land use efficiency and high nutrient use efficiency is "ecological intensification" (Cassman, 1999). In the author's words, it is "the intensification of production systems to satisfy the anticipated increase in food demand while meeting acceptable standards of environmental quality". Nutrient management decision aids are critical tools in ecological intensification as we strive to reduce uncertainty to the minimum set by our ability to predict the weather.

The general goal of nutrient management decision support tools is to increase the probability of making the correct nutrient management decision. There are many types of support tools that emphasize different factors influencing management decisions such as agronomic, economic, or environmental factors. They also vary in cropping system and cultural suitability with some being most appropriate for large scale farming in developed countries and others more appropriate for small holders in developing countries. Since it is impossible to discuss all of them in this paper, a cross section of nutrient decision aids will be presented from which decision support systems can be built. Those that will be mentioned fall into the following categories:

- Crop appearance
- Crop nutrient removal
- Soil testing
- Economic analysis
- Environmental risk assessment
- Nutrient response measurement
- Integrating nutrient management

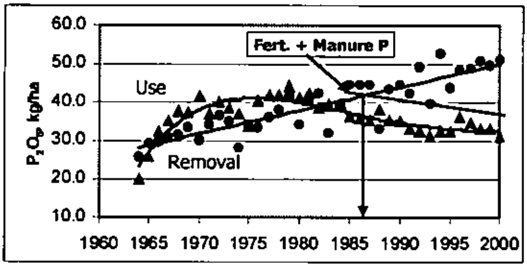
Crop appearance

Perhaps the oldest, but still useful, decision aid in nutrient management is crop appearance. One of the most popular PPI publications continues to be "Be Your Own Corn Doctor" (PPI/PPIC, 1995) even though the original version dates back to 1955. This publication provides a qualitative visual presentation of deficiency symptoms on leaves, stalks, roots, and ears of maize. The problem with this approach for most situations is that by the time the deficiency is detectable, yield loss has already occurred. A semi-quantitative tool that allows somewhat earlier detection of N deficiency is the leaf color chart used successfully to fine-tune in-season N application in irrigated, lowland rice production in Asia.

On the other end of the technology spectrum is the use of remote or local N sensors. A new example that looks quite promising is the GreenSeeker from NTech Industries (NTech, 2002). The technology is based on research conducted by Oklahoma State University (Raun *et al*., 2002), and utilizes an active sensor that determines normalized difference vegetation index (NDVI) to estimate average N uptake per day by the plant, which is related to potential yield if no additional N is applied. Expected N response is estimated by comparing the measured NDVI to that in a N non-limiting strip of crop. The sensor is mounted on a spray rig and coupled to a variable rate liquid applicator for simultaneous sensing and application. The Oklahoma research shows the approach adds 15% to N recovery in winter wheat. Company plans as of October 3, 2002, were to have 6 to 10 commercial units in fields of the U.S. Great Plains this autumn.

Crop nutrient removal

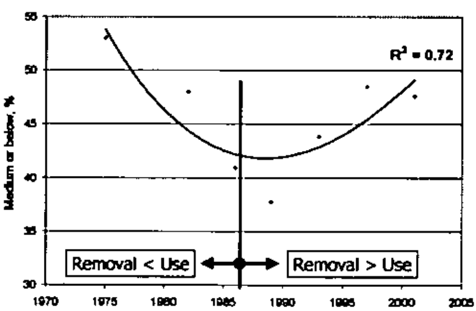
Nutrient removal by the crop gives a basic reference point for nutrient management decisions. It offers a crude estimate of the quantity of nutrient that must be replaced by some source to maintain existing soil fertility levels. Like crop appearance, it is an old nutrient management decision aid and is still under-utilized. The Corn Belt of the U.S. offers a good example. Figures 4 to 6 provide an historical sketch of P and K use relative to crop removal in this region (Fixen and Murrell, 2002).



Fixen and Murrell, 2002

Fig. 4. Average P use on corn and soybeans in the U.S. relative to crop removal.

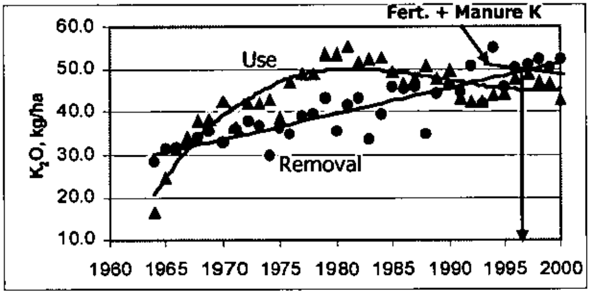
In the late 1960s and throughout the 1970s, use of P fertilizer exceeded crop removal. However, by the late 1980s, removal exceeded use, even when P in recoverable animal manure was included. Since then, the gap between application and removal has been growing and the currently declining soil test levels reflect these budget deficits (Figure 5).



Fixen and Murrell, 2002

Fig. 5. Percent of samples testing medium or below in P in the Corn Belt.

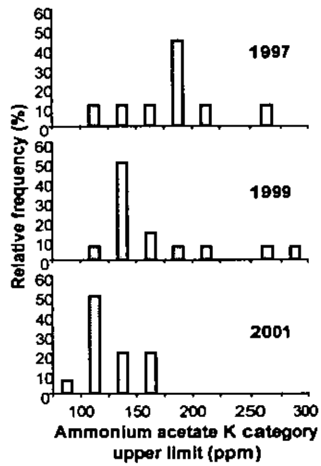
Potassium relationships for the region are similar (Figure 6). The 1998-2000 average P removal to use ratio for the six leading maize producing states is 1.71 when only fertilizer is considered and drops to 1.33 when recoverable manure P is included (Fixen and Johnston, 2002). Corresponding K values are 1.62 and 1.30 for without and with manure K, respectively. Because management practices have not sufficiently accounted for crop removal, soil fertility levels are in decline and the system is unsustainable.



Fixen and Murrell, 2002

Fig. 6. Average K use on corn and soybeans in the U.S. relative to crop removal.

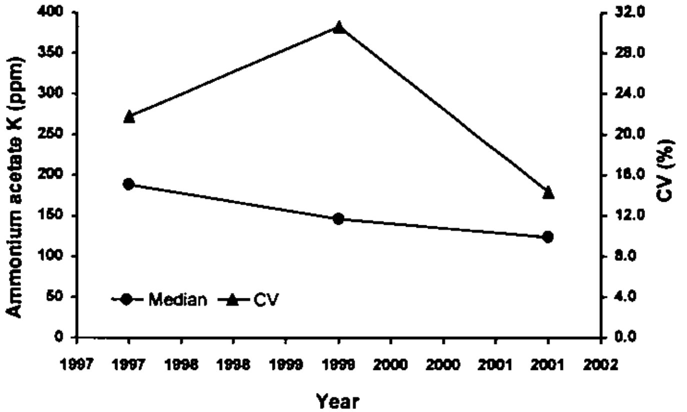
Even the most sophisticated producers sometimes lose track of this most basic of nutrient need indicators. Figure 7 (Murrell *et al.*, 2002) shows soil test K frequency distributions from intensive sampling of an Indiana maize/soybean field for three sampling dates across a five-year period.



- Years 1 & 2: Number of categories did not change
- Year 3: No samples in higher categories
- Category with most samples moved downward:
  - 1997: 176 – 200 ppm
  - 1999: 126 – 150 ppm
  - 2001: 101 – 125 ppm

Fig. 7. How have soil test levels been changing over time? Indiana precision corn field example.

The intensive management and variable rate fertilization of this field succeeded in reducing soil test variability within the field, but at the same time allowed the general field K level to drift downward into a yield-limiting range (Figure 8). The trend in this field was consistent with regional removal data and illustrates the problems use of generalized information on crop removal or soil test buffer potential can cause when applied at a refined scale. It also shows the importance of basic agronomic principles when sophisticated technology is applied. There is no free lunch in nutrient budgets: if more leaves than returns, fertility declines.



- K fertility becoming less variable but is drifting downward to yield-limiting levels
- Reinforces the message of regional removal data

Fig. 8. What has been happening to soil tests and variability?

Decision aids for nutrient removal range from simple pocket-sized charts to computerized applications that quickly calculate historical budgets or project into the future. An example is a new application from PPI called *PKcalc* that calculates nutrient balances for a field based on crop yields, manure and fertilizer applications input by the user. The software requires Microsoft Excel to run and is downloadable at no cost (www.ppi-ppic.org/toolbox).

Soil testing

Soil testing has of course been the traditional foundation of nutrient management for over 50 years in the agriculture of developed countries. It is a powerful decision aid, but with limitations. The time and space constraints of this paper will not allow more than a superficial overview of its role and precludes coverage of the many recent changes in methodology in both the field and laboratory. Though a powerful tool, it is not available in all regions of the world due to inaccessibility of reliable laboratories using methods appropriate to local soils and crops, and due to lack of calibration research relevant to current cropping systems and yield levels.

An important spin-off of the development of site-specific precision technologies and the associated supportive research has been a greatly increased understanding of the importance and magnitude of within-field variability in soil test levels. This in turn has led to an improvement in soil sampling methods whether the field being sampled will experience variable rate fertilization or not. Again, we can go back 50 years to *Better Crops with Plant Food* and note that we have been aware of within-field variability for a long time. In the May issue, P.E. Johnson wrote: "There are dozens of soil types, and also many man-made variations within each soil type. Present needs within a soil type depend so much on what has or has not been done before" (Johnson, 1952). As in the case of balanced nutrition, the concept is far from new, but the context of the times gives the concept new importance.

Many soil sampling issues have been only partially resolved. Issues today include grid vs. zone sampling, cell vs. point vs. something in-between, systematic vs. non-systematic, aligned vs. unaligned, sampling frequency vs. sampling intensity, number of cores per sample, "smart" sampling vs. the alternative, and numerous details in interpolation and mapping. We are starting to see the development of software designed to help with sampling decisions. One example is *Management Zone Analyst* (Kitchen, 2001). This program uses unsupervised fuzzy classification to create potential management zones for a given field. It is available on the World Wide Web at no cost.

Soil test interpretation for the creation of fertilizer rate maps is a continuing challenge in many regions. Questions continue on what layers of information are needed and how the needed layers should be combined, considering the potential exists for interaction. Basically, the tradition in soil fertility research has been to treat most interactions as "error" and pool data across soils, cultural practices, weather, and genetics, and generate one calibration curve. That approach is not well suited for site-specific precision agriculture applications. There is a largely unfilled need for multivariate decision aids in the form of user-friendly applications. This is a potential use of models, provided they can be developed to work in the real world of modern high-yield crop production.

Economics analysis

Budget analysis software that shows the relationship between nutrient use decisions, yield potential, and production costs can be very informative in nutrient management planning. It quickly illustrates the role of nutrient management in farm profitability. One example of such software is *MEY Analysis for Windows* (PPI/PPIC, 2002).

Environmental risk assessment

Environmental considerations have become a significant factor in nutrient management decisions, especially for N and P. Environmental P indices have become part of nutrient management plans in some states in the U.S. and are major factors determining whether manure application will be N based, P based or not allowed. The most common indices assess a specific site for its potential to contribute P to surface water by considering both source and transport factors (Snyder *et al.*, 1999). Much of the industry in North America supports the use of such indices because they represent a science-based, site-specific approach to targeting management efforts to those areas with the greatest probability of contributing to water quality problems.

Nutrient response measurement

The most certain approach to determining the nutrient response or supplemental nutrient needs of a field is to measure the response to each nutrient in question with controlled experiments. In most cases this is not practical. However, situations exist where this approach to facilitating nutrient management decisions is feasible.

One such situation is the use of omission plots as has been accomplished in lowland rice of Asia (Dobermann *et al.*, 2002; Witt *et al.*, 1999; Witt and Dobermann, 2002). In this approach, the omission plot is used to determine indigenous nutrient supply of a specific nutrient when others are non-limiting. A limited number of carefully planned omission plots conducted within a particular recommendation domain are used to estimate indigenous nutrient supply for that domain. These plots are used as a surrogate for soil tests, which may not be available for the area. Field specific fertilizer recommendations are calculated from the estimated nutrient requirement for the field yield goal using the QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) model, nutrient uptake from the omission plot, and expected fertilizer recovery by the plant. In these studies, recovery was found to be 40 to 60% for N, 20 to 30% for P, and 40 to 50% for K. In the case of N, in-season adjustments in rates are based on plant color measured using either a chlorophyll meter or a leaf color chart. Average plant recovery of applied N was increased to 40% compared to 31% for the farmer fertilizer practice while grain yield was increased by 7%. This approach requires agronomists, extension workers, and farmers to work together in farmer fields to estimate fertilizer nutrient requirements. It should be pointed out that no comparison to a soil test based approach was included in these studies.

Interest in on-farm research by North American farmers and their crop advisers has increased substantially in recent years, partially due to adoption of site-specific precision technologies. Yield monitors, global positioning systems (GPS), geographic information systems (GIS), electronic variable rate controllers, and the development of farm-oriented research management software, have made on-farm research a less onerous task than in the past. Once farmers have purchased the technology, they usually want to get the most benefit possible from their investment and they often turn to on-farm research, some of which frequently targets refinement of nutrient management decisions. In 2001, an estimated 43% of grain combines in the U.S. had yield monitors, and 50% of those with monitors were GPS equipped (Fixen, 2002). Thus, access to the technology is very good. Fertilizer industry interest in facilitating on-farm research is also very high for a number of reasons. Perceived benefits include expansion of customer base, greater customer loyalty, the development of local, defensible recommendations, and the demonstration of local agronomic expertise. Successful approaches usually keep designs simple and employ software that people already have. Free technical manuals on on-farm research and training aids are available from PPI (Murrell and Moore, 2001).

Integrating nutrient management

Since another entire paper in this session addresses the topic of integrated nutrient management, there is little need to dwell on it here. The more complete integration of all nutrient sources ... organic and inorganic, and all farming enterprises ... crop and livestock, is rapidly becoming a reality in many parts of the world, frequently by mandate. Fortunately, several excellent computer programs have been developed to assist in the integration. One example from North America is *Manure Management Planner*, developed by Purdue University (Joern and Hess, 2002). Like most software packages, it assists farmers and their advisers in developing manure management plans that will reduce the probability of water quality problems in the light of available resources, automates manure application records, and estimates supplemental fertilizer needs.

Conclusions

During the last half century, most of the scientific fundamentals of nutrient management have remained unchanged, but the technological and societal contexts have changed markedly.

Here a cross-section of decision aids available to individual growers and their advisers for use in the development of site-specific decision support systems for nutrient management that have the potential to advance production capacity and nutrient use efficiency have been reviewed. Some of these require minimal on-farm technology and are appropriate for regions of small landholders, while others are more appropriate for regions with good access to sophisticated technologies. The importance of nutrient management decision aids will increase as the demand for improved efficiency and productivity increase. Fertilizer industry involvement in development, refinement, and adoption is critical to the sustainability of the industry and of agriculture.

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Biotechnology in concert with plant nutrient management

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Abstract

Industrial agricultural practices have adverse environmental effects such as desertification, soil erosion, salinization, contamination of ground water by fertilizers and pesticides, decreased water availability, eutrophication and decreased genetic diversity. Sustainable agriculture represents the only way to guarantee adequate production rates while maintaining soil and ground water quality. To abolish or reduce agronomic practices that degrade the environment and to minimize off-farm inputs, while maintaining or increasing yields will not be possible without the developments that will be generated by the genetic manipulation of crops. To reduce the use of fertilizers could be an important trend to achieve sustainability in agriculture. Discussed here are recent advances in plant nutrient use efficiency towards the generation of crop plants that meet the requirements of environmental sustainability and agricultural productivity. It is critical to unfold the science behind the technology, and to engage all of society in an open dialogue to better identify the risks and benefits of adopting or not adopting agricultural biotechnologies. Attention is also directed to the significant positive impacts of plant biotechnology for food production and nutrition, particularly for developing countries. The importance of partnerships between the public and private sectors is stressed.

Introduction

In his acceptance speech for the Nobel Prize for Peace in 1970, Norman Borlaug said that the Green Revolution, if fully implemented, could provide sufficient food for humankind through to the end of the 20th century. Indeed, advances in plant germplasm improvement, the use of fertilizers, and expanded use of irrigation allowed food production to outpace population growth. But he also warned that unless the world's population growth decreases, the success of the Green Revolution would be only ephemeral. Since then global population has doubled to more than 6 billion people and, during the next 40 years, is projected to increase and stabilize at 8 to 9 billion. Much of this increase will occur in cities of the developing world.

Over the last 20 years, improvements in food production have almost halved hunger deaths from 41,000 per day in 1980 to 24,000 today, even as population doubled.

From a food and feed safety viewpoint, the use of *Bt* maize and *Bt* rice significantly reduces levels of potentially carcinogenic mycotoxins. Caterpillar tunneling and feeding increase the incidence of microbial growth in stalks and grains. The aflatoxin, produced by *Aspergilus flavus* in maize kernels pre- and post-harvest, is extremely toxic to humans and livestock.

The use of genetically modified herbicide tolerant crops reduces the use of the classical herbicides. Case-study analyses of 32 such cultivars in the USA show that they would cut herbicide use by 117 million pounds per year (Gianessi *et al.*, 2002). The present GM herbicide-tolerant crops also bring environmental benefits by switching to biodegradable herbicides and reducing the need to till the land to prevent weeds smothering newly sprouted crops. Thereby, soil erosion and movement is minimized, soil health and water retention is maximized, and more carbon is prevented from escaping from the soil and contributing to global warming gases in the atmosphere (Nill, 2002).

Future Genetically Modified Crops

The next generation of GM crops already in the pipeline will alter product quality characteristics – or "output traits" – the aim being to increase nutrition, modify allergens, reduce toxic compounds, and improve various functional attributes for consumers. Through the rational and selective alteration of plant metabolism it is possible to increase the production of endogenous metabolites or to achieve the synthesis of metabolites not normally produced by plants. Metabolic engineering in plants has indeed yielded remarkable and encouraging results by increasing the yield of minor components, such as vitamin A, vitamin E, and other phytonutrients, including isoflavones and lycopene. Other genetic modifications have altered major components such as the fatty acid composition in oils from soya and canola to create healthier fats.

Thanks to the emerging knowledge of plant genomes and the understanding of the regulation of their gene expression, and the rapid advances of proteomics and metabolomics, complex traits can be addressed. Challenging plant studies focusing on longevity, totipotency, apomixis, seed molecular biology, haploid plants, hybrid vigour, nutrient assimilation, symbiotic nitrogen fixation, and resistance to biotic and abiotic stresses hold promising perspectives in plant biotechnology. The introduction of physical traits such as maturity, plant architecture, pod shattering, and shelf life will improve the yield of crops.

Drought is one of the major agricultural problems in developing countries. Almost one-third of the world's total area consists of arid and semi-arid regions, and such regions are increasing by more than 10,000 ha each year. Salinization is reducing the world's irrigated area by 1-2% every year, hitting hardest in the arid and semi-arid regions. Adverse environmental conditions trigger a complex signaling network that leads to plant responses involving nearly every aspect of plant physiology and metabolism. Molecular studies on plants from arid areas help us to understand the genetic basis of the physiology of drought and salt stress. This makes it possible to identify transcription factors and functional proteins that play an important role in resistance toward these biotic stresses. The recent development of salt-tolerant tomato plants by the overexpression of an *A. thaliana* vacuolar Na^+/H^+ antiport is an example of the power of this technology (Zang and Blumwald, 2001).

Through plant technology developments it will be possible to obtain a more valuable and environmentally friendlier agriculture, for example crop varieties that fit specific ecological niches without requiring expensive and polluting inputs. There will be rapid progress in the construction of high yielding varieties for local staple crops of the southern hemisphere. These varieties can be tailored to meet the nutritional needs of the population.

Recent research progress indicates that in the near future genetic manipulation of plants will allow the development of a wide range of outstandingly valuable products for industrial purposes. These include degradable polymers, antigens, antibodies, enzymes, and other pharmaceutical products. Many fine chemicals, now synthesized from petroleum products can be made in plants. Particularly novel chiral products can bring high value to the chemical industry. It will also be possible to enhance the production of the more classical bulk products like sugars, fatty acids, waxes, speciality oils, latexes and, not to forget, wood.

Among new approaches, the use of transgenic plants specifically tailored for the bioremediation of organic pollutants and heavy metals is essential to sustainable development. Plants represent a more environmentally compatible and less expensive method of site remediation compared to standard physical and chemical approaches. The recent achievements in this field include transgenic plants changing mercury into a less toxic derivative, plants with an improved capacity to accumulate cadmium, and plants able to degrade industrial waste and harmful substances.

Target traits for improving nutrient use efficiency

The increased crop production achieved by world agriculture during the second half of the 20^{th} century required high inputs of fertilizers, pesticides and water. Crop breeding strategies favored the selection of elite cultivars under high input conditions, while a flourishing chemical industry made the agrochemicals available. Traits such as mineral assimilation efficiency and metabolic use were neglected. As a consequence, to achieve today's optimum yield and protein content, intensive fertilization with nitrogen, phosphorus, sulphur and potassium are required. Because crops were not improved to maximize mineral absorption, they often take up only half of the applied nutrients. Those that are not used can subsequently be lost to surface and groundwater. The consequences of inadvertent fertilization are reduced water quality, eutrophication, loss of diversity in aquatic ecosystems, and dominance of weed species, among other disastrous effects.

The need to increase production to fulfill the demands of the world's growing population raises questions about both the sustainability and environmental consequences of current production systems. Crop plants with improved mineral use efficiency are becoming a prerequisite for lowering production costs. Such plants protect the environment, and improve crop yield, both in developed and developing countries. Sustainable agriculture represents the only way to guarantee high levels of production while maintaining soil and groundwater quality. In developing countries, there is a strong pressure to expand the area used for agriculture resulting in a further destruction of the remaining forests. This is very undesirable with respect to biodiversity conservation, greenhouse gas emissions and regional climate and hydrological changes. Land shortage and the cost of fertilizers restrain agricultural production in developing countries. Further improvement will be possible only if marginal lands allow the cultivation of higher yielding crop varieties.

A more efficient assimilation of mineral nutrients, especially micronutrients, can become an important quality trait. It is estimated that >2 billion people, primarily women and children in developing countries, suffer from iron deficiency. A similar number of people might lack zinc. Among the present strategies to solve this problem, the biofortification programs seek to increase the iron and zinc content in some staple foods. A better assimilation of these micronutrients from soil should contribute to the achievement.

Improved mineral assimilation is a quantitative trait that involves increasing the efficiency of mineral uptake and use under limiting conditions; cross-talk between the pathways of carbon, nitrogen, phosphorus, sulphur and potassium; and the allocation of nutrients and primary metabolites. Basic research in the past few years has enabled us to understand the key steps in mineral acquisition and metabolism. However, engineering mineral use efficiency requires more knowledge on the mechanisms of nutrient sensing and signal transduction in mineral assimilation responses. Functional genomic and metabolite profiling can give a display of mRNAs and metabolites under varying growth conditions and in relevant genotypes and so allow the identification of the signal transduction components for mineral assimilation (Hell and Hillebrand, 2001).

Targets to improve mineral nutrition include manipulation of ion uptake and efflux systems, enhancement of anion oxidation and improvement of phosphate bioavailability, and changes in the architecture of the root system.

Ion uptake and efflux systems

The molecular cloning of membrane transporters for nitrate, ammonium, phosphate, sulphate, and potassium and the availability of transgenic plants over-expressing membrane mineral transporters indicates that the increased mineral uptake by crop plants will be possible in the near future. Indeed, the over-expression of the high-affinity phosphate transporter PTH1 from *A. thaliana* in tobacco cultures has already resulted in enhanced growth under Pi limitation (Mitsukawa *et al.*, 1997).

However, ion membrane transporters occur in multiple copies in the genome and have differential expression and affinities. For example, multiple transporters mediate the uptake and movement of K^+ in plants. Studies with *A. thaliana* mutants on potassium transporters identified at least two families of high affinity K^+ channels (Elumalai *et al.*, 2002). High and low-affinity transporters have been described for nitrate, sulphate and phosphate (Hell and Hillebrand, 2001 and references therein). To be applied to improve nutrient use efficiency in crop plants, more fundamental studies on the physiological role of each transporter family member that mediate the uptake and movement of minerals in plants are required. Although upregulation of ion uptake is an obvious target to improve mineral nutrition, the multigenic nature of transporters indicate that a simple increase in transporter levels will not necessarily improve plant growth because levels in wild types of plants are most likely in excess.

Not only net influx rates are relevant for nutrient uptake. Efflux systems are responsible for a significant loss of ions from cells (Forde and Clarkson, 1999). It has been suggested that one way to overcome losses caused by efflux could be pathway engineering and the creation of sinks in order to establish substrate fluxes from inorganic ions to organic high-value compounds. This could be achieved by identification and manipulation of the spatial and temporal expression patterns of biochemical pathways master switches. Such pathway engineering would avoid the accumulation of potentially toxic intermediates and provide the precursors required to produce enhanced mineral nutrient levels in crops (Hell and Hillebrand, 2001).

Anion exudation and phosphorus bioavailability

Another promising approach to improve acquisition of nutrients, particularly phosphorus (P), is genetic manipulation to enhance organic anion exudation from plant roots. Plants can suffer from P deficiency even though the total P content of the soil appears to be more than adequate. Up to 80% of the P supplied in fertilizers is retained in the soil. Because of the importance of P as a macronutrient for plant growth and livestock production, and the ability of phosphate compounds to bind important minerals, there is increasing interest in understanding the factors that underlie P uptake and bioavailability in plants used for animal feed and human consumption.

Organic anions in the rhizosphere compete with phosphate groups for binding sites in the soil and form stronger complexes with Al^{3+}, Fe^{3+} and Ca^{2+} than phosphate does. In particular, P can be liberated from Ca-P minerals as the organic anions complex with Ca or block the sorption of P to other charged sites (Ryan and Delhaize, 2001). Genetic engineering to increase anion exudation in crop and pasture species could reduce the application of costly P-fertilizers. Moreover, organic anion can potentially change the concentrations of micronutrients (Fe^{3+}, Mn^{2+}, Cu^{2+}, and Zn^{2+}) in the soil solution and possibly increase their availability to plants. (Ryan and Delhaize, 2001 and references therein). This approach benefits plants by also reducing the concentration of toxic cations in the rhizosphere.

Attempts to modify organic anion exudation from roots by changing the activity of organic acid biosynthetic enzymes with gene manipulation has met with mixed success. The use of the citrate synthase gene from *Pseudomonas aeruginosa* in transgenic tobacco resulted in controversial results (Ryan and Delhaize, 2001 and references therein). The expression of the carrot mitochondrial citrate synthase in *A. thaliana* plants resulted in enhanced release of citrate into the growth medium. These transgenic plants also showed improved growth due to the release of Pi from aluminum phosphate in the soil (Koyama *et al.*, 2000).

Physiological studies have recently indicated that the limiting step is not the synthesis of organic anions, but the transport across the membrane. Organic anions transporters are likely to regulate exudation (Ryan and Delhaize, 2001). The current challenge is to clone the genes that encode these channels or other proteins that facilitate organic anion exudation.

Another strategy that might be important for mobilizing phosphate reserves in the soil is engineering plants to secrete phytases from their roots. This enzyme can release bioavailable phosphate from one of the most important compounds in the phosphate cycle, phytic acid. In agricultural systems, seeds are used either for plant production or as feed for livestock production. The major phosphate storage compound in seeds is phytic acid. Feeding of non-ruminant animals causes the excretion of large amounts of undigested phytic acid because the digestive system of these animals lacks phytases. Intensive manure fertilization oversupplies the soil with phytic acid, contributing to the accumulation of P (Brinch-Pedersen *et al.*, 2002).

One approach that has been devised to improve phosphate bioavailability in animal feed and to reduce the environmental load is engineering crop plants for increased phytase production in the seeds. The constitutive expression of heterologous phytase has been obtained in tobacco and has subsequently been shown to function in soybean, oilseed rape, rice and wheat (Brinch-Pedersen *et al.*, 2002 and references therein). The results indicate that the strategy is efficient in improving phosphate bioavailability and in reducing phytic acid excretion. This is beneficial not only to the environment, but also to human and animal nutrition. Phytic acid forms complexes with important minerals preventing their uptake, being therefore considered to be an important anti-nutritional factor. Genetic modifications of food staples for expression of phytase could facilitate absorption of micronutrient minerals such Zn^{2+} and Fe^{2+}, one of the major targets of biofortification initiatives.

Architecture of the root system

The rapid advances on plant functional genomics, proteomics and metabolomics will soon allow complex plant architecture traits to be addressed. The developmental plasticity of the root system in response to changes in mineral availability offers an alternative way of improving mineral use efficiency. Adaptations of root architecture are reported for nitrate, phosphate and sulphate (Hell and Hillebrand, 2001 and references therein).

Some species modify their root anatomy in response to nutrient limitation, and to local nutrient-rich soil patches. Developmental adaptations to P deficiency include increase in root hair density and length, formation of shallow adventitious roots in topsoil, and local changes in lateral root length in Pi-rich zones in the subsoil (Lynch and Brown, 1998). These specialized roots enhance the ability of plants to access poorly available pools of P in the soil by increasing the surface area available for nutrient absorption, exudation of large amounts of citrate, malate, acidification of the rhizosphere, and release of phosphatases. However these adaptive phenotypes of the root architecture is not a common feature in plants. Most species lack comparable response systems. Biotechnological tools such as differential expression analysis can help to unravel the genetic basis of these valuable properties. In this way a MADS-box-like transcription factor was identified that mediates auxin-regulated control of lateral root growth in *A. thaliana* in response to local nitrate supply (Zhang and Forde, 1998). Natural variation within wild relatives of crop species is a genetic resource that can be exploited for the identification of regulatory genes that control developmental switches under nutrient limitation.

GM-technologies and public perception

Plant biotechnology and in particular GMO-plants has received a very bad press in Europe where it is estimated that 70 to 80% of the population is opposed to food and feed from GM crops. For scientists, this attitude is totally incomprehensible because not the slightest detrimental effect on the health of humans or animals has been demonstrated with GM plants currently available commercially. Also no ecological problems have been observed.

The concept that this laboratory technology is unnatural is a problem of semantics. None of the plants or animals we use in agriculture and husbandry are "natural". They are all the product of many thousands of years of crossing and selection. Since the last century, laboratory crosses and mutation breeding (irradiation of seeds in nuclear reactors) where often the source of new genes presently used in our bread wheat and in many other staple foods.

A recent overview of ecological risk assessment, by Conner *et al.* (2003), provides an analysis examining the potential impacts of biotech crops based on a review of 250 publications on the topic. As already stated by many others, the authors argue that any secondary ecological impacts of a biotech crops must be balanced against the impacts of the agricultural practices the biotech crops will replace. The authors, based on scientific data, provide answers to the main issues that have been subject to intense criticism by environmental activists. The general conclusion is that biotech crops are neither more, nor less likely to affect biodiversity than any other change in agriculture.

Instead of damaging the environment, biotechnology will enhance agrobiodiversity, where classical breeding strongly favours the use of monocultures. Also, biotechnology techniques are providing the tools to unravel how gene spreading and variety development occur.

It is ironic that green activists are so adamantly against plant biotechnology because it becomes more and more clear that plant biotechnology will bring crucial contributions in the field of environmental sciences. Above all, it will bring the basic tools for constructing a non-polluting agriculture. As discussed above, studies on drought stress and water uptake by plants, improved non-tillage agriculture and the reconstitution of soil fertility, all suggest that novel plants that help preserve the water supply are a possibility.

The worldwide action of some pressure groups to identify science and technology development with the "aggressive" actions of multinationals and "capitalistic exploitation" is an interesting sociological observation. It is of the greatest importance that scientists understand the fears of society and that they listen carefully to realize where rational and science-based arguments can help to progress the dialogue and where emotions through fear take over. These dialogues should be greatly increased worldwide until a climate of trust and confidence is reached. The European authorities understand these needs very well. Hence one can predict that in the coming years the respective governments will help so that such debates take place in mutual respect.

Final remarks

Agricultural biotechnology has the potential to develop more sustainable farming practices. However, it must be pointed out that current research is mostly focused on a small number of crops such as maize, soybeans, rice, wheat, canola and cotton that bring large profits to agribusiness and large-scale farmers. To benefit people in developing countries, biotechnology must focus on crops that fit specific ecosystems and that are important to poor farmers, in particular crops such as cassava, millets, sorghum, yams and pulses like common beans and lentils. Such crops will meet the nutritional needs of the people most in need of food.

It is also important to realize that universities will not make the innovation in agriculture and these "plants for the future". Their task is research and capacity building. Universities can bring tools and suggest approaches. They can bring "state of the art" technology. But constructing a prototype for a novel plant requires a lot of repetitive work far removed from the competitive research expected from the universities.

Prototype development is also at least ten times more expensive than fundamental research. In the developed world and particularly in the United States, this concept is well understood. "Start-up" companies make prototype products. Small dynamic enterprises, some with a limited life span as they are bought up by major industries when successful, bring together the right expertise of science and product research.

For tropical agriculture it is unlikely that analogous start-up activities will develop. The financial return on investment will be too low for too long a period. Which structure could replace them? If there is no private money available, government and international institution money will have to take on the task. The CGIAR institutes are well positioned to make a crucial contribution. We may expect that major plant research institutes will try, stimulated by the EU 6th framework program of the DG-Science and Technology, to take up their role as technology providers for the CGIAR centers. Our own institution IPBO in Belgium, the genomic centre at John Innes in the UK, the CIRAD in France, ETH in Zurich - Switzerland, Wageningen in The Netherlands, all have the expertise and the tradition to interact with overseas institutions. So does ILTAB at the Danforth Center in St Louis (US). It should however be clear, as stated above, that this will only deliver candidate novel plants. Notwithstanding the help of the National Agriculture Research institutions (NAR's), there will be a need for private entrepreneurship. It will be essential that private seed companies be established in third world countries to develop, supply and distribute the plants well adapted to the different regions.

In order to finance prototype development, we cannot count on industry, it is not their mandate. The public sector has very limited means so we can only hope that private funds from charities and foundations can be attracted. European authorities will need to see if they can develop tax incentives as stimulating as those in the USA, so that here also we would see a better financial climate for charities and foundations. We notice indeed the goodwill of many wealthy individuals to help poverty and the alleviation of underdevelopment through the introduction of new technologies.

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Integrated plant nutrient management – the way forward

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Abstract

Maintaining soil fertility to meet crop requirements is the key to successful and profitable crop management. However, the inappropriate use of inorganic fertilizers and, in particular, organic manures, such as slurries, can lead to excessive nutrient losses from soil to air and water with consequences for the environment. Responsible crop nutrient use must be based on a field-by-field knowledge of nutrient inputs and offtakes, so that nutrient balances can be calculated. The effect of the balance between inputs and outputs on soil nutrient reserves must be monitored by regular soil analysis and the keeping of records and crop yields.

Under an Integrated Farm Management (IFM) system, forward planning is critical. Farmers review the accuracy and suitability of previous applications of nutrients and calculate all inputs. On a field by field basis the aim is to maintain soil nitrogen (N), phosphorus (P) and potassium (K) levels through the use of nutrient balance sheets and regular soil testing while meeting the nutrient requirements of the current crop. In particular, taking into account contributions from grazing stock, soil nutrient reserves, previous crop residues, and relating them to predicted current cropping requirements, and the nutrients that will be removed in harvested crops. When determining fertilizer requirements the nutrient contribution from organic manures is accounted for.

The paper illustrates practical examples of 'Integrated Plant Nutrient Management' as part of a fully integrated farming system. Showing how, through the adoption of responsible practices, farmers can reduce risk, improve environmental performance and save money. Such an approach is a clear vision and practical way forward for the majority of farmers because it is logical, progressive and achievable.

Introduction

'*Effective soil management and care is the starting point for all crop decisions on the farm. We place a strong emphasis on ensuring we have a full working knowledge of the soil status, any problems that may occur and the crop nutrient requirement before we make any final decisions. To us Integrated Farm Management (IFM) makes sense.*' Philip Ashton, LEAF Demonstration Farmer.

Integrated Farm Management (IFM) is geared towards sustaining and optimising the use of all resources on the farm, including soil, water, air, staff, machinery and capital together with wildlife habitats, landscape and archaeological features. Its successful uptake requires a detailed understanding of the business and an innovative and challenging approach. It is built around existing knowledge and sound husbandry principles and many of the practices are constantly being improved in accordance with current research and new technology. This encourages farmers to review their current practices and make changes.

In particular, soil is the basis of all agricultural production and the conservation and improvement of this valuable resource is a high priority in the adoption of IFM. This allows produce to be grown on healthy and biologically active soil with a satisfactory level of organic matter, a good physical structure and sufficient fertility. With IFM, management decisions are site specific giving careful consideration to maintaining or increasing production potential, biodiversity and water quality. They are also focused to protect soil quality and minimise the requirements for off-farm inputs.

In the past, researchers and Governments have tended to develop separate strategies for either nitrogen (N) or phosphorus (P) and implemented these at farm level. However, because of the different critical sources, pathways, and sinks controlling P and N export, remedial efforts directed to either P or N can negatively impact the other nutrient. For example, basing manure application on crop N requirements to minimise nitrate leaching into groundwater can increase soil P and enhance potential surface runoff losses. Conversely, reducing surface runoff losses of P via conservation tillage can enhance N leaching. Such trade-offs are not restricted to just nutrients, for example where efforts have been made to enhance the organic matter content of soil, which is beneficial in terms of soil fertility, pesticides will be adsorbed onto the humus and become less effective.

Thus the farmer is left in a situation to opt for the best 'fit' to the specific farm – a question of balance. It is critical that these positive and negative impacts of conservation practice on resulting water quality should be considered in nutrient management planning. Clearly, a technically sound framework must be developed, which recognises, for example critical sources of P and N export from agricultural land to water courses, so that optimal strategies at farm level can be implemented to best manage both P and N. Integrated Farm Management provides such a framework. And more specifically Integrated Crop Management (Fig. 1) and Integrated Plant Nutrient Management provides a clear focus for plant and soil nutrient decisions.

Integrated Farm Management – the LEAF definition

'*A whole farm policy aiming to provide efficient and profitable production which is economically viable and environmentally responsible. It integrates beneficial natural processes into modern farming practices using the most appropriate technology and aims to minimise the environmental risks while conserving, enhancing and recreating that which is of environmental importance.*' (LEAF, 1991)

Integrated Plant Nutrient Management (IPNM) – a definition

'Integrated plant nutrient management (IPNM) pertains to the combined use of organic and inorganic fertilizers in proper proportion accompanied by sound cultural management practices in crop production. Such cultural practices include the use of appropriate varieties, good water management, pest control (including weeds) and crop rotation (Philippine Rice Research, 1991).'

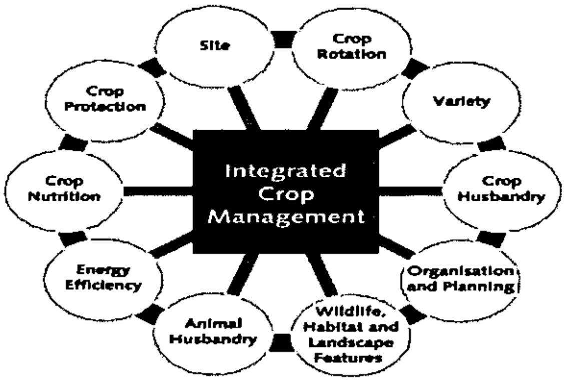

Fig. 1. Integrated Farm Management (adapted from LEAF, 2000).

The main principles of IPNM are to optimise the use of organic inputs while minimising nutrient losses and to make supplementary use of fertilizer (Aune and Raynor, 1998). It adopts a holistic view of plant nutrient management by considering the totality of the farm resources that can be used as plant nutrients.

According to Singh and Suboah (1994), the basic concept of IPNM is to limit the unfavourable exploitation of soil fertility and plant nutrients. This is principally through the maintenance and improvement of soil fertility and plant nutrition at an optimum level to sustain the desired crop productivity while optimising the benefits from all possible sources of plant nutrients in an integrated manner. The combination of organic and inorganic fertilizer, particularly relating to a mixed farming situation seems to be more practical than the use of organic or inorganic fertilizer alone. In addition, many researchers have shown that such a combination is needed to achieve a sustainable productivity of soils to meet the demands of the growing food requirement (Singh and Suboah, 1994). However the adoption of an IPNM system as part of an IFM approach is complex and there are many factors that should be considered including the farmer's socio-economic and cultural conditions.

Combining inorganic and organic fertilizers in a planned way can lead to many benefits. The use of organic manures can bring about many changes in the chemical, microbiological and physical properties of soil but these do not take place overnight. It may take two years or more before the benefits of organic manures can be realised. Incorporating large amounts of organic residue, especially in fine textured soil, improves its structure which is beneficial to upland crops (Paningbatan, 1997). This author claimed that the deterioration of soil structure in upland soil, an unstable soil property, takes place through intensive cultivation and improper cultural practices. Soil porosity, pore size distribution, bulk and particle densities, aggregate stability, water holding capacity, aeration, infiltration and hydraulic conductivity, as well as the recycling of soil derived nutrients, are improved through proper organic residue management. Maintenance of good soil structure is the key to sustain crop productivity of upland soils.

The rudimentary requirements of best practice for IPNM thus involve a combination of organic and inorganic sources of nutrients. Types of organic sources of nutrients are crop residues, fixed nitrogen from legumes, farmyard manure, household waste, sewage sludge and mulches, whether from composted material or decomposing vegetable matter. Organic sources of nutrients can be low cost sources. Limitations to their use are the low availability of the P; high labour demand and nutrient release not well synchronised with crop demand. In addition, the total of the available plant nutrients is often insufficient to meet crop demand.

The messages and experience of the adoption of IPNM technologies are consistent across the globe. The successful uptake of a fully integrated system needs to be linked to an enabling socio-economic environment. This includes improving the market for agricultural products and rural infrastructure, ensuring competition among dealers of agricultural inputs and outputs, and access to credit. Likewise it is important that farmers are involved in technology generation at an early stage.

IPNM technology should, in general, be:
- production and conservation effective
- simple to understand
- easy to maintain

and have:
- low labour requirements
- low cost
- low risk in terms of pollution

Specifically is needs to be flexible to allow for a sound management within the individual's own resources – depending on the market situation, availability of inputs, labour costs, farmer's knowledge, etc. Local adaptation is always necessary.

Resource efficiency – Using all available resources

LEAF (Linking Environment And Farming) has been active in the development and promotion of IFM for over 11 years. Specifically this has been through the setting up of demonstration farms throughout the UK and developing guidelines and management tools to assist farmers in the uptake of IFM. The approach has been one of collaboration and practical 'bottom up' solutions. Working with many farmers and organisations, LEAF has drawn up a framework that guides farmers through the structured uptake of IFM.

From our experiences there are several factors that encourage farmers to make changes and IFM operates on a win-win basis offering many benefits for farmers, consumers and the environment, namely:

- More effective use of available soil resources and nutrient inputs
- Cost savings
- Improved soil quality, crop yields, animal production and health
- Build-up and maintenance of soil fertility
- Efficient use of all available nutrient sources
- Improvement and maintenance of soil structure and water holding capacity
- Maintenance of soil organic matter status
- Minimisation of soil erosion
- Reduced pollution through reduced nutrient loss from soil to water and air
- Improved protection and reliability of drinking water
- Conservation of agricultural water supplies
- Improved crop establishment and reduced weed seedbank by appropriate cultivations
- Enhanced natural habitats and diversity of wildlife
- Increased capital value of the land

One of the most important aspects is the planning process behind such a management approach as IFM. The potential of a site for crop and livestock production depends greatly on the interactions between soil type, climate, topography and location near to potential market opportunities. Site potential can generally only be modified slightly within these constraints. In addition, the site may be subject to specific statutory designations, e.g. Sites of Special Scientific Interest (SSSI), Nitrate Vulnerable Zones (NVZ's) or voluntary ones. Thus it is critical to divide the soil into physical features (soil type, field size, land elevation and slope, hedges and water supplies etc.) and site attributes (locality, history, climate, special characteristics, etc.). Furthermore when putting IFM into practice, management decisions must be site specific giving careful consideration to maintaining or increasing the production potential, biodiversity and water quality. All decisions must also protect soil quality and minimise the requirement for off-farm inputs. For these reasons, the management approach must include consideration of the following factors:

- Account for the broad characteristics of the site, e.g. slope, its opportunities and restrictions when planning appropriate cultivations, grazing and cropping.
- Consider and evaluate the need for fundamental changes in land use, and plan actions with the involvement of appropriate specialists.

- Identify different soil types throughout the farm and within fields using a soil map. This will help greatly to:
  * Assess soil texture and structure: identify risk areas, such as those prone to erosion by wind or water, leaching, compaction, poor drainage, etc. and plan to minimise the risk and solve existing problems.
  * Draw up a programme of regular soil analysis for plant available P, K, sulphur (S), magnesium (Mg) and pH every 3-5 years, depending on cropping system and soil type, and consider assessment of mineral N status. Consider the analysis of trace elements, organic matter status, especially where crop growth is limited.
  * Identify pollution risk areas from manure spreading (no spreading, very high risk, high risk and lower risk) where special care or avoidance of manure applications is needed. Highlight these areas on a Farm Waste Management Plan to ensure staff and contractors are familiar with these areas and carry out operations appropriately.
- Examine soil structure and profile characteristics prior to cultivations.
- Plan timing of cultivations according to soil type, condition, required weed control, weather and seedbed requirements.
- Collect details of land drainage schemes and consider the use of drain outlets as inspection points for sampling to assess water quality.
- Use a grazing management system that reduces poaching, particularly in wet weather e.g. reverse strip grazing. Avoid, where possible, high stocking rates.
- Site animal feeders and drinking water points on hard standing areas or move regularly to avoid soil compaction and waterlogging, or erosion problems, and site where they are unlikely to directly affect watercourses.
- Consider the construction of dedicated cow tracks. These can provide benefits to soil, water and animal welfare. Ensure these are well-drained and comfortable for cattle to walk on.
- Increase access points to fields to reduce poaching and ensure gateways are well managed and drained.
- Assess the existing and potential wildlife value of the farm as a whole.
- Identify the wildlife value of cropped areas, including set aside.
- Identify adjacent wildlife areas. Also, note areas of value belonging to neighbours, which could be at risk from farm operations, and protect or enhance the value of these areas in association with others. Incorporate these areas into a Whole Farm Conservation Plan.
- Maintain and manage field edges and hedges for stock control, environmental and wildlife benefit and reduce impact of farm operations on the margins, e.g. by the use of devices such as headland deflectors and cut-off mechanisms when applying fertilizer.
- Establish buffer zones, conservation headlands and grass/wildflower margins adjacent to features such as rivers, ditches and hedges, to protect watercourses, enhance habitats and prevent weed ingress from boundaries.

Crop rotation

The appropriate choice of a diverse crop rotation is probably the most effective, indirect means of managing soil fertility for optimal plant growth. Rotations have considerable benefits for soil structure, soil flora and fauna, farmland wildlife, management of soil water and soil organic matter status, utilising nutrients in crop residues, minimising soil erosion and pest, weed and disease incidences. A diverse crop rotation has the added advantages of spreading cash flow and workload, in this respect traditional mixed farming offers the greatest benefit.

A crop rotation, which integrates cereals, broad leaved crops, grass and/or a leguminous crop, offers benefits in terms of soil fertility and habitat diversity for wildlife. A properly managed and adequately fertilized grass ley can improve the structure and moisture retention properties of soil. All-year ground cover not only reduces erosion, but also reduces leaching of nitrates. Overwinter stubbles make a major contribution to winter food for many birds, although consideration should be given to the possible overwintering of pests and diseases. A balanced crop rotation, permanent grassland and applications of slurries, manures, compost, green manures etc., can build up organic matter and help to reduce soil degradation. Such practices can prevent capping and soil compaction and stabilise soil structure making it more resistant to erosion by wind and water.

Soil fertility and fertilizer management

Under an IFM system farmers are required to calculate all nutrient inputs and outputs, taking into account contributions from grazing stock, soil type, nutrient reserves, previous crop residues, and current cropping requirements, nutrients removed in harvested crops and seasonal weather. The nutrient contribution from organic manures must also be accounted for when determining fertilizer requirements. Soil N, P and K levels can be maintained on a field-by-field basis by the use of nutrient balance sheets and regular soil testing. Furthermore, these can be used for forward planning and as a check on the suitability of previous applications. Inappropriate use of fertilizer can affect the yield potential and crop quality and have a negative impact on the environment and is costly.

Record keeping of all operations builds up a historic knowledge of fields and helps identify future problem areas. These should include all operations, such as primary cultivations and applications (with rates), operator name, date, field, crop, soil and weather conditions, type of fertilizer or organic manure applied, storage details, etc. Involving staff is essential and they should have access to records, be fully trained and have a clear understanding of the farm's approach to both production and environmental issues. They should be aware of the importance of avoiding spreading fertilizers, slurries, etc. at times of the year when they are likely to be used inefficiently by the crop and could result in excessive nutrient loss to water.

Furthermore they should take care to avoid applications to sensitive wildlife habitats, such as hedgerow bottoms, field margins and near water courses.

When spreading organic manures the setting up and maintenance of machinery is important with an aim to achieve a coefficient of variation of less than 25%. With inorganic fertilizer application operators should be able to identify fertilizer types and follow recommendations for setting and calibrating equipment. Equipment must be regularly serviced, and well maintained and frequently recalibrated to ensure the correct rate and evenness of application. The aim is to achieve a uniformity of application with a coefficient of variation less than 15%.

Organic and inorganic sources

Organic manures and other organic nutrient sources can make a significant contribution towards meeting a crop's nutrient requirement and enhancing the soil's condition in terms of physical quality. They have both economic and environmental value, although care needs to be taken to avoid environmental pollution and spread of animal and human diseases. Preservation of soil organic matter by organic additions is important for a good soil structure, improved water retention and for reducing soil erosion. Utilisation of organic manures can be beneficial in this respect. Where organic manures are used it is important to determine their total and available nutrient value either by analysis or by calculation from stock numbers and duration of housing. Diagnostics kits are becoming increasingly available for more accurate analysis.

Applications of organic wastes, such as food processing wastes, sewage sludge, paper waste etc. that are not produced on the farm, must be carefully introduced and in the UK in accordance with the Waste Management Licensing Regulations. Pre-notification of their use must be provided to the Environment Agency, which should include a Farm Waste Management Plan, soil analysis and analysis of material to be spread. It is essential that farmers are aware of their potential to cause pollution, odour nuisance to the public, disease risk to humans, wildlife or crops as well as possible contamination from heavy metals. Farmers should also be fully aware of any recent legislation and any market induced restrictions governing the use of these products.

In the UK, LEAF recommends that all farmers should devise a Nutrient Management Plan using MAFF: Fertilizer Recommendations for Agricultural and Horticultural crops (RB209), as a guide with help from an adviser registered under the Fertilizer Advisers Certification and Training Scheme (FACTS). Where organic manures are applied to the land it is important that a Nutrient Management Plan is integrated with a Farm Waste Management Plan to ensure best use of resources and reduce risk. Nutrients need to be managed so that the supply to the crop is matched by demand. Oversupply at any time is not only wasteful and expensive, but can lead to crops being more susceptible to pests and diseases. Increases in crop yield from applied fertilizer, particularly N, become less as the amount of fertilizer is increased. This means that above a certain point the value of extra crop produced is less than the cost of the fertilizer needed to produce it.

Under an IFM approach farmers are recommended to calculate rates and frequency of fertilizer applications using their knowledge of crop requirements and soil nutrient reserves, taking account of previous cropping, soil conditions, including temperature, soil type, nutrient availability and the nutritive value of crop residues and other organic manures. Regular testing for P, K, S, Mg and pH should be done every 3-5 years, with testing for other elements where there is a history of deficiency. The aim is to meet crop nutrient requirements as accurately as possible taking into account nutrient removal throughout the year and the availability to the crop of soil reserves. When organic manures are used in conjunction with inorganic fertilizers, leaf tissue analysis of the growing crop provides valuable information of micronutrients and nitrogen status of the plant, allowing better targeting and more accurate applications to help achieve optimum yields.

Case study examples

Case study One

Robert Kynaston, Great Wollaston Farm, North Shropshire

* *The farm mission*: 'I became a LEAF Farm in 2002. As a LEAF Demonstration Farmer, I want to show that IFM has a place on a smaller mixed or livestock unit.'

Great Wollaston is a 98 ha mixed family farm situated on the edge of the Shropshire Hills, on the English/Welsh border. The crops grown are winter wheat, winter barley, spring lupins together with maize, peas and spring barley. There are 110 dairy cows. The family has farmed Great Wollaston for more than fifty years and conservation has always been a priority but never seen to be in conflict with commercial farming.

* *Livestock*: Mr Kynaston notes that, 'The key to a happy herd is always to put the animals first. We breed all our own stock which reduces the risk of disease coming onto the farm and improves traceability. Our herd of 110 cows and 50 followers enjoy stress-free conditions; we have good hygiene standards and pay careful attention to the amount of space per cow. Many health problems are dealt with at the fortnightly veterinary visit. Manure is seen as a valuable resource and recycled onto the land to improve soil fertility and structure.'

* *Management*: Most meetings and decisions take place around the kitchen table and although they employ just one other person, teamwork is the key to their approach. Mr Kynaston has monitored and recorded all inputs and outputs but IFM has helped him organise and plan operations much better - though things still occasionally do go wrong! In particular, the LEAF Audit has helped him step back and really think about what they are doing and where they could improve, believing

that IFM simply makes good sense and good farming. To reduce costs and improve efficiency, they collaborate with other farms in the area wherever possible - sharing machinery, labour and other resources.

Mr Kynaston notes that, 'Effective soil management and care is the starting point for any integrated farming system. The integration of the grass leys into the arable rotation is key to improving the soil's overall organic matter and structure as well as productivity. On the cultivation side, we currently use a plough/power harrow/drill system but are moving towards minimal cultivation techniques which have potential economic, environmental and husbandry advantages.'

Two points in the management of the farm are important. First, slurry is regularly stirred to encourage the composting process and farmyard manure (FYM) is part composted to ensure a more consistent nutrient value so that only a limited amount of compound fertilizer is used. Fertilizer use is linked with FYM and slurry applications, and the amounts applied are calculated using 'ADAS Fertiplan', a predictive computer programme.

Second, sound crop rotations along with appropriate seed varieties play a key role in the farm's crop protection policy. Fertilizers and sprays are only used where necessary. Pest, disease and weed levels are carefully monitored by crop consultants and, together with on-farm knowledge of the fields, decisions are taken on which sprays to apply.

Case study Two

Chris Butler, Greenstead Farm, Essex

* *The farm mission*: 'To improve and enhance the farm from a conservation and business point of view, for present and future generations.'

With land bordering a large town and criss-crossed by footpaths and bridleways, Greenstead Farm is very much in the public eye. The farm, which runs to 445 ha (1099 acres), has always been managed with conservation in mind and all farm operations are carried out with consideration for others – Integrated Farm Management has been the guiding philosophy for the past 8 years.

In many ways Greenstead is typical of an all-arable farm in this area of eastern England, but it tends to have smaller fields and more hedgerows than most. The character of the soil lends itself to a rotation of crops, which is fundamental to farming in harmony with the environment.

Greenstead Farm became a LEAF Demonstration Farm in 1996, Mr Butler noting that 'As a Demonstration Farm, I want to raise awareness of environmentally friendly, sustainable farming practices and to demonstrate the ways in which farmers are balancing the requirements of running a profitable business with environmental sensitivity.'

* *Cropping*: A traditional, mixed rotation of autumn and spring sown crops is grown. This spreads the workload, reduces disease and pest problems, encourages wildlife and means that weeds can be controlled in a more economical and environmentally sensitive way. Winter wheat is the main crop, grown for biscuit and export milling markets. Winter barley is grown for malting by a local maltster. Winter oilseed rape for margarine oil, linseed for timber coating and linoleum, winter beans for stock feed and sugar beet complete the rotation. The character of the soil lends itself to this type of mixed rotation. A large majority of the wheat straw is chopped and ploughed in to provide a valuable source of organic matter, which has steadily improved the character, and condition of the soil. A full soil analysis every three years allows fertilizer decisions to be made in a structured and informed way. All machinery is regularly maintained and calibrated to ensure accurate applications. One metre grass margins have been established around all fields by regular mowing. These act as a buffer between hedgerows and the crop and provide valuable habitat for birds, small mammals and insects.

* *Management*: Good planning and flexibility are fundamental to the success of the farm. The LEAF Audit forms the basis of the management approach and helps the farmer to take a step back and identify improvements. All the staff is involved in decision making and the adoption of IFM is discussed with them at regular staff meetings.

* *Encouraging biodiversity*: Mr. Butler believes that Integrated Farming is all about balancing the needs of his business with making a living. He has always farmed with environmental care and is keen to preserve and enhance the wildlife habitats on the farm. Besides being good for wildlife and providing habitats for many important species, Mr. Butler considers that IFM also makes business sense. Through assessing the risks he can fine-tune his management decisions.'

Conclusion

There are several incentives that change farming practices, they include a system that works and is practical, that saves money and meets market requirements. Integrated Farm Management is such an approach. It is one of the most realistic ways forward for the majority of farmers. It provides a logical framework to satisfy the many and various requirements demanded of farmers, to deliver a profit, satisfy the market and demonstrate environmental and social benefits.

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Optimizing fertilizer use efficiency

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1. Summary

Until about two decades ago, optimizing the efficiency of fertilizer use was mainly geared towards increasing crop yields and quality. With the huge intensification of agriculture and an increasing awareness of human health and the sustainability of natural resources, the focus has widened and the optimization is subject to a range of additional goals such as food safety, environmental protection and soil/ ecosystem sustainability.

The level and sophistication of the optimization depends on: agronomic, environmental and ecological goals ("target functions"); the scale of farming; and the intensiveness of the cropping system (e.g., rainfed, irrigated, protected crops, hi-tech greenhouse production). However, different fertilization practices and the approaches to their optimization are based on some common principles and technical features. These include broad and inter-related optimization goals, decision support tools and techniques and practices for improving fertilizer application.

The different techniques for improving and optimizing fertilization application are described and focus on their inter-relations with and dependence on agronomic, environmental and ecological goals, the scale of farming, and the intensiveness of the cropping system.

2. Introduction

Despite the remarkable developments in crop production over the past five decades, nutrient use efficiency (NUE) or recovery, especially that of nitrogen (N), and phosphorus (P), remain small. Thus, nutrients applied under conditions of poor control over fertilizer and water supply pose serious concerns with regard to environmental, health, energy and resource conservation aspects. At the same time plants are exposed to non-optimal conditions, which adversely affect yields and food quality.

Poor control of the application makes nutrients prone to pathways of loss, which may induce both economic losses and environmental problems. At the same time, it may expose plants to growth conditions that are far from optimal.

The greatest losses are associated with nitrate leaching into water sources (e.g., Feigin and Halevy, 1989; Smith *et al.*, 1990); volatilization of ammonia (e.g., Fenn and Hossner, 1985); volatilization of di-nitrogen or nitrous oxides (Delgado and

Moiser, 1996; Smith, 1997); leaching and runoff losses of P and N leading to euthrophication (e.g. Bockman *et al.*, 1990).

Excessive (local or temporal) nutrient supply, resulting from the application of conventional fertilizers, may result in a high concentration of soluble salts in the root zone (Shaviv, 1993; Trenkel, 1997). This may induce osmotic stress and cause specific injuries to plants at different growth stages, or an undesired development such as lodging. Excessive accumulation of nitrate or nitrite in plant parts consumed by humans or animals is likely to cause detrimental effects similar to those associated with nitrate contamination of water sources (Nelson, 1984). Many studies have reported nitrate, nitrite and other N derivatives poisoning livestock, particularly ruminants (Nelson, 1984; Keeney, 1997).

Preplant basal application of soluble fertilizers does not meet the temporal demand for nutrients by plants during the whole growing season, having peak periods of demand and normally accumulating nutrients according to a sigmoidal pattern (Shoji and Kanno, 1994; Shaviv, 2000). The advantages to be expected from exposing plants to the optimal and preferred compositions of nutrient forms in the soil solution (e.g., the ammonium/nitrate ratio, applying phosphate with ammonium, induction of rhizosphere acidification; see Shaviv, 2000) has little chance of realization with the basal application of fertilizers.

Until about two decades ago, optimizing the efficiency of fertilizer use was mainly geared towards increasing crop yields and quality. With the huge intensification of agriculture and an increasing awareness of human health and the sustainability of natural resources, the focus has widened and the optimization is subject to a range of additional goals such as food safety, environmental protection, and soil/ecosystem sustainability (e.g., Campbell *et al.*, 1995; Gasbi, 1995; Roblin and Barrow, 2000).

The level and sophistication of the optimization depends on: agronomic, environmental and ecological goals; the scale of farming; and the intensiveness of the cropping system (e.g., rainfed, irrigated, protected crops, hi-tech greenhouse production; Robert, 2002). Highly productive but sustainable agricultural practices are a key future requirement, in particular, those that take a more systematic approach to the monitoring and control of agricultural processes.

Different fertilization practices and optimization approaches are based on some common principles and technical features that include the following:

1. The need to consider broad and inter-related optimization goals – such as yield and product quality, food and product safety, environmental impact, sustainability (Roblin and Barrow, 2000; Robert, 2002).
2. Decision support tools for: i. Evaluating yield and product quality; ii. Monitoring nutrient availability; iii. Monitoring adverse effects on the environment, soil and ecosystems; iv. Assuring food/product safety; and v. Management-assistance tools to integrate information.
3. Techniques and practices for improving fertilizer application: their effectiveness strongly depends on their ability to synchronize nutrient demand by plants with

its supply and the possibility to apply easily available and optimal nutrient compositions.

This paper focuses on six techniques/approaches to fertilization in which the different aspects described in sections 1 and 2 above are implemented at various levels:

i. Application method: split (side dressing) or localized ("depot") application (e.g., bands, nests, super-granules).
ii. Use of Bio-Inhibitor amendments (e.g., nitrification and/or urease inhibitors) and combinations of i. and ii.
iii. Controlled and Slow Release Fertilizers – CRF/SRF.
iv. Fertigation.
v. Automated and Controlled Greenhouse Production with Water and Nutrient Recirculation.
vi. "Precision Application" techniques in large-scale farming.

3. Application method – Split or localized application

Often similar effects from applied nutrients can be obtained either by splitting the application in time (denoted split application) or by spatial dosing in bands, nests or supergranules (also denoted "depot" application). Although the principles of each system are different the end result may be similar with a decrease in N losses and increased availability of P, potassium (K) and micronutrients compared to a basal application (Shaviv, 2001).

While the split application technique requires repeated use of the application machinery (or manpower) and may also be restricted by crop status/stand and trafficability in the field, the "depot" method can be practiced only once.

The increased NUE obtained with a split application stems from a better distribution of the nutrients through the growing season, thus improving nutrient availability and reducing losses.

The localized, "depot" application creates "microsites" with a large local nutrient concentration by banding, nesting or application of super granules. Application of ammonium-based fertilizers in bands, nests or super granules offers the potential to reduce the nitrification rate in soil due to the local increase of ammonium concentration (Darrah *et al.*, 1987; Yadvinder Singh and Beauchamp, 1987; Shaviv, 1988; Glasscock, 1995). This in turn increases NUE and reduces leaching losses of N (Hauck, 1985; Shaviv, 1993).

Nitrification of the ammonium in the concentrated "microsite" decreases pH (Shaviv and Schnek, 1989; Wang *et al.*, 1998). The uptake of ammonium from the source induces local acidification due to proton excretion from root tips (Nye, 1986). This in-turn, assists in increasing the bio-availability of P and micronutrients whose solubility is pH dependent (Marschner, 1986; Nye, 1986; Shaviv and Schnek, 1989). Similar effects due to rhizosphere acidification by K ions that

resulted in raising the bio-availability of iron (Fe) were reported by Barak and Chen (1982) and Shaviv and Hagin (1987).
According to a mathematical analysis by Mokady and Zaslavsky (1967), "localized" (e.g., banding) application of nutrients for which the response curve is sigmoidal (concave) should lead to improved response to the nutrient mainly due to a reduction in the rate of fixation. Barber (1985) demonstrated this effect showing the advantage of banding or limiting the volume of applied P in soil.

4. Use of bio-inhibitor amendments

Addition of bio-inhibitor amendments such as nitrification inhibitors (NIs) or urease inhibitors (UIs) to ammonium based or urea fertilizers can stabilise the forms they are added to. The addition induces several agronomic and environmental advantages (e.g., Hauck, 1985; Trenkel, 1997). Below is a brief description of the mode of action of the major NIs and UIs, and a summary of their main advantages and limitations.

4.1. Nitrification inhibitors

The addition of NIs to ammonium based fertilizers aims to retard the activity in soil of bacteria such *Nitrosomonas,* which oxidise ammonium to nitrite. The nitrite is further oxidised in a relatively fast reaction to nitrate. Effective NIs have the potential to prolong the typical nitrification period from a week or few weeks to a month or several months. Nitrification inhibitors are expected to be effective in soils that can retain/adsorb ammonium and soils to which the addition of the NIs can indeed significantly reduce the activity of the nitrifiers. Therefore NIs are unlikely to be effective in very light textured soils with little cation exchange capacity (CEC) and in many cases, they have a poor microbial activity. The activity of NIs in soils strongly depends on temperature, pH, and organic matter content (e.g., McCarty and Bremner, 1990; Trenkel, 1997; Zerulla *et al.*, 2000).
Addition of the NIs thus has the potential to reduce losses of nitrate due to leaching or denitrification (Hauck, 1985; Trenkel, 1997). At the same time, it increases the ratio of NH_4/NO_3 in soil. This in turn can induce effects such as rhizosphere acidification thus increasing uptake of P and micronutrients from neutral and basic soils (e.g., Shaviv and Mikkelsen, 1993, Trenkel, 1997) and/or increase grain yield and protein content (e.g., Bock, 1987; Hagin *et al.*, 1990; Shaviv, 1993).
Trenkel (1997) provided a list of about 20 products that have been tested as nitrification inhibitors during recent decades. Of these, Nitrapyrin [2-chloro-6-(trichloromethy)-pyridine] and DCD (dicyandiamide) are singled out as NIs, which gained practical and commercial importance. Recently, ENTEC (DMPP) seems to have emerged as an effective NI.

4.1.1. Nitrapyrin (N-Serve)

This NI selectively acts on the Nitrosomonas bacteria, not only retarding them but perhaps also destroying them (Trenkel, 1997). It cannot be added to fertilizers during granulation due to its volatility but is commonly added after granulation or directly to soil prior to addition of the ammonium based source (Hauck, 1985). McCarty and Bremner (1990) considered that N-Serve was more effective than DCD. It has been found that the activity of N-Serve strongly decreases with increasing soil organic matter (SOM) and with increasing temperature (e.g. Hendrickson and Keeney, 1979; McCarty and Bremner, 1990). These findings practically imply that the application of N-Serve to soils having much SOM and at temperatures above 20°C may require increased application rates. The application of N-Serve in the US is commonly in a band or area where the N fertilizer/source is placed and this is done by injecting a liquid solution of N-Serve.

4.1.2. DCD (dicyandiamide)

This NI is produced both in Europe and the Far East as a white powder having relatively low water solubility. Unlike N-Serve, it can be granulated with ammonium sources such as urea, ammonium sulphate and UAN. In Europe the material is classified in many countries as a nitrification inhibitor used for stabilizing the ammonium in fertilizers. Unlike N-Serve, DCD is a bacteriostatic agent and only depresses the Nitrosomonas bacteria in soil (Zacherl and Amberger, 1990; Biau *et al*., 2000). DCD can stabilise the ammonium for up to 5, 6 or even 8 weeks (McCarty and Bremner, 1990; Shaviv *et al*., 1987; Hagin *et al*., 1990). Like N-Serve, it is reported to be less effective as the soil temperature increases (Sachdev and Sachdev, 1995; Puttanna *et al*., 1999). Yet, according to Puttanna *et al*. (1999), it is almost unaffected by the amount of SOM. Yadvinder Singh and Beauchamp (1987) showed in laboratory and field studies, respectively, that incorporation the DCD in 3g urea granules inhibited nitrification much more than the same rate of DCD in 0.02g granules. This effect can be attributed to the effect of nitrification inhibition due to high local concentrations of ammonium (e.g., Darrah *et al*., 1987; Malhi and Nyborg, 1985; Shaviv, 1988). Glasscock *et al*. (1995) demonstrated a synergistic effect of increasing ammonium concentration in increasing the effectiveness of DCD or N-Serve added to the fertilizer.

4.1.3. Other nitrification inhibitors

Reports on inhibitors such TU (Thiourea), CMP (1-carbamoyle-3-methylpyrazole); ATS (ammonium thiosulphate) are also found in quite a number of publications dealing with their effectiveness as single additives or as compounds used with other NIs (e.g., Orphanos, 1992; Trenkel, 1997; Blaise *et al*., 1999). In recent years, a new nitrification inhibitor, ENTEC or DMPP has been launched. The producers consider it to be more effective than those currently available (e.g. Zerulla *et al*., 2000; Benckiser *et al*., 2000).

4.2. Urease inhibitors

The main role of this type of bio-amendment is to reduce the rate of urea hydrolysis (e.g., Hauck, 1985; Trenkel, 1997; Watson, 2000). Under normal field conditions urea may hydrolyse to ammonium carbamate within a few hours. This compound is unstable and decomposes to ammonia and carbon dioxide, thus increasing soil pH and enhancing volatilisation of ammonia. These products may affect plants (by for example ammonia burning), reduce the microbial oxidation of nitrite and thus induce accumulation of nitrite, and cause significant losses of ammonia (e.g., Bremner & Chai, 1989; Watson, 2000). Such problems are prominent when urea is surface applied and the chances for ammonia volatilisation are greatest (e.g. on calcareous or basic soils).
Of several urease inhibitors, NBPT [N(n-butyl) tiophosphoric triamide] is the only UI that has gained practical and commercial importance (Trenkel, 1997; Watson, 2000). This UI has been usefully applied to crops under flood conditions (e.g., Phongpan *et al.*, 1997), to vegetable crops in the glasshouse (e.g., Montemurro *et al.*, 1998) and to various field crops like maize and wheat and grasslands (e.g., Grego *et al.*, 1995; Trenkel, 1997; Watson, 2000).
Several interesting efforts were made to combine NIs with UIs to minimize problems of ammonia volatilisation (upon surface application) and nitrate losses. Grego *et al.* (1995) and Montemurro *et al.* (1998) successfully combined NBPT with DCD. Xu *et al.* (2000) found the combination of hydroquinone and DCD to be very effective.

4.3. Combining bio-inhibitors with the "Depot" concept

The possibility of further increasing the inhibition of nitrification by combining the effect of a high local ammonium concentration with the action of bio-amendments such as NIs was reported by Yadvinder Singh and Beauchamp (1987) and Glasscock (1995). Shaviv and Nedan (1992) demonstrated the possibility of further increasing the availability of P by co-placement of ammonium, phosphate and NIs in one granule or in a band. Wang *et al.* (1998) demonstrated the effect in a simulation model.

5. Controlled and slow release fertilizers

Controlled and slow release fertilizers offer an effective way to improve nutrient use efficiency, particularly N, and reduce environmental hazards, with one single application (Hauck, 1985; Shaviv and Mikkelsen, 1993; Peoples *et al.*, 1995; Shaviv, 2000). The use of controlled release fertilizers (CRFs) has almost doubled over the past decade, but still comprises only about 0.15% of the total use of nutrients (Trenkel, 1997). The largest proportion of these fertilizers is used outside agriculture (e.g., for lawn care, golf courses, landscaping). The use of CRFs in agriculture slightly exceeds 10% of the total amount of CRFs in use, but the demand increases impressively at an annual rate of about 10% (Trenkel, 1997).

The term CRF is best applied to fertilizers in which the factors controlling the rate, pattern and duration of release are well-known and controllable during manufacture (Shaviv, 1996; 2000). In general the release pattern of such CRFs is linear or sigmoidal and good synchronization between nutrient release and plant demand can be achieved. Slow release fertilizers (SRFs) involve the slower release of nutrients than in normal fertilizers but the rate, pattern and duration of release are not well controlled. The practicality of the matching plant nutrient demand and release is less precise than with CRFs. Commonly, the microbially or chemically decomposable products (e.g., urea-formaldehyde or sulphur coated urea – SCU) are denoted SRFs (Trenkel, 1997; Shaviv, 2000).

Controlled or slow release fertilizers can be generally classified into the following three types:

i. Organic-N, low-solubility compounds - they can be divided into biologically decomposing compounds usually based on urea-aldehyde condensation products, such as urea-formaldehyde (UF), and chemically (mainly) decomposing compounds, such as isobutyledene-diurea (IBDU) (Trenkel, 1997; Shaviv, 2000).
ii. Fertilizers in which a physical barrier controls the release - they appear as cores or granules coated with hydrophobic polymers or as matrices in which the soluble active material is dispersed in a continuum that restricts the dissolution of the fertilizer. According to Shaviv (1999, 2000), coated fertilizers can be further divided into those coated with organic polymer coatings, and fertilizers coated with inorganic materials such as sulphur (e.g., SCU). Organic polymer coatings can be either thermoplastic or resins and in most cases such fertilizers are considered CRFs due to reasonable to good control over their release characteristics.
iii. Inorganic low-solubility compounds - fertilizers such as metal ammonium phosphates (e.g., Mg NH_4PO_4), and partially acidulated phosphate rock (PAPR), are typical slow release fertilizers of this type (e.g., Hauck, 1985; Hagin and Harrison, 1993).

5.1. Potential benefits from controlled nutrient supply

Effective CRFs (e.g., polymer coated ones) offer good synchronisation of nutrient supply with plant demand and have the potential to provide the optimum nutrient composition for plants and at the same time reduce losses by the processes competing with nutrient uptake (Hauck, 1985; Shoji and Kanno, 1994; Shaviv, 1996; 2000).

The important economic advantages of using CRF/SRFs include the following:

i. Potential for reducing nutrient losses - this is attributed to the fact that all pathways for loss such as nitrate leaching, volatilisation of ammonia and emission of denitrification gases are significantly lower when using CRF's

(Hauck, 1985; Shoji and Gandeza, 1992; Shaviv and Mikkelsen, 1993; Trenkel, 1997; Shaviv, 2000).

ii. Cost of fertilizer application - CRF/SRFs can meet the crop nutrient demand for the entire season through a single application, involving savings in spreading costs. CRFs displaying a lag in release could be used to apply nutrients prior to the "annual spring rush" or when trafficability in the field is less restricted, such as fall application for winter- or spring-planted crops. Moreover, CRFs can reduce the demand for short-season manual labour for top dressing, such as for rice paddies (Shoji and Gandeza, 1992), that is required during critical periods.

The physiological factors that are of great importance are:

i. Stress reduction and lower specific toxicity - the use of CRFs involves improved germination and crop quality together with reduced leaf burn, stalk breakage and disease infestation (Allen, 1984; Hauck, 1985; Givol, 1991; Trenkel, 1997).

ii. Improved nutrient availability - controlled and slow release of nutrients into a "fixing" medium has the potential to increase the availability of nutrients. Hagin and Harrison (1993) demonstrated this effect with partially acidulated phosphate rock, as compared with conventional, highly soluble P fertilizers. Givol (1991) found a much higher P accumulation in plants fertilized with CRFs containing NPK, as compared with applications of conventional granular fertilizers. Increased availability of Fe due to its supply in a controlled release fertilizer has been shown by Mortvedt *et al.* (1992).

iii. The supply of nutrients in forms that are preferred by plants and the induction of synergistic effects. Significant increases in grain yields and protein content induced by mixed ammonium-nitrate nutrition compared to nitrate or ammonium alone have been reported (Bock, 1987; Hagin *et al.*, 1990; Shaviv, 1993). The synergistic effects between different types or species of nutrients, simultaneously supplied or co-placed near absorption sites on the root surface play an important role in improving NUE. For example, ammonium or potassium can significantly increase the availability of Fe in calcareous soils due to the physiological acidification of the rhizosphere (Barak and Chen, 1982; Marshner, 1986). Ammonium was also found to be very effective in increasing P bio-availability via the rhizosphere acidification mechanism (Nye, 1986; Hagin *et al.*, 1990; Shaviv, 1993). Such advantages can be achieved with compound CRFs containing N, P and K (with proper ammonium to nitrate ratios) and micronutrients.

From the environmental point of view - nutrient losses to the environment depend on their concentration in the soil solution. Any application method that improves NUE, and consequently reduces the surplus of nutrients over plant needs, also has the potential to reduce losses to the environment (Hauck, 1985). Shoji and Kanno (1994) and Shaviv (1996) illustrated this principle in experiments in which N release from CRFs was well synchronized with plant demand. Nitrogen release from SCU was less synchronized with plant demand and thus plant response was poor and the losses of N due leaching significantly greater.

5.2. Disadvantages and shortcomings

The most prominent problem with CRFs is their cost, which limits their use to high value cash crops or to specialities such as professional turf, landscaping and horticulture. The fertilizers based on coating, which have the best release characteristics, are also the most expensive ones.

The cheaper SRFs have the potential for environmental damage if the users are not aware of characteristics such as "burst" or "lock-off" (tailing) (Shaviv, 2000). The prevailing polymer coatings of the CRFs that perform well are such that their decomposition is too slow and may lead to accumulation of undesired polymeric materials (polyethylene, polyurethane, alkyds) in the soil.

The application of CRFs is by that nature, non-reversible, and once the expensive CRFs is placed in soil it cannot be removed or its release cannot be stopped/slowed if plant development is retarded. This problem does not exist with fertigation.

6. Fertigation

Fertigation is defined as the application of fertilizers though irrigation water allowing good control over timing, concentration and composition of the nutrient solution. If properly practiced it can optimize yield and product quality while maintaining a safer environment as compared to conventional fertilization practices (e.g., Bar-Yosef, 1999; Hagin and Lowengart-Aycicegi, 1999).

Micro-fertigation is the most precise method of water and nutrient delivery and offers several advantages in addition to those mentioned with regard to the other methods (Bar-Yosef, 1999). Among these are:

i. Reduced time fluctuations in nutrient concentration in the root zone;
ii. Flexible supply of optimal nutrient concentration/composition and bio-availability according to plant requirements;
iii. Possibility to deliver the nutrients and water directly to the active root zone, thus assuring increased NUE and reducing losses;
iv. Reduced dependence on labour and/or application machinery (but high dependence on infrastructure and high installation costs);
v. Using micro-irrigation has advantages related to problems associated with irrigation systems such as – improved (local) leaching of salinity, increased water use efficiency and reducing problems related to wet foliage.

Despite its significant advantages, the use of micro-fertigation is limited because of its high investment costs, including the irrigation system, the required infrastructure for pressurized irrigation systems and the limited availability and high cost of good quality soluble fertilizers (e.g., Bucks, 1995; Steffen *et al.*, 1995). Successful micro-fertigation is dependent on the quality of the irrigation water due to the fact that the roots utilize the water from a restricted volume of wet soil or growth-medium and the salinity of the solution in the confined volume may reach undesired levels. Thus proper and well managed leaching are essential (Bar-Yosef, 1999).

The most intensively fertigated agricultural systems are the protected crops grown in soilless cultures (also denoted "substrate" or "detached media"). Fertigation in these systems has several characteristics, which are different from fertigation of field crops. Precipitation of salts in the detached-substrates, which are inert, is much lower than in soil. The control over water and nutrient supply is improved, but there is the inherent disadvantage of salinity build-up, which needs to be leached out from the substrate. This is of particular importance in low volume substrates (e.g., rockwool, perlite, tuff, pumice, etc.) and even more so with high nutrient-demanding crops (Sonneveld, 1995). For instance, the volume of water available per unit area of greenhouse soil is about 7-8 times larger than that available with rockwool slabs (Sonneveld, 1995) for high yielding tomatoes. This implies that fertigation frequency in the inert substrate has to be much higher and the control /management of nutrient and water supply must be much better when using rockwool as compared to greenhouse soil. If not properly managed, salinity with soilless culture may accumulate much faster than in soil and thus high osmotic values are likely to reduce yields (Sonneveld and Welles, 1988) and particularly so in regions where the evapo-transpiration is high and/or where irrigation water quality is poor.

The need to supply nutrients to a relatively small bed volume and at relatively high concentrations (e.g. 150 to 300 ppm-N, 170-350 ppm-K for tomatoes; Hagin and Segelman, 1990) make the control over nutrient supply and salinity (EC) important factors for obtaining high yields of good quality. At the same time, the control over the amount of nutrients leached out to the environment becomes a difficult task. In many cases, the supplied nutrient solution has two counteracting tasks: to supply nutrients at relatively high (and constant) levels on one hand and to leach the excess salinity on the other hand. The final result is that N and P supply in greenhouse production in Holland is about 2 to 3 times higher than the uptake by the plants (Hagin and Segelman, 1990; Sonneveld, 1995). Under the conditions prevailing in Israel and other locations in the Mediterranean region (higher water salinity and stronger irradiation) the situation is even worse due to the larger leaching fractions (LF) needed to maintain salinity at reasonable levels. This implies that achieving large yields and good quality may be at the expense of relatively high "point pollution" (drainage) and calls attention for special care and more sophisticated management of fertigation in such systems.

7. Automated and controlled systems with water and nutrient recirculation

The main solution to the large waste of nutrients and pollution damage from the relatively concentrated effluents is recirculation of fertigation solutions in greenhouse production based on soilless cultures (e.g. Avidan, 1997; Raviv *et al.*, 1998; Bar-Yosef, 1999; Langlais *et al.*, 2000). This technology is still under development and is practiced mainly in advanced greenhouses in the Netherlands and on a smaller scale in some countries in the Mediterranean region. In such systems, each crop receives its required nutrient solution based on accumulating knowledge. The composition of the solution is adjusted according to phenological stages during growth and is based on solution analysis in the root environment, the composition of the irrigation water, and that of the drainage water (e.g. De Kreij, 1995; Jones and Benton, 1982; Grillas *et al.*, 2001). Recirculation of nutrient solution can be performed in different ways. In liquid hydroponic growing systems the roots are continuously exposed to the nutrient solution, whereas solid hydroponic growing systems use solid substrates, such as rockwool, perlite, peat, combined with nutrient irrigation (e.g. Jung *et al.*, 2002).

The main advantage of closed systems (Savvas and Gizas, 2002) is the restriction of surface and groundwater pollution through greenhouse effluents, which are rich in nitrates and phosphates. Moreover, recycling the excess nutrient solution, which runs off after each watering, resulting in considerable fertilizer savings (e.g. Raviv *et al.*, 1998). Yet, systems based on continual nutrient solution recirculation, such as NFT (Graves, 1983) proved to be rather unfavourable for long term crops. This has been attributed to the progressive appearance of nutrient imbalances in the recirculating solution (e.g. Zekki *et al.*, 1996). The accumulation of harmful organic compounds exuded by the roots (Jung *et al.*, 2002), as well as limitations in oxygen supply, may also exert an adverse influence on plant growth and yield in such systems. In contrast, hydroponic systems based on collection and reuse of the drain solution after replenishment with nutrients and water seem to be more efficient. According to some reports based on studies with tomatoes and roses (Raviv *et al.*, 1998; Zekki *et al.*, 1996), closed systems of this kind do not seem to be inferior in terms of growth and yield to the soilless culture techniques based on free drainage. However, in long term crops, the continual reuse of all the drain solution may also result in the occurrence of nutrient imbalances in the supply solution after some time (Lopez *et al.*, 1996; Zekki *et al.*, 1996). Contaminants, such as sodium and recalcitrant organics tend also to increase over time in solutions containing reclaimed minerals (Mackowiak *et al.*, 1997). De Kreig (1995) mentions several potential problems associated with the long use of recirculated solution (e.g. Zn and B toxicity, extreme pH). Each crop species may respond differently to a continued reuse of the drainage solution. Many investigations on the influence of nutrient solution recycling in hydroponics on plant growth and yield have been with tomatoes and roses and they should be extended to other crops.

The prevention of nutrient imbalances in the irrigation solution is mainly dependent on the proper replenishment of the drain solution with nutrients. Various strategies (Raviv *et al.*, 1998) and techniques (Savvas and Manos, 1999) may be employed to optimize the recycling of the drain solution. However, to prevent the appearance of nutrient imbalances in the solution supplied to the crop, the ratio of the nutrients added when replenishing the drain solution should be similar to the mean absorption ratio of these elements (Sonneveld, 2000; Savvas, 2001). Thus, a prerequisite for the correct replenishment of nutrients in the drain solution is their accurate determination. This can be implemented by measuring EC and pH and combined with models based on past knowledge (e.g. Son, 1996) or by direct measurements of nutrient composition (e.g. De Kreig, 1995; Rodriques *et al.*, 1999), which is more costly and requires reliable sensors.

Pathogen and disease transmission from infected plants to healthy ones is also of great concern in hydroponic systems subject to recirculation (e.g. Park *et al.*, 1999; Guo *et al.*, 2002). A variety of methods are available to remove pathogens: UV irradiation, Ozone, bio-filters, chemical or biological control agents (e.g. Grote *et al.*, 1992; Schuerger and Mitchell, 1992; Zang and Tu, 1999; Paulitz and Belanger, 2001).

The recirculation systems are of great promise from agronomic, environmental and food/crop safety and quality aspects but they strongly depend on high technology, highly developed infrastructure and reliable and specific knowledge on the needs of individual crops.

8. "Precision application" in large-scale farming

Precision farming is a management system that promotes environmental monitoring and control in agriculture (Roblin and Barrow, 2000; Robert, 2002). This approach was first adopted in the USA in the mid-1980s but has now spread to Europe and other parts of the world (Robert, 2002). The system is a technology- and information-based management system that promotes controlled agricultural practices (Cook and Bramley, 2000; Haneklaus and Schnug, 2000). It aims to: (i) understand the spatial distribution of factors affecting the growth of the crop; (ii) manage this spatial variability by applying a variable rate treatment of agrochemicals and plant nutrients within a field according to site conditions; and (iii) maximize profits and minimize environmental impacts.

The main technologies available to farmers for precision farming include: global positioning systems (GPS); field sensors; variable rate applicators (VRT) for nutrients and agrochemicals; yield monitors for harvesting; computer systems in the cab; user-friendly software for data collection storage and feedback control systems; remote sensing devises and systems; soil sampling; and geographic information systems (GIS) (Roblin and Barrow, 2000; Robert, 2002).

It is possible to adopt the above technologies for use in site-specific applications at varying levels of sophistication according to the needs and capacities of the individual producer. In its most intensive form, there will be precise management of every step in the management program. By contrast, the simpler interpretation will require manual application and non-automated implementation. The former is, in the main, more suitable for the larger highly capitalized farms.

A schematic representation of the system is shown in Figure 1. A central database (GIS) is used to control and analyze input and output data functions. Inputs include raw data on the physical, chemical and biological nature of the soil and the factors that affect plant growth. Data are collected using a wide range of tools, including remote sensing, field sensors, topography, soil type, drainage, rainfall, yield sensors and soil analysis. Outputs take the form of yield/nutrient maps and managerial decisions for variable rate treatments of plant nutrients to crops.

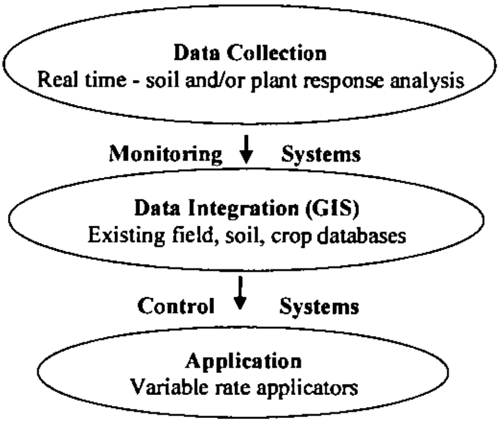

Fig. 1. Schematic representation of a precision farming system.

8.1. Advantages and potential

Robert (2000) summarized the main benefits expected from precision farming, stating that "It offers a variety of potential benefits in profitability, productivity, sustainability, crop quality, food safety, environmental protection, on-farm quality of life and rural economic development".

The potential of precision agriculture to reduce the emission of N_2O while maintaining large agricultural yields was investigated by Sehy *et al.* (2001). In an area within a field with large yields, emissions from 2 plots receiving different amounts of fertilizer were not significantly different. In this area, the content of nitrate in the soil did not appear to be limiting for N_2O emissions, which may be attributed to intensive mineralization from the soil N pool. However, in an area with small yields, decreasing the amount of fertilizer resulted in the reduction of N_2O emissions by 35%.

8.2. Difficulties, technology gaps and problems to be solved

The critical missing technologies to form effective monitoring and control systems are appropriate diagnostic tools for "on-the-go" analysis of key parameters, such as soil pH, nitrates or indicators of plant health. Rugged, low power, high precision tools need to be developed for this purpose.

Traditional methods involve manual data collection, but this is limited by time and cost and is not suitable for precision farming practices. There is an immediate need for "real time" automatic sensors to produce data that can be readily integrated into the decision-making components of a precision farming system. The development of appropriate sensors is a major hurdle that needs to be overcome, and a concerted program of research and development is required to attain this objective.

Haneklaus and Schnug (2002) recognize the importance of "site-specific fertilization" in preserving the fertility status of soil while coping with the needs of increasing food supply. However they state that even after more than a decade since precision agriculture technologies became available, their implementation on farms is low, mainly for economic reasons. Additional problems that they identify have to do with the need for efficient capturing of geo-coded soil and crop information and the development of tailor-made algorithms for the variable input of different nutrient sources such as mineral, organic and secondary raw material fertilizers.

9. Conclusion

The systems described and discussed in this paper deal with a variety of agronomic concepts and techniques some of which are basically very different from the others. Some are based on simplified and easily available technologies that require little capital and skill to implement, like the split application, the "depot" and even the use of Bio-Inhibitor amendments. On the cutting edge of high technology that requires considerable skill and investment are the emerging techniques of recirculated systems for nutrient and water in fertigation and precision farming. The controlled release fertilizers (CRFs) and field-based fertigation systems are positioned somewhere in between but are still costly and/or infrastructure dependent and thus far from being implemented in most agricultural sectors.

The big differences between the methods and approaches make it difficult to compare them in a systematic manner. Table 1 shows the main features of each method trying to point to the niches associated with it and to show also the special requirements, advantages and drawbacks, and technological and knowledge gaps associated with each.

Table 1. Characteristic features of the different methods and approaches for plant nutrient use optimization.

Method: Feature	Split application	"Depot"	Bio-inhibitor amendments	SRFs / CRFs	Fertigation	Automated & recirculated	Precision farming
Relative appl. cost[1]	1	1	2	2 or 3	4	5	5
Appl. equip. requirements	Common	Common	Common	Common	Fertigation equip.	Fertigation & recirculation	Variable rate applicators
Infrastructure requirements	Common	Common	Common	Common	Pressurized irr. constructions, control systems	Pressurized irr. constructions, control systems	Common
Fertilizer requirements	Common	Common	Amended fertilizers	Specially produced	High quality/ solubility	High quality/ solubility	Common (+modifications)
High-tech requirements	no	no	no	no	Computerized-control	Adv. computer control, monitoring	Advanced distrib., Monitoring GPS[2] GIS[3]
Required operational knowledge & information	Common	Common	Product effectiveness	Release charac. & dependences	Operation skill plant optimal-response	Operation skill, Advanced plant optimal-response Decision-support	Operation & integration skill Plant response databases Decision-support
Knowledge & technology gaps	Straight forward	Straight forward	Improved performance	Improved performance, more cost-effective products	Straight forward	Wider & better plant-response databases, More cost-effective technologies	Wider site/plant response databases Improved monitoring Cost-effective technologies
Crop / farming systems	Rainfed, flood/ surface-irrigated common crops	Rainfed, flood/ surface-irrigated common crops	Rainfed, flood/ surface-irrigated common crops	Turf - intensive -vegetables, fruit, flowers, ornamentals	Intensive – vegetables, fruits, flowers, ornamentals	High-income vegetables, fruits, flowers, ornamentals	Rainfed, flood/ surface-irrigated Large scale

[1] 1=lowest and 5 = highest cost; [2] Geographical Positioning Systems; [3] Geographical Information Systems

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Session 3: Panel Discussion

Imbalance in nutrient supply as a threat to sustainable crop production

Effects of rates and sources of potassium on field, horticultural and plantation crops in Iran[1]

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Introduction

Potassium (K) is an essential element for all living organisms. It is the most important cation in terms of its abundance in plant tissue as well as its physiological and biochemical functions. Potassium improves N efficiency, increases the tolerance of plants to stress and improves quality. In the arid and semi-arid calcareous soils of Iran, K-bearing illite clay minerals are abundant and because of this, it was generally believed that the soils had enough K. Until recently, the use of K fertilizers in Iran was less than 1% of the total amount of fertilizers used but now, after a decade of research activities, the ration of N-P_2O_5-K_2O-micronutrients has been changed to 100-55-23-1 (Amirmokri, 1992; Siadat *et al.*, 1993; Olfati *et al.*, 1999; Sepehr and Malakouti, 1999; Torabi and Malakouti, 1999; Shahabi and Malakouti, 2000; Shahabi, 2001).

To assess the need for potassium (K) fertilizers in Iranian crop production a major project is being undertaken on the effects of different amounts of K, and a comparison of potassium chloride (MOP) and potassium sulphate (SOP), on the yield and quality of various crops. Statistically designed, randomised block experiments, with three to five replicates, have been conducted on 14 different agricultural, horticultural and plantation crops at 41 different sites in various regions of Iran during the first phase in 1999-2000. The basic design was the same for all experiments; the amounts of both K to be tested and of the basal nutrients were based on the results of soil analytical data. For K plant available soil K was determined. The basic treatments are shown in Table 1. In the experiments with field crops and ornamental plants the fertilizers were applied to the soil and cultivated in, for the horticultural crops deep placement or fertigation was used.

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[2] Professor of Tarbiat Modarres University, ten members of the Scientific Staff of Soil and Water Research Institute, and Assist. Professor, Tehran University, respectively.

Table 1. The basic treatments used in the field experiments testing potassium.

Treatment number	Treatment
T1	Nitrogen (N) and phosphorus (P) based on soil analysis
T2	T1 plus micronutrients based on soil analysis
T3	T2 plus K_1 as MOP, amount of K_2O based on soil analysis
T4	T2 plus K_1 as SOP, amount of K_2O based on soil analysis
T5	T2 plus $K_{1.5}$, 1.5 times K_1 as MOP
T6	T2 plus $K_{1.5}$, 1.5 times K_1 as SOP
T7	T2 plus K_2, 2 times K_1 as MOP
T8	T2 plus K_2, 2 times K_1 as SOP
T9	T2 plus 0.5 times K_1 as MOP plus 0.5 times K_1 as SOP

Effect of potassium on field crops

Wheat

The experiments on wheat were carried out in five important wheat-growing regions: Kermanshah, Yazd, Fars and two locations in Karaj during 1999-2000. Composite soil samples and irrigation water from each region were collected and analysed. Each experiment tested all nine treatments in Table 1and there were three replicates. Treatment K_1 was 50 kg/ha K_2O and the basal treatments per ha were 268 kg urea, 100 kg triple superphosphate, 20 kg sequestrin of iron, 20 kg zinc sulphate and copper sulphate, 50 kg manganese sulphate and 10 kg boric acid.

Some physico-chemical properties of the soil are given in Table 2 and the chemical analysis of the irrigation water is in Table 3.

Table 2. Some physico-chemical properties of the experimental soils.

Experiment site	EC (dS/m)	pH	T.N.V. (%)	O.C.	P (mg/kg)	K	Cu	Mn	Fe	Zn	Texture
Kermanshah	-	7.9	49	1.82	11.6	240	5.1	2.8	4.4	0.51	-
Darab, Fars	0.7	8.5	44	0.51	8.6	168	-	-	-	-	C.L
Karaj 1	-	-	8	0.44	2.2	168	0.7	3.3	8.0	-	-
Karaj 2	0.8	7.8	15	0.69	16.0	160	0.5	3.9	2.8	0.76	-
Yazd	13.5	7.7	20	-	7.6	195	-	-	-	-	SL

Table 3. Chemical analyses for the irrigation water.

Experiment site	EC (dS/m)	pH	Turbidity	(meq/l) HCO_3^-	$SO_4^=$	Na^+	Cl^-	SAR
Kermanshah	0.70	7.3	-	5.1	-	-	-	0.16
Darab, Fars	0.44	7.6	0.48	4.0	0.11	0.61	0.5	-
Karaj 1	0.42	7.7	-	2.4	-	0.50	0.7	0.35
Karaj 2	0.42	7.7	-	2.4	-	0.50	0.7	0.35
Yazd	8.16	7.7	-	2.6	14.3	55.0	59.5	-

Table 4 and Fig. 1 show the effects of K and micronutrients on the yield, thousand-grain weight and grain protein of the crops grown in Kermanshah (Table 3) and Darab, Fars (Fig. 1). In these experiments, the K_1 treatment was 50 kg K_2O/ha. Although there was a difference of 800 kg grain between treatments in the experiment at Kermanshah this difference was not statistically significant. The effect of 50 kg K_2O/ha plus micronutrients on thousand-grain weight and grain protein was significant at the 5% and 1% level, respectively. Most probably the yields were not significantly different because there was a relatively large amount (240 mg/kg) of available K in the soil. The results for the experiment in the Karaj 1 region (not given) showed that both SOP and MOP at 1.5 times the rate indicated by soil analysis gave only 2.94 t/ha grain compared to 2.44 t/ha on the control and this difference was not statistically significant. The small yields in Karaj 1were much less than those in some of the other experiments and it would appear that with these small yields it is not necessary to apply K. Micronutrients significantly increased grain protein suggesting that it would be worthwhile to apply them.

Table 4. The effects of fertilizer treatments on some of the yield components of wheat crop in Kermanshah test.

Treatment	Grain yield (kg/ha)	Wt. of a thousand seeds (g)		Grain protein (%)	
T_1	6200	30.5	b	11.0	c
T_2	5367	30.8	ab	11.6	c
T_3	6150	31.2	ab	11.8	c
T_4	6617	30.3	b	14.3	ab
T_5	6175	30.1	ab	12.7	bc
T_6	6400	31.0	ab	12.9	abc
T_7	6333	31.3	ab	13.0	abc
T_8	6200	31.3	ab	13.2	abc
T_9	6983	32.7	a	14.5	abc

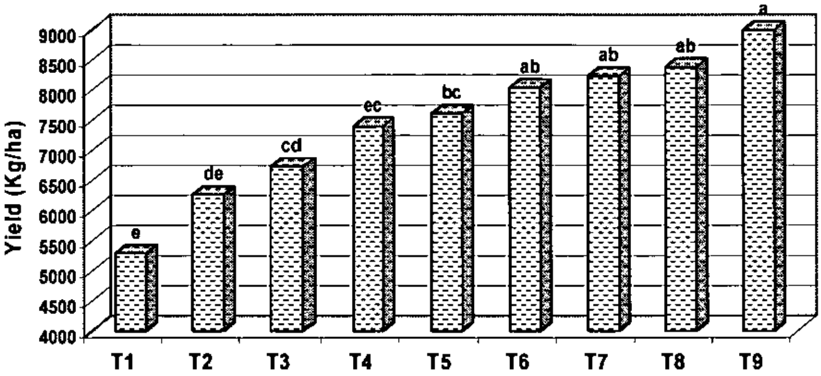

Fig. 1. Wheat yield increases due to different potassium treatments in Darab, Fars.

There were also no significant yield differences in the other wheat experiment in Karaj 2 testing three Mahdavi wheat varieties, M-70-12, M-75-7 and M-75-10 and six fertilizer treatments on a soil with 160 mg/kg available K. For M-70-12 and M-75-7 the largest yield was with 75 kg/ha K_2O plus micronutrients and for M-75-10, 50 kg/ha K_2O plus micronutrients. The largest yield was 4.6 t/ha. For all three varieties the largest % grain protein was given by 50 kg/ha K_2O plus micronutrients. As at Karaj 1, yields at Karaj 2 tended to be much less than those elsewhere.

There were differences in grain yield between treatments in the Darab, Fars experiment but the maximum difference was only significant at the 5% level due to the large CV values.

Results from experiments in Yazd varied between sites. At one site there were no significant yield differences due to treatment and the largest yield was given by K_1 applied as SOP. At another site a combination of SOP and MOP at 1.5 times the rate indicated by the soil test give the best yield while on another farm MOP at twice the rate indicated by the soil test gave most grain. On another farm the largest yield was given by the treatment without K.

Ignoring the small yields in the Karaj region, the data from the other three regions indicate that a combination of SOP and MOP applied at rates indicated by soil tests have the greatest effect in improving wheat grain yields.

Maize

Experiments on maize were conducted in seven major maize producing regions, West Azarbayjan, Fars, Kermanshah, Khorsan and three locations in Karaj. The K1 treatment was 240 kg/ha K_2O. Maize yields from experiments in the Fars province are in Table 5.

Table 5. Fertilizer treatment effects on maize grain yield in Fars.

Fertilizer treatment	Grain yield (kg/ha)
T_1	9283 cd
T_2	9433 cd
T_3	10330 b
T_4	11330 a
T_5	10100 bc
T_6	9583 bcd
T_7	9417 cd
T_8	8850 d
T_9	7067 e

Maize, both grain and silage, showed no significant yield response to K at Kermanshah, Karaj and Khorasan. The amount of K indicated by soil analysis was required to get the maximum yield in experiments in Fars and West Azarbayjan provinces.

Potatoes

Yields obtained in potato experiments in East Azarbayjan and Hamadan are in Table 6.

Table 6. The effects of fertilizer treatments on potato yields, kg/ha, in the East Azarbayjan and Hamadan experiments.

Treatment	East Azarbayjan	Hamadan
T_1	21,478 b	30,943 c
T_2	23,100 ab	32,576 c
T_3	24,600 ab	33,683 bc
T_4	26,933 a	36,500 ab
T_5	25,067 ab	34,610 abc
T_6	24,500 ab	37,610 a
T_7	17,100 c	36,306 ab
T_8	16,800 c	37,476 a
T_9	14,000 c	33,460 bc

Potato yield and quality parameters were best when the amount of K applied was 1.5 times larger than that indicated by soil analysis. SOP was superior to MOP.

Sugar beet

The experiments on sugar beet were in Khoy (West Azarbayjan) and Isfahan. The experiment in Isfahan was on a soil with 210 mg/kg available K. The yields are in Table 7.

Table 7. The effects of treatments on the yield and quality of sugarbeet in the Isfahan region.

Treatment	Yield (kg/ha)	Sugar (%)
T_1	31,200 b	17.0
T_2	33,500 ab	18.0
T_3	35,800 a	18.2
T_4	36,000 a	18.5
T_5	35,300 a	17.3
T_6	36,700 a	18.7
T_7	36,200 a	18.4
T_8	39,500 a	20.1
T_9	35,400 a	18.0

Sugar beet showed no significant yield response to K in the experiments in Isfahan and West Azarbayjan. However, at Semirom in Isfahan the largest amount of K applied as SOP increased sugar yield by 50%, compared to the control mainly due to the increase in % sugar in the beet.

Oilseed rape

These experiments were in Karaj, Khorasan (Mashhad) and Khuzestan (Dezful) and the yields are in Table 8. In these experiments, the K_1 treatment was 125 kg K_2O/ha.

Table 8. The mean yields of oilseed rape in the Khorasan experiments.

Treatment	Yields, kg/ha
T_1	1,928 b
T_2	2,333 a
T_3	2,571 a
T_4	2,505 a
T_5	2,467 a
T_6	2,333 a
T_7	2,429 a
T_8	2,305 a
T_9	2,429 a

Neither the amount nor source of K increased yields in the Khorasan experiments.

Cotton

The experiments on cotton were in the cotton growing areas of Golestan and Darab Fars and the yields are in Table 9. In these experiments, the K_1 treatment was 60 kg K_2O/ha in Golestan and 150 kg K_2O/ha in Darab.

Table 9. The effects of fertilizer treatments on cotton yield in Golestan and Darab, Fars experiments.

Treatment	(Cotton yield, kg/ha) Fars		Golestan	
T_1	1,509	a	2,996	ab
T_2	1,634	bc	3,192	ab
T_3	1,825	abc	3,396	ab
T_4	2,578	a	3,252	ab
T_5	1,918	abc	2,848	ab
T_6	1,910	abc	2,931	ab
T_7	2,192	ab	3,261	ab
T_8	2,393	a	2,832	b
T_9	1,934	abc	3,435	a

Yields were not significantly effected by K at Golestan, but in Darab Fars K applied as SOP, at the rate indicated by soil analysis, together with micronutrients gave the largest yield, some 71% more than the control.

Tomatoes

There were tomato experiments in the Boushehr and Hormozgan provinces. The yields in the Boushehr experiments are in Table 10. In these experiments, the K_1 treatment was 85 kg K_2O/ha in Boushehr and 100 kg K_2O/ha in Hormozgan.

Table 10. The effect of various potassium treatments on tomato yield in Boushehr experiments.

Treatment	Yield, kg/ha	
T_1	30,800	c
T_2	32,370	bc
T_3	34,470	abc
T_4	31,080	c
T_5	37,080	a
T_6	35,950	ab
T_7	33,790	abc
T_8	36,320	ab
T_9	36,210	ab

Potassium increased yields at all three sites but there was no effect of increasing rates or K sources.

Onions

The onion experiments were in Isfahan and East Azarbayjan. The yields in the East Azarbayjan experiment are in Table 11. In these experiments, the K_1 treatment was 100 kg K_2O/ha.

Table 11. The effect of various fertilizer treatments on onion yields and quality in E. Azarbayjan.

Treatment	Yield (kg/ha)		T.S.S. (%)		Acidity (%)		Vitamin C (mg/100 g)		Dry matter (%)		Crop spoiled (%)	
T_1	35,300	f	12.00	c	0.37	b	13.00	d	14.00	c	40	a
T_2	44,500	e	12.50	bc	0.38	b	13.40	d	14.50	c	14	b
T_3	46,000	de	13.00	b	0.36	bc	14.10	cd	15.00	bc	13	bc
T_4	46,500	de	14.00	ab	0.42	a	14.80	bc	15.60	b	14	b
T_5	48,000	de	14.50	a	0.43	a	14.50	c	16.00	ab	12	bc
T_6	47,500	de	14.00	ab	0.42	b	15.00	b	25.50	b	10	c
T_7	48,700	d	14.50	a	0.41	a	15.40	ab	16.00	ab	9	cd
T_8	52,500	c	13.00	b	0.40	ab	15.80	a	15.00	b	10	c
T_9	55,700	c	14.50	a	0.41	a	16.00	a	16.50	ab	8	cd

At both experimental sites, onions responded significantly to K but larger rates than those indicated by soil analysis were necessary to achieve maximum yields and to improve the quality of the bulbs, especially at the East Azarbayjan site.

Effect of potassium on plantation crops

Apples

The experiments on apples were in Ghazvin, Padena, Semirom and West Azarbayjan. At each site the treatments were based on soil analytical data. In the experiment at Ghazvin the nine treatments were tested on 25 year-old trees. Treatment K_1 was 180 g K_2O per tree and the basal application per tree was 0.5 kg ammonium nitrate, 0.5 kg ammonium phosphate, 150 g zinc sulphate, 50 g manganese sulphate, 100 g magnesium sulphate, 50 g sequestrin of iron. Some soil analytical and irrigation water analyses are in Tables 12 and 13, respectively.

Table 12. The soil analyses data for the apple orchard in Ziaran (Ghazvin).

Depth	EC (dS/m)	pH	TNV (%)	OC (%)	N (%)	P (mg/kg)	K (mg/kg)	B (mg/kg)	Fe (mg/kg)	Zn (mg/kg)
0-30	0.76	7.8	11	1.50	0.066	5.00	180	0.68	2.50	0.84
31-60	1.50	7.9	10	0.53	0.140	2.30	195	1.64	4.50	3.30

Table 13. The water analyses data for the apple orchard in Ziaran (Ghazvin).

EC (dS/m)	pH	$CO_3^{=}$ (meq/l)	HCO_3^- (meq/l)	Cl^- (meq/l)	$SO_4^{=}$ (meq/l)	Ca^{++} (meq/l)	K^+ (meq/l)
0.624	8.3	0.40	3.60	0.90	1.34	0.6	0.04

Nutrient concentrations in the leaves are in Table 14.

Table 14. The leaf analyses data for apple trees in Ziaran (Ghazvin).

Treatment	(%)					(mg/kg)					
	N	P	K	Ca	Mg	Fe	Zn	Mn	B	Cu	Cl
T_1	1.91d	0.11	1.89d	1.47b	0.39b	92e	15b	62	70	11	0.06de
T_2	2.10c	0.10	1.73d	2.06ab	0.50a	139a	18a	64	70	11	0.06e
T_3	2.39a	0.10	2.22bc	2.16a	0.49a	120c	17a	63	65	10	0.09cd
T_4	2.28b	0.11	2.40ab	1.98ab	0.42b	114d	13c	61	69	11	0.10ab
T_5	2.27b	0.11	2.12c	2.05ab	0.49a	120c	18a	69	68	10	0.08de
T_6	2.28b	0.10	2.27bc	2.15a	0.50a	133b	18a	69	64	10	0.11ab
T_7	2.25b	0.10	2.27bc	2.19a	0.49a	121c	18a	61	65	10	0.09cd
T_8	2.18bc	0.11	2.25c	2.02ab	0.49a	123c	18a	64	68	10	0.10ab
T_9	2.11c	0.09	2.47a	2.22a	0.52a	121c	18a	67	68	10	0.12a

The effects of the treatments on fruit diameter and weight, fruit acidity and juice pH are in Table 15, and on nutrients in the fruit are in Table 16.

Table 15. The effect of treatments on fruit juice quality of apple fruit in Ziaran (Ghazvin).

Treatment	Fruit diameter (mm)	L/D	TSS	Juice pH	Acidity (mg)	Fruit wt. (g)	% juice
T_1	59.2 c	0.83 b	13.30 bc	3.72 ab	0.61 de	91.85 d	78.16 abc
T_2	60.4 c	0.88 a	12.99 c	3.75 ab	0.60 e	98.23 cd	79.47 a
T_3	61.2 c	0.88 ab	14.20 a	3.65 ab	0.73 a	115.20 bcd	76.73 c
T_4	62.8 bc	0.85 ab	14.16 a	3.76 a	0.63 cde	110.70 bcd	77.55 bc
T_5	68.2 b	0.86 ab	14.69 a	3.65 ab	0.67 bc	123.60 b	86.83 c
T_6	61.0 c	0.87 ab	14.57 a	3.73 ab	0.65 bcd	114.70 bcd	89.86 c
T_7	73.7 a	0.86 ab	14.60 a	3.73 ab	0.65 bcd	166.80 a	78.57 ab
T_8	64.8 bc	0.88 ab	14.30 a	3.63 b	0.67 ab	119.20 bc	77.67 bc
T_9	64.8 bc	0.86 ab	14.48 a	3.63 b	0.67 bc	114.50 bcd	77.58 bc
T_{10}	64.2 bc	0.89 a	14.49 a	3.65 ab	0.67 bc	113.80 bcd	77.46 bc

Table 16. The apple analyses data for Ziaran.

Treatment	%						mg/kg			
	N		P	K			Ca		Mg	
T_1	0.088	c	0.021	0.198	b		67	b	79	c
T_2	0.094	abc	0.021	0.201	a		84	a	102	a
T_3	0.109	a	0.022	0.233	bc		61	bc	94	ab
T_4	0.095	abc	0.021	0.232	bc		60	bc	87	bc
T_5	0.094	bc	0.021	0.239	bc		59	bc	92	ab
T_6	0.096	abc	0.021	0.228	b		67	b	93	ab
T_7	0.095	abc	0.020	0.231	c		50	c	86	ac
T_8	0.092	bc	0.021	0.235	b		67	b	91	abc
T_9	0.105	ab	0.022	0.231	bc		50	bc	9	abc
T_{10}	0.105	ab	0.021	0.231	b		64	b	89	ac

Treatment	mg/kg										
	Fe		Zn		Mn		B		Cu	Cl	
T_1	2.02	ab	0.76	ab	0.69	ab	10.14	e	0.26	34.14	ab
T_2	2.45	ab	0.83	ab	0.74	ab	13.05	ab	0.23	38.33	ab
T_3	2.29	ab	0.94	a	0.72	ab	11.98	bcd	0.25	33.97	ab
T_4	1.73	b	0.77	ab	0.70	ab	10.02	e	0.26	32.29	ab
T_5	2.51	a	0.80	ab	0.67	ab	12.53	abc	0.25	32.00	ab
T_6	2.48	ab	0.77	ab	0.60	b	13.34	a	0.25	40.30	ab
T_7	2.41	ab	0.88	a	0.72	ab	11.10	de	0.25	30.70	a
T_8	2.47	ab	0.75	ab	0.76	a	13.18	ab	0.25	39.22	ab
T_9	2.38	ab	0.78	ab	0.71	ab	11.39	cd	0.25	40.85	a
T_{10}	2.48	ab	0.65	b	0.67	ab	11.79	bcd	0.26	38.41	ab

Balanced fertilization, using the "manure pit method" where the fertilizers are applied to the soil in the pit in which the tree is planted, had little effect on yield or tree growth indices in the first year because of the time required for the nutrients to become available to the plant in the soil exploited by the roots. Nevertheless, in some instances fruit qualities like texture, total soluble solids (TSS), acidity and the ratio of TSS to acidity and pH were desirably altered by balanced fertilization (see also Shahabi and Malakouti, 2000). As these experiments showed little difference between the effects of MOP and SOP, in the short term at least, and where sulphur is not deficient, MOP is recommended as the K source because of its higher concentration of K and lower cost. Consideration should be given to varying the amount of K applied depending on the level of available K in the soil. It may also be important to increase foliar applications of calcium chloride, to perhaps as many as ten per growing season, where there is a risk of the larger rates of K interfering with calcium absorption.

Citrus, pistachio and grapes

The treatments followed the same pattern as for the apple experiments with the rates of the fertilizers being adjusted according to soil analytical data. Potassium was tested at three rates and MOP and SOP were compared. The citrus experiments were on soil with 193 mg/kg available K and K_1 was 150 g K_2O per tree. The smallest rate of K (applied as SOP) with micronutrients gave the largest yield of citrus, c.v. Valencia. On the other hand, the largest amount of K applied as SOP gave the biggest yield of grapes, 82% more than the NP control while MOP at the same rate increased yield by only 25%.

Cut flowers

These experiments were carried out at the Mahallat Flower and Plant Research Station. There were three experiments, one for each type of flower, gladiola, marigold and tuberose. The soil for all three experiments had 143 mg/kg available K, and the amounts of K tested and the basal nutrients applied were based on data from soil analysis. MOP and SOP were compared and treatment K_1 was 180 kg K_2O/ha. The basal treatments, per ha, were 250 kg urea, 100 kg triple superphosphate, 100 kg magnesium sulphate, 10 kg boric acid 30 kg each of iron sulphate, zinc sulphate and manganese sulphate.

The yields and quality characteristics are in Tables 17 (gladiola), Table 18 (marigold) and Table 19 (tuberose).

Table 17. The effects of various treatments on the mean values of the yield and quality characteristics of gladiola.

Treatment	From planting to formation of flower cluster (day)	Height of flowering branch (cm)	Length of flowering branch (cm)	Diameter of flowering stem (cm)	Vase life (day)	No. of florets per cluster	Total Wt. of bulbs and bulblets (g/m^2)	Total No. of bulbs and bulblets (g/m^2)
T_1	101 a	90.60 a	38.10 a	1.39 ab	8.40 b	14.9 a	727 a	58.10 a
T_2	105 a	90.30 a	38.30 a	1.27 ab	8.8 ab	14.7 a	720 a	53.60 ab
T_3	103 a	90.60 a	39.50 a	1.30 ab	9.64 a	15.4 a	572 a	41.30 ab
T_4	104 a	91.80 a	38.50 a	1.25 b	8.92 ab	14.4 a	726 a	46.50 ab
T_5	101 a	93.40 a	40.40 a	1.30 ab	9.87 a	15.5 a	687 a	50.20 ab
T_6	99 a	91.70 a	38.20 a	1.42 b	9.72 a	15.5 a	740 a	48.00 ab
T_7	101 a	94.60 a	39.30 a	1.41 ab	9.61 a	15.4 a	647 a	45.30 ab
T_8	105 a	89.50 a	38.00 a	1.26 ab	8.92 ab	14.4 a	536 a	36.10 b
T_9	100 a	91.30 a	38.40 a	1.30 ab	9.72 a	14.9 a	643 a	40.40 ab

Table 18. The effect of various treatments on the mean values of marigold yield and quality characteristics.

Treatment	Height of flowering branch (cm)		Diameter of flowering stem (cm)		Vase life (day)		From planting to formation of flower clusters (day)		Flower diameter (cm)		Diameter of bud (cm)	
T_1	83.90	c	1.13	ab	11.10	a	59.20	a	8.67	b	1.75	a
T_2	82.90	c	1.12	ab	11.90	a	59.20	a	8.80	b	1.95	a
T_3	85.40	bc	1.12	ab	11.50	a	60.80	a	8.28	b	1.98	a
T_4	89.30	abc	1.14	ab	14.40	a	60.60	a	8.08	b	1.93	a
T_5	85.30	bc	1.12	ab	13.40	a	59.50	a	8.56	b	1.97	a
T_6	97.00	a	1.31	ab	16.30	a	59.00	a	8.73	b	1.98	a
T_7	95.60	ab	1.36	a	14.40	a	60.20	a	8.19	b	1.94	a
T_8	82.10	c	1.15	ab	14.90	a	61.30	a	8.36	b	1.88	a
T_9	81.50	c	1.10	b	13.00	a	58.50	a	10.3	a	1.98	a

Table 19. The effect of various treatments on the mean values of tuberose yield and quality characteristics.

Treatment	From planting to formation of flower cluster (day)	Height of flowering branch (cm)	Length of flowering branch (cm)	Diameter of flowering stem (cm)	Vase life (day)	No. of florets per cluster	Total Wt. of bulbs and bulblets (g/m^2)	Total No. of bulbs and bulblets (g/m^2)
T_1	99.40 a	67.00 b	26.7 b	0.678 b	9.12 a	29.90 ab	2,689 a	307 a
T_2	99.40 a	67.90 ab	29.7 ab	0.717 ab	9.72 a	25.70 b	2,923 a	312 a
T_3	101.60 a	67.80 ab	28.5 ab	0.724 ab	9.64 a	28.10 ab	2,542 a	302 a
T_4	101.60 a	67.10 b	28.6 ab	0.700 b	9.76 a	27.80 ab	2,546 a	301 a
T_5	101.00 a	70.40 ab	29.0 ab	0.739 ab	9.29 a	29.60 a	2,724 a	325 a
T_6	101.00 a	69.40 ab	29.6 ab	0.712 ab	9.69 a	28.00 ab	2,806 a	314 a
T_7	102.20 a	70.70 ab	29.8 ab	0.740 ab	9.35 a	28.70 ab	2,698 a	332 a
T_8	99.80 a	71.30 a	31.5 a	0.775 a	9.80 a	30.00 a	2,949 a	340 a
T_9	98.60 a	69.10 ab	29.0 ab	0.721 ab	9.60 a	28.30 ab	3,005 a	304 a

Conclusions and recommendations

For the wide range of crops tested balanced fertilization with NPK and micronutrients increased yield and improved quality, although the responses to K were not always statistically significant. Even in the short term the fruit quality parameters of apples, pH, acidity and TSS were improved. However excessive rates of K applied to apples can upset the desirable K/Ca ratio, which reduces shelf-life.

Long-term effects of Cl- accumulation from applying MOP, especially in large amounts were not determined in these short duration experiments, nor were reports that applying MOP to grapes adversely effects grape sugar content.

For crops with a small K requirement like wheat, oilseed rape and some horticultural crops, applying the amount of K as indicated by soil and plant analysis gave maximum yield. Crops with a large K requirement like maize, potatoes, onions and some ornamental plants required more K than was indicated by soil analysis.

No significant differences were found between MOP and SOP especially at the rate of application indicated by soil analysis. However, SOP is recommended for use in the long term for orchards and sensitive crops like potatoes, while MOP is recommended for field crops and ornamental plants.

Soil factors other than plant available soil K such as CEC and texture appear to have effected the response to K in some cases and these need to be determined.

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Imbalance in nutrient supply as a threat to sustainable crop production in India

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Abstract

Fertilizer consumption in India has made impressive progress during the last half century having increased from 0.07 Mt in 1950-51 to 16.7 Mt in 2000-01. The N, P_2O_5, K_2O consumption ratio also changed from 7.2: 0.9: 1.0 to 7.0: 2.7: 1.0 during this period, although there is lot of variation between regions. It is 29.0: 8.5: 1.0 in the northern zone compared to 3.8: 1.7: 1.0 in the southern zone. The rice-wheat cropping system, which is followed on more than 10 Mha in the northern zone of India has the widest ratio of 205.0: 47.0: 1.0. In this system, removal of potassium (K) is greater than that of nitrogen (N). The very small amount of K used is a matter of concern for the future sustainability of rice-wheat system. At the current level of 206 Mt of food grain production, there is an annual deficit of about 10 Mt of nutrients between removal (28 Mt) and additions (18 Mt). For feeding a population of 1.4 billion by 2025, India will need to produce 311 Mt of food grains and will require 35 Mt of fertilizers. But it will be not only the total consumption, but also the balance of applied nutrients that will ensure sustained crop production.

While application of phosphorus (P) is always more than its removal, K removal is always much greater than its addition, irrespective of cropping system and type of soil. Mining of K from the soil may create a highly unbalanced situation for sustained productivity of crops in the decades to come. Long-term experiments in different regions on different soil types suggest that during the initial stages of the experiments, there was a substantial response in most of cropping system to N alone. However, with the passage of time the response to N has declined in alluvial alkaline soils and become negative in acidic red and laterite soils. Initially, there was no response to P, or in some cases it was negative, but it has become positive with the passage of time. The application of both N and P is not enough to sustain crop yields and the use of K is becoming essential to achieve the yield potential of many crops and sustain their productivity. Besides increased yield, balanced fertilization should also improve the quality and fertilizer use efficiency of different crops.

Introduction

The nutrient supply from Indian soils was maintained for quite a long period of time during the "low yield, single crop a year" era. With the introduction of high yielding and nutrient responsive crop varieties and with the intensification of agriculture, crop yields increased. For example, there was a 4-fold increase in food grain production from 50.8 Mt in 1950-51 to 196.1 Mt during 2000-2001. In consequence, soil nutrient depletion was observed on a large scale due to an unbalanced supply of nutrients. The main reasons for the increased rate of nutrient depletion are the high temperatures, which speed up the decomposition of organic matter, large soil losses through erosion, nutrient leaching in the monsoon-type climate and large scale flood irrigation. There was also a mismatch between nutrient additions and removals. The Ministry of Agriculture estimates that 8.4 Mt of plant nutrients are lost from Indian soils every year. This is a threat to sustainable crop production. To cope the future food demand, grain production has to be increased. It could be increased either through the expansion of the area grown or through an increase in productivity. There is little scope to increase the area. Therefore, an increase in yield per unit area and the intensification of agriculture by increasing the cropping intensity is the only alternative.

Total fertilizer use and nutrient consumption ratios differ widely between regions/states in India (Table 1). Of the four regions, North, South, West and East, consumption per unit gross cropped area is largest in the South followed by North, East and West, respectively. the North-zone is considered to be the food grain bowl of India and has the highest consumption of N but the lowest consumption of potash. Comparing Punjab in the north and Tamil Nadu in the south, the N: P_2O_5: K_2O consumption is much wider in Punjab (42.6: 11.9: 1.0) compared to Tamil Nadu (2.6: 1.0: 1.0). This indicates that the state using most fertilizer has the greatest imbalance in nutrient use. The neglect of K applications in a highly productive region of India with the highest cropping intensity is a matter of concern. The main reason of the variation in fertilizer consumption ratios between the north and the south is due to the nature of the soils and cropping patterns. In the north, the soils are alluvial with illite as the predominant K bearing mineral compared to red and lateritic soils with kaolinitic minerals or swell-shrink soils with smectite as the predominant mineral in the south. Cereals are predominantly grown in the north region whereas, in addition to cereals, plantation crops are grown in the southern region. The procurement price of food grains is not based on quality and therefore, farmers in the northern region of India are not quality conscious. On the other hand in southern India, cash crops like tea, coffee, pepper or cardamom, etc. are paid according to the quality of the produce. The farmers are well aware that crop quality depends upon balanced nutrition including K and, therefore, they apply more balanced fertilizer. Five cropping systems, such as rice-wheat, rice-pulse, maize-wheat, potato-wheat and sugarcane, need immediate attention to correct the imbalances in nutrient consumption and to prevent further deterioration in soil quality and to break the yield barrier (Swarup and Ganeshamurthy, 1998). The rice-wheat cropping system with an N: P_2O_5: K_2O consumption ratio of 250.0: 47.0: 1.0 is the most unbalanced cropping system in the country.

Table 1. Consumption of nutrients per unit gross cropped area (2000-01) and N: P_2O_5: K_2O ratio in different regions/states in India.

Zone / State	kg ha^{-1} N	P_2O_5	K_2O	Total	Consumption ratio N	P_2O_5	K_2O
North	95.2	28.0	3.3	126.5	29.0	8.5	1.0
Punjab	125.3	35.1	2.9	163.3	42.6	11.9	1.0
Uttar Pradesh	85.0	25.8	3.8	114.6	22.4	6.8	1.0
South	81.5	37.0	21.5	140.0	3.8	1.7	1.0
Tamil Nadu	83.4	31.7	31.7	146.8	2.6	1.0	1.0
Kerala	24.8	12.7	20.8	58.3	1.2	0.6	1.0
West	30.8	14.7	4.3	49.8	7.2	3.4	1.0
East	48.2	17.6	10.8	76.6	4.5	1.6	1.0
All India	57.2	22.1	8.2	87.5	7.0	2.7	1.0

Source: Fertilizer Abstract 2000-2001, FAI, New Delhi.

Nutrient uptake in important cropping systems in India

A continuous mismatch between nutrient removals and replenishment has been observed in various cropping systems (Yadav *et al.*, 1998). Nutrient requirements as well as their removal vary in various cropping systems (Table 2). The application of P to all cropping systems is always more than its removal. The difference in added and removed N differs in different systems e.g. removal is less than applied in the maize-wheat, rice-wheat and the maize-rapeseed-wheat cropping systems but is larger in all the other systems. The nutrient of concern is potassium where its removal is always much greater than the addition resulting in K mining from the soil and creating a highly unbalanced situation for the future.

Table 2. Nutrient uptake in important cropping system.

Crop sequence	Applied (kg ha^{-1}) N	P	K	Total yield (t ha^{-1})	Total uptake (kg ha^{-1}) N	P	K
Maize-wheat-green gram	260	70	50	8.21	306	27	232
Rice-wheat-green gram	260	70	50	11.15	328	30	305
Maize-wheat	250	54	75	7.60	247	37	243
Rice-wheat	250	44	84	8.80	235	40	280
Pigeonpea-wheat	144	52	100	4.82	219	31	168
Pearl millet-wheat-cowpea (fodder)	245	66	66	9.22	500	59	483
Soybean-wheat	145	61	0	7.74	260	37	170
Maize-Indian rape-wheat	330	69	0	8.63	250	41	200

Source: Yadav *et al.* (1998)

At the current level of food grain production (206 Mt during 1999-2000) at the national level (Anonymous, 2001), there is a gap of 10 Mt of nutrients per year between their removal (28 Mt) and additions (18 Mt). It becomes imperative that, to sustain soil productivity, this present trend has to be changed by adequate replenishment of soil K reserves by inputs. This is because food security is very much related to fertilizer inputs. For feeding a population of 1.4 billion by 2025, India will need to produce 311 Mt of food grains. For this it will need 45 Mt of plant nutrients, out of which 35 Mt should come from chemical fertilizer sources containing 2.3 to 4.7 Mt K_2O.

With the advent of the green revolution, which triggered all types of resource management to meet the requirements of high yielding and potentially fertilizer responsive crops, it was necessary to develop a data base on changes in soil fertility under intensive farming to provide decision support system for agricultural policy. The Indian Council of Agricultural Research sponsored various All India Coordinated Research Projects and Long-Term Fertilizer Experiments are one of the projects. These were initiated in 1972-73 and they are providing a useful information on changes in soil fertility, nutrient balances and the response of crops to various nutrients over time. These experiments are also expected to provide alternative fertility management strategies for a given site and how these need to be refined with the passage of time. They will also indicate where nutritional imbalances are being created as shown by the following examples from different zones and cropping systems.

Temperate zones of the western Himalayas

Maize – wheat cropping system

In the wet temperate zone on an acidic soil (pH 5.8) at Palampur (Himachal Pradesh) with N only the grain yield of maize decreased from 22.8 q ha^{-1} (1973-74) to 0.2 q ha^{-1} (1992-93) and of wheat from 14.0 to 0.5 q ha^{-1} (Fig. 1 and Fig. 2). The response to N was 18.6 and 6.9 q ha^{-1} for maize and wheat, respectively, in the first year of the experiment and this decreased to -1.0 and -3.0 q ha^{-1}, respectively, in the 20th year, the decreasing response starting after the 1st year. The application of N alone acidified the soil and increased the concentration of various toxic elements, especially aluminium which content increased about 5 times. Application of NP improved the yield initially but could not sustain it. The yield of maize decreased from 34.0 q ha^{-1} to 13.0 q ha^{-1}, and of wheat from 28.0 to 14.2 q ha^{-1}. At the start of the experiment, the response to K in the presence of NP was only 1.2 q ha^{-1} for maize but increased to 26.4 q ha^{-1} and for wheat increased 1.9 to 13.0 q ha^{-1}. The small response to K initially indicated an adequate supply of K from soil reserves but these were soon depleted. The balanced application of NPK, however, sustained the yield of maize around 30-35 q ha^{-1} and of wheat between 25 to 30 q ha^{-1}. The consistently larger yields of both the crops with the 150% NPK treatment indicated the need for an upward revision of the fertilizer recommendations.

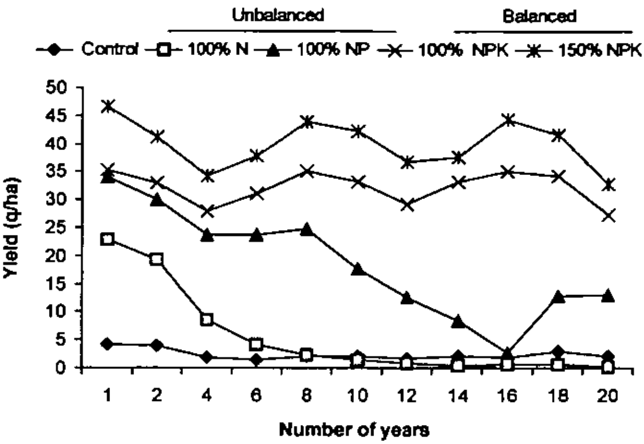

Fig. 1. Effect of unbalanced fertilization on grain yield of maize from 1973 to 1993 (adapted from Sharma *et al.*, 1998).

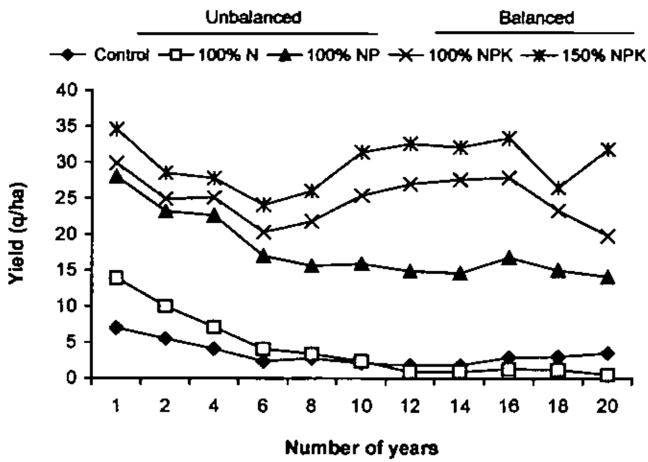

Fig. 2. Effect of unbalanced fertilization on grain yield of wheat from 1973 to 1993 (adapted from Sharma *et al.*, 1998).

Rainfed vertisols of the western zone

Cotton based cropping system

The long-term experiments (1969-1980) on farmers' fields showed that N alone, NP and NPK increased the yield of seed cotton by 44, 91 and 112%, respectively, over the unfertilized plots under irrigated conditions (Randhawa and Tandon, 1982). There was a progressive increase in seed cotton yield with increasing amounts of NPK fertilizers (Patel *et al.*, 1996). The long-term fertilizer trial under rainfed conditions at CICR, Nagpur (Kairon and Venugopalan, 1999) reinforced the need for balanced application of NPK to prevent a decline in cotton yields. Yield Trend Analysis of selected treatments indicated a negative slope with N alone and NP, and a positive slope with NPK (Fig. 3). Data (not shown) also revealed that during first eight years of the experiment, there was no difference between the yields with NPK and NPK+FYM but differences started from the 9th year onward, indicating the long-term benefits of balanced fertilization along with FYM. Nutrient utilization efficiency in terms of kg seed cotton per kg uptake was lowest under unbalanced fertilization and increased under balanced fertilization at both low and high fertility levels (Table 3).

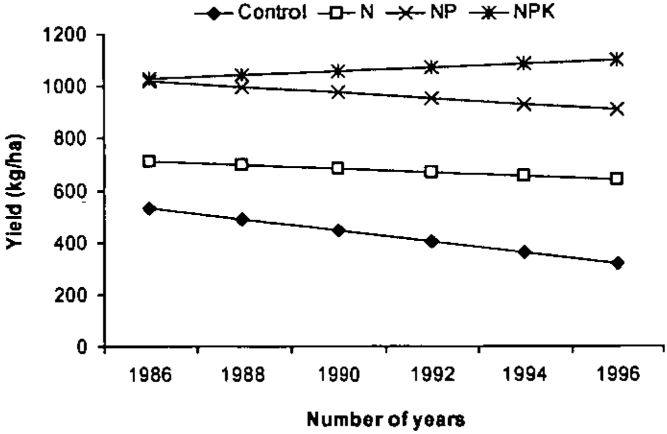

Fig. 3. Long-term effect of unbalanced fertilization on seed cotton yield.

Table 3. Nutrient utilization efficiency (kg seed cotton kg^{-1} uptake) under different fertilizer treatments in cotton.

Treatments (kg ha^{-1})	N utilization efficiency		P utilization efficiency	
	G. hirsutum	*G. arboreum*	*G. hirsutum*	*G. arboreum*
Control	11.6	14.7	52.5	65.5
60 kg N	11.7	13.7	54.5	71.6
60 kg N + 13 kg P	12.3	15.8	54.2	78.8
60 kg N + 13 kg P + 25 kg K	14.9	18.7	81.8	90.3

Source: Venugoparlan and Pundarikakshud (1998).

Lateritic soils in the humid tropics of the eastern zone

Rice-rice cropping system

Long-term experiments were conducted at the central research station of Orissa University of Agriculture and Technology, Bhubaneshwar, Orissa, on a lateritic alluvium, classified as fine loamy mixed hyperthermic Aeric Haplaquept with pH 5.6, very low CEC (2.0 $cmol_c\ kg^{-1}$), kaolinite-illite as the predominant clay minerals, very little organic carbon (0.26%). The soil has 256 kg ha^{-1} exchangeable K and 31 kg ha^{-1} Olsen P. Rice consistently responded to N when grown in both the kharif and rabi seasons but the response was larger with rabi compared to kharif rice (Table 4). There was no response to P until after the 8 year when Olsen P had decreased to 15 kg ha^{-1}. The response was then variable with kharif rice but more consistent and larger with rabi rice before the 9th year because of K release from the non-exchangeable pool. The response to K then increased and its mean contribution to total productivity was 35.4% during 1986-90. Severe K deficiency also aggravated the Fe-toxicity.

Table 4. Effect of unbalanced fertilization on grain yield of kharif and rabi rice (q ha^{-1}).

	Kharif rice					Rabi rice				
Year[a]	C[b]	N	NP	NPK	1.5 NPK	C	N	NP	NPK	1.5 NPK
1	19.7	22.7	23.2	25.3	25.1	14.3	23.1	21.7	26.2	26.6
2	16.0	19.1	20.8	23.5	25.7	15.2	27.5	28.7	30.2	33.2
3	16.4	17.1	18.8	22.1	20.6	13.7	24.1	25.8	26.2	26.6
4	20.9	33.9	30.6	35.6	38.9	15.1	28.1	30.4	30.8	32.9
5	12.4	26.5	22.7	30.2	30.2	14.9	26.8	28.5	30.0	30.7
6	14.8	26.8	28.8	30.7	31.7	16.5	28.2	31.8	34.0	35.8
7	16.2	24.7	24.7	28.2	30.5	13.2	23.8	32.2	33.2	34.5
8	14.8	22.5	24.3	26.2	29.5	10.5	19.8	23.0	23.7	27.5
9	17.7	23.7	27.8	31.2	34.2	17.0	28.3	33.3	34.3	36.0
10	20.2	36.0	40.0	43.8	47.2	14.2	21.2	26.2	28.8	30.8
11	14.2	19.8	22.2	28.8	29.7	18.6	28.2	31.7	34.9	38.2
12	18.2	20.0	22.8	30.3	33.0	18.4	28.9	30.7	34.7	38.7
13	19.1	17.8	15.4	25.9	28.5	11.3	16.1	24.4	31.3	34.7
14	14.2	17.7	14.5	27.7	25.8	16.3	21.1	26.7	31.3	37.1
15	16.8	20.2	21.6	28.5	32.9	17.7	17.0	28.0	33.2	40.4
16	16.0	18.2	18.5	25.7	32.1	15.2	16.3	26.8	27.2	34.5
17	12.2	16.7	21.3	26.3	28.7	12.0	13.5	21.0	24.7	29.5
18	11.3	14.0	17.2	23.5	27.0	7.3	10.8	19.2	23.9	27.3
19	13.2	16.2	19.0	22.5	27.8	10.1	16.9	22.2	26.9	32.7
20	14.0	15.2	17.8	23.3	28.7	8.0	11.1	21.8	24.8	27.6

Source: Sahoo *et al.* (1998).
[a] 1973-74 to 1993-94 [b] Control

Application of the standard rate of NPK was sufficient only during the first 11 years in kharif rice and first seven years in rabi rice, the amount of NPK then became too little and a larger application was required and crop yield increased significantly with the 1.5 NPK treatment (Sahoo *et al.*, 1998). The adverse effect of applying N alone in the rice-rice system was not as severe as in other cropping systems on acidic soils probably due because pH was maintained near neutrality under the flooded conditions of the rice-rice system.

Red and lateritic soils

Soybean-wheat cropping system

Results from experiments on an upland acidic Haplustalf soil with pH 5.3 and available N, P and K of 295, 13 and 158 kg ha^{-1}, respectively, showed that there was no response to any fertilizer at the start of the experiment (Table 5).

Table 5. Effect of unbalanced use of fertilizers on the yield of soybean (q ha^{-1}) on acidic red loam soil (1973-74 to 1996-97).

Treatments	1973-74	1974-75	1978-79	1982-83	1986-87	1990-91	1994-95	1996-97
C	12.3	12.2	12.8	7.9	5.4	4.4	6.0	4.0
N	10.2	8.6	10.0	1.6	1.4	2.7	2.8	1.9
NP	9.7	10.9	16.5	9.6	6.7	8.8	10.1	5.4
NPK	12.8	14.8	17.0	13.4	17.4	16.2	20.6	15.4
1.5 NPK	10.1	14.0	17.6	11.7	19.0	16.4	20.9	15.8

Source: Singh and Sarkar (1998).

The response to N alone was negative throughout the period of the experiment with the adverse effect of ammonium sulphate being larger than that of urea because it acidified the soil. Compared to the control, the NP treatment increased the yields but not to those on the NPK treatment indicating a substantial response to K. The NPK treatment maintained the yields of soybeans and there was no additional benefit from the 1.5 NPK treatment. However, there was additional benefit to the application of lime and FYM in the red loam upland acidic soils especially when ammonium sulphate was applied (Sarkar *et al.*, 1989; Singh, 1991). There was a higher Sustainable Yield Index (SYI) with NPK (0.49) compared to 0.03 with N alone and 0.24 with NP further indicating that the yield of crops on acidic upland soils can only be sustained by balanced fertilization and can further be improved by the application of lime and FYM.

Alfisols of the southern zone

Finger millet-hybrid maize cropping system

Results from the long-term experiments at Banglore (Karnatka) on a Typic Kandi Ustalf with initial pH 6.05, sandy clay loam texture and available N, P, K of 257, 34 and 123 kg ha^{-1}, respectively, showed that both finger millet and maize grain yield decreased on the control plots. The moving 3-year average grain yields of finger millet indicated about a 74% decline in the initial period compared to the yield, about 5.0 q ha^{-1}, given by NPK (Table 6). Maize yields on the control plots declined even more to 0.65 q ha^{-1}. Applying N and P increased the yield appreciably only for initial few years but did maintain larger yields than on the control. By about the 8^{th} year, yields with NP were only a little larger than those on the control plot due to a decrease in the K content of the soil. Addition of K in the fertilizer schedule improved the yield tremendously and maintained the productivity of finger millet but not the yield of maize which dropped during last few years. This could be explained by the slight decrease in pH, which perhaps affected hybrid maize more than finger millet. The initial soil pH (6.05) increased in control plots to 6.28 but decreased to 5.0 with the different chemical fertilizer treatments.

Table 6. Effect of unbalanced fertilization on the yield of finger millet and hybrid maize.

	Years (1986-87 to 1994-95)								
Treatments	1	2	3	4	5	6	7	8	9
			Finger millet (Kharif)						
Control	-	13.6	3.7	4.5	6.1	6.6	3.3	5.4	6.3
N	-	16.9	7.4	14.8	10.7	12.5	1.3	6.6	7.2
NP	-	19.7	18.5	24.3	12.2	12.7	10.5	7.4	7.6
NPK	-	22.8	19.3	38.2	43.1	49.6	46.3	47.9	50.7
1.5 NPK	-	31.1	29.3	52.1	43.8	52.2	56.7	50.8	57.5
			Hybrid maize (Rabi)						
Control	14.9	4.0	4.2	1.2	2.5	1.4	0.3	1.4	0.7
N	24.1	9.0	12.4	3.6	2.3	0.8	1.2	1.9	1.6
NP	29.6	15.6	15.0	6.6	4.5	3.3	0.4	3.5	2.7
NPK	26.8	17.5	20.4	23.4	28.3	35.8	2.8	16.6	13.9
1.5 NPK	33.8	14.6	25.2	22.3	31.6	28.2	6.2	22.5	23.2

Source: Sudhir *et al.* (1998).

Available P decreased from 34.2 to 10.6 kg ha^{-1} in the control plot and 8.5 kg ha^{-1} with N alone. Available K decreased from 123.1 to 70.8 kg ha^{-1} on the control and 63.4 kg ha^{-1} with the NP treatment. The larger yields with the 1.5 NPK treatment throughout the experimental period with finger millet and after six years with hybrid maize, indicated the need for a revision of the fertilizer schedule with the intensive cultivation of these two crops. The deleterious effect of unbalanced use of nutrients on the yield of crops in irrigated inceptisols has also been reported by Muthuswamy *et al.* (1990).

Nutrient balance in alluvial soils of the north zone

Data of the long-term fertilizer trial conducted at Ludhiana, Punjab for 27 years (1971-1997) on the wheat-maize-cowpea system indicated that N balances were negative, where none was applied but was positive with all N treatments (Table 7).

Table 7. Mean annual N, P and K balance (1971-97) in wheat-maize-cowpea system.

Treatment	Wheat	Maize	Cowpea	Applied (kg ha^{-1})	Removed (kg ha^{-1})	Balance (kg ha^{-1})	Change in soil test after 26 years
				Nitrogen			
Control	0	0	0	0	51	-51	-5.4
N	150	150	20	320	134	186	16.7
NP	150	150	20	320	229	91	17.1
NPK				430	258	172	37.0
				Phosphorus			
Control	0	0	0	0	8	-8	-5.7
N	0	0	0	0	17	-17	5.0
NP	33	33	17	83	32	51	73.5
NPK	33	33	17	83	39	44	69.9
				Potassium			
Control	0	0	0	0	50	-50 (-20)[a]	-69.1
N	0	0	0	0	113	-113 (-83)[a]	-64.5
NP	0	0	0	0	152	-152 (-122)[a]	-62.5
NPK	31	62	17	110	217	-107 (-77)[a]	-24.9

Source: Brar and Brar (2002).
[a] After considering the contribution from Ground Irrigation Water.

The net mean annual N balance was 186 kg ha^{-1}, with N alone, and 91 kg ha^{-1} with NPK, indicating the better utilization of N with balanced fertilization. In spite of the positive N balance, there was little build-up of N in the soil indicating loss of N either through denitrification or leaching. The mean annual P balance was negative without applied P and positive where P was applied. The small P balance in the presence of K indicated a better utilization of P by crops with balanced fertilization. Mean annual K balances were always negative irrespective of whether K was applied or not, the largest negative being on the NP plot. The K balances were negative even after taking into consideration the K applied with the irrigation water.

The negative K balances indicated the contribution of soil K reserves to K uptake by the crop. The results from a long-term field experiment on similar soils in Haryana showed that non-exchangeable K decreased from about 4500 kg ha^{-1} to around 1000 kg ha^{-1} with 12 years of cropping (Grewal and Mehta, 1996). With the depletion of exchangeable K, the crop has to rely increasingly on K released from reserves (Yadvinder Singh and Khera, 1998). The depletion of the soil K reserves alters the soil minerals and increases K fixation. The amount of K required for a 1% increase in the available K in an exhausted soil is 3 to 5 times more than in a fertile soil (Krauss, 1998). Therefore, the K fertilization program in India needs to be re-examined.

Balanced fertilization and fertilizer use efficiency

The "fertilizer use efficiency" calculated on the basis of data collected for 25 crops on alluvial soils of Ludhiana, Punjab (Table 8) indicated that generally fertilizer use efficiency was lower with maize than with wheat. This is probably due to N leaching during the rainy season and an increase in native P availability due to the high temperatures during the maize growing season. Fertilizer use efficiency was increased by the balanced use of fertilizers. Greater N utilization by the plants leaves less residual N in soils, thus decreasing its leaching and preventing the pollution of underground waters. Similarly greater P use efficiency will decrease its build-up in soils and minimise any risk of loss.

Table 8. Apparent N, P and K use efficiency (%) of crops under various treatments.

Crops	Number of crops	N	NP	NPK
		N use efficiency		
Maize	25	16.2	30.6	32.0
Wheat	25	32.2	51.4	64.0
		P use efficiency		
Maize	25	-	10.0	17.6
Wheat	25	-	21.0	30.4
		K use efficiency		
Maize	25	-	-	43.0
Wheat	25	-	-	93.0

Source: Brar and Pasricha (1998).

Balanced fertilization and quality of vegetable crops

Balanced fertilization including K resulted in increasing early yields and total yields of tomatoes and an improvement in the ascorbic acid, total soluble solids, reducing and non-reducing sugars (Table 9) (Nandal *et al.*, 1998).

Table 9. Effect of omitting potassium on the yield and quality of vegetable crops.

Parameters	NP	NPK	LSD 0.05
Tomato (Nandal *et al.*, 1998)			
Weight of fruit (g plant^{-1})	597	886	40
Early yield (q ha^{-1})	67.5	84.3	4.2
Total yield (q ha^{-1})	190	222	7.0
Ascorbic acid (mg kg^{-1})	205	227	9.0
Total soluble solids (%)	4.9	5.3	NS
Lycopene content (g kg^{-1} fruit)	204	208	3.3
Reducing sugar (g kg^{-1} fruit)	25	27	2
Non-reducing sugar (g kg^{-1} fruit)	11	13	NS
Pea (Kanaujia *et al.*, 1997 & 1999)			
Number of nodules per plant	31.2	43.7	3.4
Fresh weight of nodules (g)	68.6	92.6	2.9
Green pod yield (q ha^{-1})	83.5	104.2	3.0
Shelling percentage (%)	47.7	54.3	0.7
Protein content (%)	23.2	24.5	0.4
Total sugar content (%)	3.5	3.8	0.1
Cabbage (Sarkar *et al.*, 1994)			
Days to maturity	76	72	4
Equatorial diameter (cm)	12.7	15.7	1.3
Polar diameter (cm)	13.2	13.9	NS
Average head weight (kg)	1.07	1.35	0.2
Head yield (t ha^{-1})	30.0	47.4	11.1
Turmeric (Sharma *et al.*, 2001)			
Productivity (q ha^{-1})	61.4	93.2	
Protein (%)	8.04	9.63	
Curcuman (%)	2.60	2.72	

Kanaujia *et al.* (1997) reported that for peas, both the number of nodules and the fresh weight of nodules per plant increased with NPK compared to NP treatments. Additionally, green pod yield, shelling percentage, protein and sugar content in the green peas were significantly improved by applying NPK. The green pod yield was increased due to increase in pod length, pod girth and seeds per pod. With the treatments NP_{30} K_0, NP_{60} K_0 and NP_{90} K_0, the net return to farmers was 14036, 31530 and 25770 rupees ha^{-1}, with the additional application of 90 kg K_2O ha^{-1} the returns increased to 22505, 40398 and 30025 rupees ha^{-1}, respectively (Kanaujia *et al.*, 1999). Days to maturity, circumference and height, average head weight and head yield of cabbage were favourably influenced by applying NPK (Table 9) (Sarkar *et al.*, 1994). The days to maturity decreased, which enabled the farmers to obtain a higher price. The increase in diameter and weight of the head improved the quality of the cabbage besides its yield. Sharma *et al.* (2001) working in mountain acidic lands of western Himalayas found that yield and quality parameters of turmeric rhizomes such as protein and curcumin content improved with NPK (Table 9). These parameters improved the crops marketability ensuring better economic returns to the small and marginal farmers of Himachal Pradesh (Western Himalayas).

With potatoes, chips of the variety Kufri Bahar had a colour score above 5 at the recommended rate of K and hence the tubers were not considered suitable for making chips. However, K applied at 225 kg K_2O ha^{-1} significantly improved chip quality as indicated by a colour score of 3.2 (Bansal and Umar, 1998).

Concluding remarks

Fertilizer consumption in India is very uneven with only 8% of the total number of districts consuming 25% of the total fertilizer consumed. It is also highly unbalanced with regard to K consumption which is one-seventh that of N compared to its removal being 55% of the total NPK uptake. For example in Punjab, total K removal is 140% that of N but the application is less than 2% that of N. Punjab soils show annual depletion of 100 kg K ha^{-1}, an alarming situation in the country's most intensively cropped state and foremost food grain producer. The implications of such an unbalanced supply of nutrients will, in the long run, be reflected in more widespread and acute nutrient deficiencies, a decrease in fertilizer use efficiency and net returns to the farmers, unsustainable crop production and large remedial costs of rebuilding the fertility of depleted soils. Dr. J.S. Kanwar has commented that "Serious note should be taken of the damage which unbalanced fertilizer use, specially that of nitrogenous fertilizers alone without adequate inputs of P and K has done. The fertilizer policies which encourage the use of only one type of fertilizer particularly N alone can lead to decline in productivity and reduction in response to N". All the major states of the country except 5 have a N : K ratio greater than 4 : 1. Mean annual K balances are always negative ranging from 20 to 370 kg ha^{-1} in different cropping systems and on different soils even when K is applied. The responses to the application of K are increasing with time. The levels of fertilizer application which were considered as optimum a few years back have now become sub-optimal at many places for supporting large yields in intensive cropping systems. Appropriate initiatives are needed quickly and on a large scale, to change the ratios in which nutrients are used to improve the balance between N, P and K to secure large crop yields of acceptable quality.

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Imbalance in nutrient supply as a threat to sustainable agriculture in China

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Abstract

China is the biggest country in the world for both production of food and consumption of fertilizers. The consumption and production of chemical fertilizers in 2000 were 41.46 and 31.86 Mt, respectively. Fertilizer production has not yet met the needs of agriculture in China, especially for potassium (K) fertilizers. Fertilizer applications have played a very important role in crop production in China and account for 50% of the total investment in agricultural production by Chinese farmers. However, the fertilizer use efficiency is much lower than that in developed countries. One of the major reasons is the imbalance of nutrient supply. The ratio of $N:P_2O_5:K_2O$ in fertilizer consumption in 1999 was 1:0.39:0.26. Now the supply of nitrogen (N) and phosphorus (P) as chemical fertilizers is in surplus in some regions, but K from organic manures is still the major source of K to farmland. As a result, a deficit of K is found in most of the arable land in China. The imbalance in nutrient input not only affects the benefit from the fertilizer application, but also crop production and the environment. To realize our food security goal, there must be an increase in fertilizer use because fertilizer applications are one of the key factors affecting the yield and quality of agricultural products. Therefore, a great effort must be made to improve our fertilizer use efficiency and to maintain soil fertility. The measures to be taken include fertilizing according to soil conditions and crop requirements, exploring new management patterns to continue with the application of organic manures, greatly increasing the input of potash and supplementing soil micronutrients, establishing and improving the advisory systems to extend balanced fertilization techniques, and enhancing macroscopic regulation and control of fertilizer distribution.

Introduction

Sustainable agriculture in China is always the most important issue because 22% of the world's population must be fed from only 10% of the world's arable land. As the progress of industrialization and urbanization continues, the amount of arable land will be further reduced. As a result, increases in food production must depend on increasing yield per unit area of land. According to current predictions, the population of China will reach a peak of 1.6 billion in the 2030s. If we maintain the current annual grain yield per capita of 400 kg and the existing arable land area, the total output of grain will be 640 Mt, and to achieve this total production the unit yield must increase by 28%. If the goal is to achieve the international average of 500 kg per capita, the total output will have to be 800 Mt, with an increase of 60% in the unit yield. To realize these goals of food security, an increase of fertilizer input cannot be avoided because nutrient inputs are one of the key factors affecting grain yields (Fig. 1). Fertilization has a largest contribution to the food production in China (Xie *et al.*, 1998). Although fertilizer consumption has continued to increase, the increase in grain production has slowed in recent years (Fig. 1). One of the reasons is that a larger proportion of total fertilizer consumption has been used for cash crops and fruit production. Also fertilizer use efficiency in China is much lower than that in developed countries. One of the major reasons is the imbalance of nutrient supply that affects not only the benefits of the fertilizer itself, but also overall crop production and the environment.

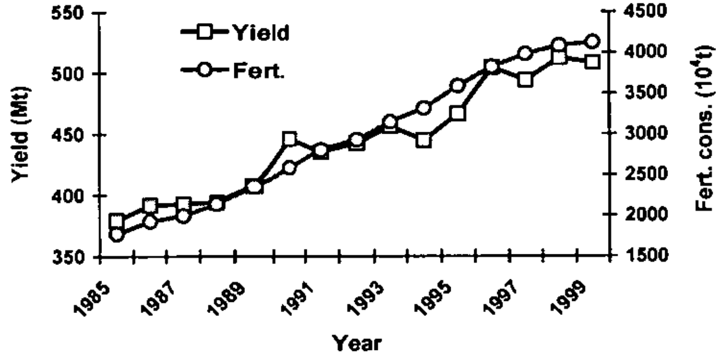

Fig. 1. Total grain yield and chemical fertilizer consumption of China in recent years.

Nutrient balance in Chinese farmland

The nutrient balance for nitrogen, phosphorus and potassium in different periods in China

The nitrogen (N), phosphorus (P) and potassium (K) balance for Chinese farmland for different periods from the 1950s to the mid 1990s are shown in Figs. 2-4. Before the 1970s, the N balance was very negative because little chemical fertilizer was used; but since then the N balance has become more and more positive due to large inputs of N fertilizers (Fig. 2). However, the N content in farmland soils did not increase significantly indicating that most of the surplus N was lost. The P balance has been positive since the early 1970s, and has increased very sharply recently (Fig. 3). Most of the surplus P has accumulated in the soil because of its low mobility.

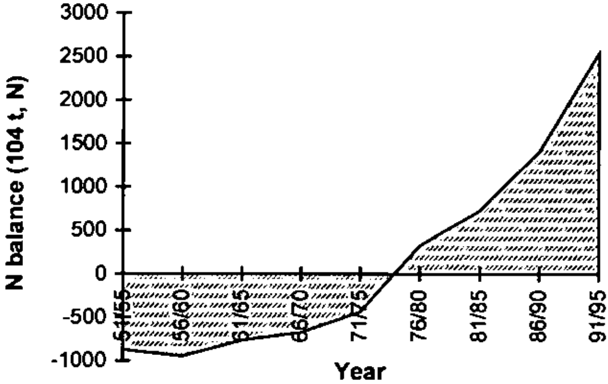

Fig. 2. Changes in the nitrogen balance in the farmland of China.

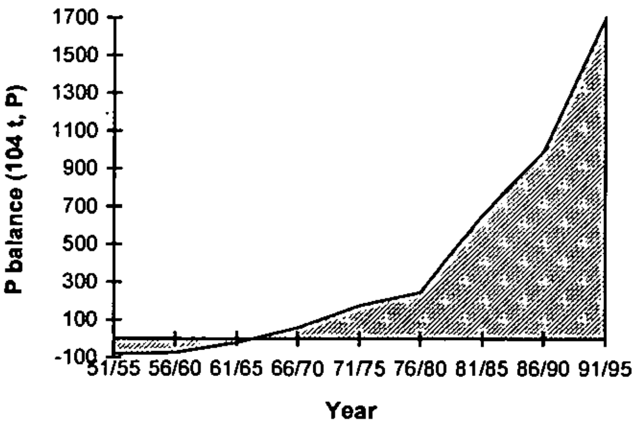

Fig. 3. Changes in the phosphorus balance in the farmland of China.

The K balance has always been negative in spite of a gradual increase of K fertilizer use (Fig. 4). On one hand, the amount of K removed by crops has increased with larger yields but on the other hand, the current input of K in fertilizers is not enough to meet the requirement of crop uptake, causing the negative K balance.

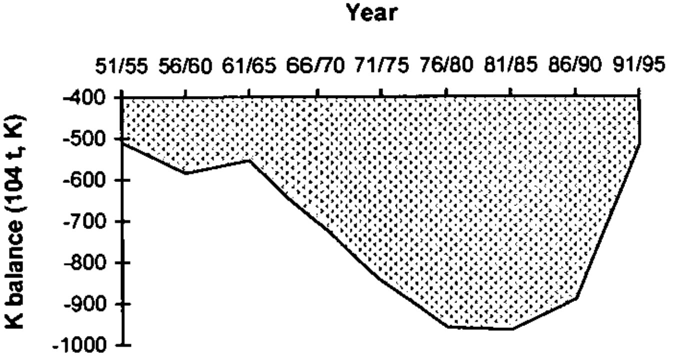

Fig. 4. Changes in the potassium balance in the farmland of China.

The current nutrient balance for nitrogen, phosphorus and potassium in China

In 1997 the nutrient balance status was investigated as part of an IPI program in selected, representative provinces: Heilongjiang, Shaanxi, Henan, Jiangsu, Sichuan, Guangxi and Hunan (Table 1). The cropping systems choosen involved those with one, two and three harvests each year and those with three and five harvests every two years.

The data in Table 1 show that N and P balances were positive in all provinces except for N in Guangxi, and that the K balance was negative in all provinces. The area of uplands in Guangxi province was only a little less than that of the lowlands, but because the input of fertilizers in the uplands was very much lower than that in paddy fields, the uplands were seriously deficient in N and this resulted in the negative N balance for the whole province. In this investigation N losses were estimated to be 45%, therefore surplus N input was widespread in China, which can influence both the quality of agricultural products and the environment. The P balance was positive in every region and although P is retained in soil, its excessive accumulation may partially increase its mobility resulting in a possible environmental risk. At the same time, the low use efficiency of P directly influences the economic benefit of its use.

Table 1. Nutrient budgets for farmland in seven agro/eco-regions in China (kg/hm^2).

Province	N			P			K		
	Input	Output	Balance	Input	Output	Balance	Input	Output	Balance
Heilongjiang	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: "-" means nutrient deficiency.

Current fertilizer production and consumption in China

China is a country with a history of using only organic manure in agriculture for thousands of years and before the 1950s, almost all applied nutrients came from organic manure. The use of N, P and K chemical fertilizers started in the 1950s, 1960s and 1970s, respectively. Fertilizer production in China has developed very quickly, especially in the last two decades. Total production in 2000 reached 31.86 Mt, including 23.98 Mt N, 6.63 Mt P_2O_5, and 1.25 Mt K_2O, much greater than that in 1980 (12.32 Mt in total), of which N, P_2O_5 and K_2O were 9.99, 2.31, and 0.02 Mt, respectively (Table 2). Correspondingly, the consumption of fertilizer also has grown greatly. Since the early 1970s, the input of fertilizer N has exceeded that from organic manure, and similarly for P from the early 1980s. Until now, however, organic manure still plays the leading role in the input of K.

Table 2. Chemical fertilizer production in China (Mt).

Year	Total ($N+P_2O_5+K_2O$)	N	P_2O_5	K_2O	N: P_2O_5: K_2O
1980	12.32	9.99	2.31	0.02	1:0.23:0.002
1990	18.80	14.64	4.12	0.05	1:0.28:0.003
2000	31.86	23.98	6.63	1.25	1:0.28:0.052

Despite these great achievements, fertilizer production does not yet met the needs of agriculture in China. In 2000, the consumption and production of the chemical fertilizers were 41.46 and 31.86 Mt, respectively. Of the total consumption of fertilizers, there were 21.62 Mt N, 6.91 Mt P_2O_5, 3.77 Mt K_2O and 9.18 Mt compound fertilizers, with a ratio of N: P_2O_5: K_2O of 1:0.39:0.26. For the production of fertilizers, the ratio of N: P_2O_5: K_2O was 1:0.28:0.052 (Tables 2 and 3). Obviously, the production of fertilizers was much less than the amount consumed, especially for K and this was quite inappropriate.

The proportion of K_2O in the consumption of fertilizers was also lower than the world average of 1:0.47:0.32 (Xie, 1994). If the nutrient input ratio continues at the present level, the K deficit in the soil will become more serious. Thus the existing problems in both the current production and consumption of fertilizers will inevitably hinder the sustainable development of agriculture in China. The predicted amount of fertilizer consumption will have to reach 65.2-68.7 Mt by 2030 with a ratio of N: P_2O_5: K_2O of 1:0.40:0.30 to achieve food security and agricultural sustainability targets (Table 4).

Table 3. Chemical fertilizer consumption in China (Mt).

Year	Total ($N+P_2O_5+K_2O$)	N	P_2O_5	K_2O	Compound fertilizer (total)	$N: P_2O_5: K_2O$*
1957	0.37	0.32	0.05			
1965	1.45	1.33	0.11	0.003	0.005	
1975	5.21	3.31	1.46	0.11	0.33	
1980	12.69	9.34	2.73	0.35	0.27	1: 0.29: 0.037
1985	17.76	12.05	3.11	0.80	1.80	1: 0.26: 0.067
1990	25.90	16.38	4.63	1.48	3.42	1: 0.28: 0.090
1995	35.94	20.22	6.32	2.69	6.71	1: 0.31: 0.133
1996	38.28	21.45	6.58	2.91	7.35	1: 0.31: 0.136
1997	39.81	21.72	6.89	3.22	7.98	1: 0.32: 0.148
1998	40.85	22.34	6.83	3.46	8.22	1: 0.31: 0.155
1999	41.24	21.81	6.98	3.66	8.80	1: 0.32: 0.168
2000	41.46	21.62	6.91	3.77	9.18	1: 0.32: 0.174

* Nutrients from compound fertilizer were not included.

Table 4. Prediction of chemical fertilizer consumption (Mt).

Year	2010	2015	2030
Consumption	50.9-52.2	55.7-57.6	65.2-68.7
$N:P_2O_5:K_2O$	1:0.40:0.25	1:0.40:0.30	1:0.40:0.30
$N - P_2O_5 - K_2O$[1]	30.8-12.3-7.7	32.8-13.1-9.8	38.3-15.3-11.5
$N - P_2O_5 - K_2O$[1]	31.7-12.7-7.9	33.9-13.6-10.2	40.4-16.2-12.1

[1] Lower and upper targets.

Threat of unbalanced nutrient supply on sustainable agriculture in China

Economic loss and waste of energy and resources

The large amount of N fertilizer lost as NH_3, N_2O, nitrite, nitrate, to the atmosphere or water has brought enormous economic loss. It has been reported that 21,717,000 t N_2 in N fertilizer was applied to farmland in 1997. If the average loss was 45%, as estimated by Zhu (1998), the total loss of N_2 would be as much as about 9,773,000 t which is equal to 21,000,000 t urea. If the price of urea is 2000 yuan (RMB, the same below)/t the total loss is 42 billion yuan (Chinese Yearbook of Agriculture, 1998). In addition, poor crop quality influences its value, which can result in a loss to the farmer. The production of chemical fertilizers requires energy as well as N from the air and the use of some natural mineral resources containing P and K, consequently there will be a perpetual loss of non-renewable resources.

Exhaustion of soil potassium fertility

With the increasing input of N and P, a low K input inevitably results in the missing of soil K reserves to meet crop requirement for normal growth. The exhausting of soil K will further decrease the efficient use of N and P and threaten the sustainable productivity of the soil and thus sustainable agriculture.

Effects on yields and crop quality

When K inputs and soil K cannot meet the crop's needs, both quality and quantity decrease together with their ability to resist diseases and pests.

Effects on fertilizer use efficiency and costs of production

A lack of K adversely effects normal crop growth, and lowers their ability to use N and P inputs efficiently. In order to achieve as large a yield as possible – to some extent quantity is more important than quality for many farmers – more fertilizers have to be applied. If lack of K results in the inefficient use of other agricultural materials, labour, etc., then these costs are not fully covered by the decreased value of the produce.

Contamination of the environment

Surveys suggest that most of the residue from applied N fertilizer does not accumulate in soil but is lost in different ways into the atmosphere and water. An increase of the flux of ammonia led to soil acidification and altered vegetation succession, thereby influencing non-agricultural ecosystems. Nitrate in surface and ground water may be increased and when N and P enter surface water, the resulting eutrophication may alter the biological balance within rivers and lakes.

Strategy to resolve nutrient imbalance in China

Balanced fertilization according to soil condition and crop requirements and development of advisory systems for fertilizer application

The efficient use of fertilizers is affected by soil conditions, fertility, texture, etc., as well as crop requirements. For K in China, if a soil has a low clay content and less than 500 mg kg^{-1} of slowly available K, then there is insufficient K to rapidly replace readily plant available soil K. For such soils potash application is generally beneficial because a quickly growing crop with high photosynthesis efficiency and large amount of synthesised organic compounds to be translocated, needs much K. At present, most Chinese farmers do not understand the need for appropriate fertilization methods and technologies. Thus there is an urgent need to establish and improve the agrochemical service system if balanced fertilization techniques and the efficient use of fertilizers are to become more widespread in China.

Continuing and efficient use of organic manure

The application of organic manure is well recognized in China. The return of organic manure to cropland is an efficient utilization of nutrient resources reducing the use of chemical fertilizers and possible environmental pollution. Organic manure is characterized by its uniform composition and balance of nutrients and can help to alleviate the nutrient imbalance in Chinese cropland. For example, the K applied by organic manures may be as much as 70% of the total K applied to cropland in China. But organic manure is also characterized by its low nutrient content, slow release of N and P, and inconvenience of application. These aspects restrict the application of organic manures. It is necessary to explore new management patterns to apply organic manure more efficiently, including the return of straw and stalks to cropland, and the commercialization of organic manure.

Increase of potassium inputs and the need for micronutrients

The amount of K used now is very small and soil K is still decreasing. Thus increasing K fertilizer use is very necessary, not only to gain larger yields, but also to increase product quality and maintain soil fertility. The application of macronutrients with an increase in crop production inevitably leads to an exhaustion of micronutrients in soil and some other beneficial elements that subsequently result in a decrease in crop production and quality. Thus when shown to be necessary, micronutrients need to be added and perhaps some other beneficial elements to maintain the nutrient balance in cropland. The application of organic manure and the return of straw and stalks to cropland is an important way to supplement micronutrients.

The need for regulation and the control of fertilizer distribution

The agrochemical service system has not been well developed in China and government control will still play an important role in the use of fertilizers. The government must both continue to conduct research on the appropriate use of fertilizers by farmers and change the serious imbalance of the production and importation of fertilizer nutrients. It also should pay attention to the rationalization of distribution of various fertilizers. For example, fertilizer use should be encouraged in those regions where larger returns could be obtained, i.e. reduce fertilizer amounts in regions where fertilizers are applied excessively and supply more fertilizers to those regions where fertilizer use is less than optimum. An important aspect to improve the use of fertilizer resources and maintain nutrient balances in cropland in the future is to strengthen the development of the agrochemical service system in China.

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Session 4

Potash in agriculture

Status and outlook of regional potash supply and demand

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Introduction

Today there are many fertilizers containing potassium (K) as a basic nutrient. Many producers also offer potash fertilizers with additions of various microelements like iron, manganese, zinc, copper, boron and molybdenum, which are indispensable for the nutrition of a crop. In this paper, only the major types of potash fertilizers will be discussed, namely potassium chloride (MOP), potassium sulphate (SOP) and potassium nitrate (NOP).
Potash fertilizers are commonly used for direct application as well as in the production of NPK complex fertilizers and blends. The direct use of potash is decreasing worldwide but is increasing a little mainly in the developing countries or for additional applications for some crops. While NPK production declines in *West Europe* and *North America*, it increases in the developing countries creating a basis for the development of world potash consumption.
Global demand for potash fertilizers has started to increase again after declining between the mid 1980s and 1990s. In the early 1960s, world potash consumption amounted to only 14.1 Mt of product and in 2000, it exceeded 37 Mt (Fig. 1).

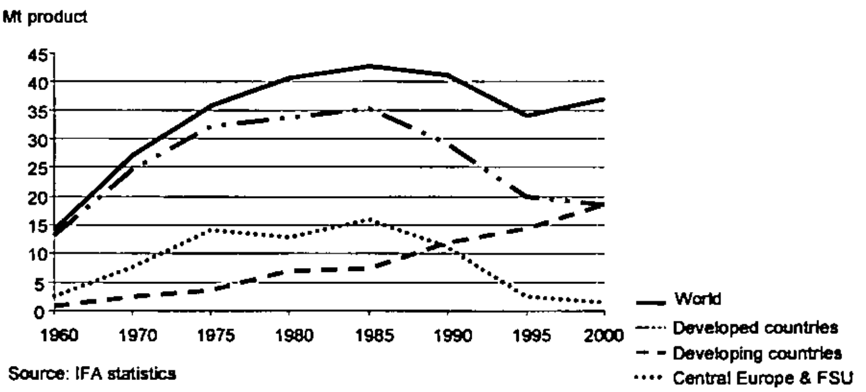


Fig. 1. Trends of world potash consumption in 1960-2000 (Mt product).

The main growth in potash fertilizer use has been in the developing countries, which accounted recently for 50% of the world demand for potash fertilizers. This could be explained by the phenomena of a "green revolution", which led to a dramatic increase in yields in many developing countries from the late 1960s.

The increase in potash consumption in the developing countries accompanied a considerable growth in the production and export of such potash consuming crops as cereals, sugarcane, tea and coffee (Fig. 2). According to the FAO data, the production of cereals, tea and sugarcane in the developing countries increased between two- and four-fold during the last 40 years.

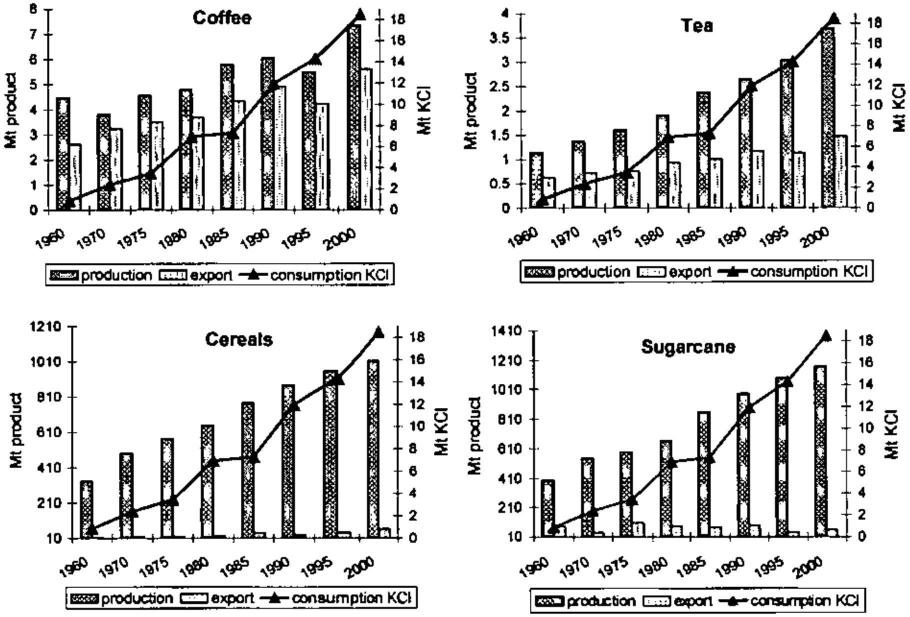


Fig. 2. Potash imports and production and exports of coffee, tea, cereals, sugarcane in developing countries in 1960-2000 (Source: FAO statistics).

On the other hand, the share of the developed countries in the world potash consumption has declined from 93% to 50% during the last 40 years, which could be explained by the use of optimum potash application rates in such regions as *North America* and *West Europe* as well as policy changes in these countries that were designed to restrict the area cropped and reduce food stocks, for example, the Common Agricultural Policy (CAP) in the European Community (EC) and agricultural reforms in *the United States*. Additionally, a huge drop in potash consumption in *Central Europe* and *the FSU* in the early 1990s also provoked a significant decline of the world potash demand in the last 15 years.

In general, the use of potash in the world is relatively small compared to that of nitrogen (N) and phosphorus (P). For example, FAO statistics for 2000/01 give the consumption of N, P_2O_5 and K_2O as 81.62, 32.66 and 22.16 Mt respectively a ratio of 1:0.40:0.27.

World production of potassium

Potash salts which can be accessed economically occur either in underground deposits or in salt lakes. A major part of global potash capacity is concentrated in two regions: *North America*, largely *Canada*, and *the Former Soviet Union*, namely *Russia and Belarus*, with these countries accounting for 85% of known economic reserves in the world. The major world potash capacities were commissioned in the 1960s and 1970s, when the potash resources of *Canada* and *the FSU* were being increasingly developed to meet growing local and world demand for potash fertilizers.

The main product is potassium chloride (muriate of potash, MOP), which comprised about 91% of total primary production in 2001. Potassium sulphate (sulphate of potash, SOP) and potassium nitrate (nitrate of potash, NOP) are secondary products. The world potassium chloride production capacities have remained almost unchanged during the last 10 years amounting to 62.2 Mt of product (Fig. 3) with a slight increase of capacity in *North America, Latin America and Middle East* and a steady decline in *West Europe*. There was a considerable decrease in MOP production at the beginning of the 1990s. The collapse of the USSR along with a drastic fall in potash consumption in *the FSU and Central European countries* led to a huge drop in capacity utilization at the potash enterprises of *Russia and Belarus*. Though the global production volumes of potash fertilizers totalled almost 43 Mt of product in 2001, having increased by more than 9 Mt of product, they have not still reached the level of 1990, when production amounted to 45.7 Mt of product.

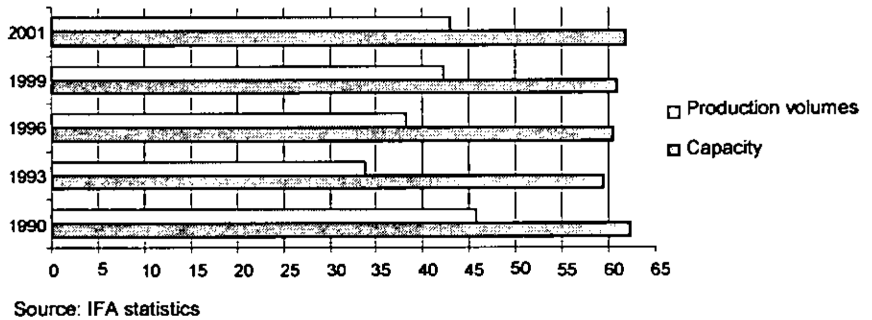


Fig. 3. World capacities vs. production volumes of potassium chloride in 1990, 1993, 1996, 1999 and 2001 (Mt product).

Production of potassium chloride takes place only in 15 countries worldwide with the main producing regions being (i) *North America* (34%), where *Canada* accounts for 91% of the total regional volume, (ii) *the Former Soviet Union* (31%), namely *Russia and Belarus*, (iii) *West Europe* (19%), basically *Germany* with 74% of the production in the region, (iv) *Israel* and *Jordan*, in the *Middle East* (11%) (Fig. 4).

Other significant potassium chloride producers are the *USA, Spain and the United Kingdom*. Production recently ceased in *Italy* and is steadily declining in *France* to end in August 2003.

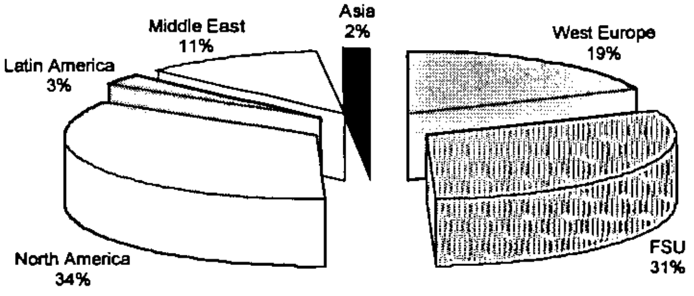


Fig. 4. World production of potassium chloride by region in 2001 (Source: IFA statistics).

The other potash products are mainly potassium sulphate and potassium nitrate, which are chlorine free sources of potassium. Nowadays, potassium sulphate and potassium nitrate account for 7% and 2% of total world potash production respectively.

Potassium sulphate supplies two essential plant nutrients, potassium and sulphur, forming a highly concentrated fertilizer with a low salt index, which makes it more appropriate for such chloride sensitive crops as tobacco, fruit and vegetables. There is capacity to produce potassium sulphate in 14 countries with capacity growing steadily with the main increase in *China* and *Chile* (Fig. 5). However, it should be stressed that in physical terms the growth amounted to only 350,000 t product and this had not significant influence on its share of the world market of potash fertilizers.

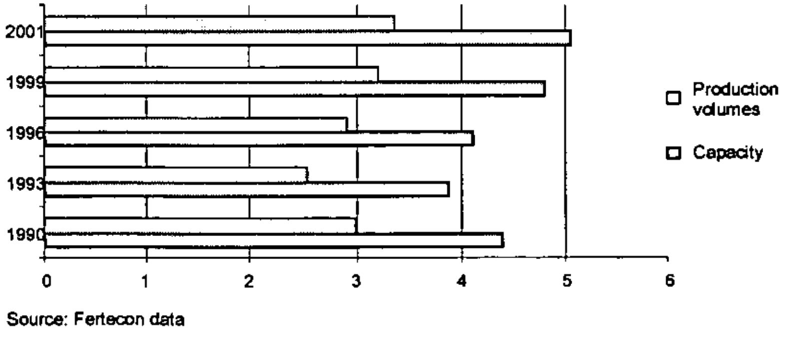


Fig. 5. World capacities vs. production volumes of potassium sulphate in 1990, 1993, 1996, 1999 and 2001 (Mt product).

More than a half of world potassium sulphate production is concentrated in *West Europe* (55%), *Asia* (19%) and *North America* (17%) (Fig. 6).

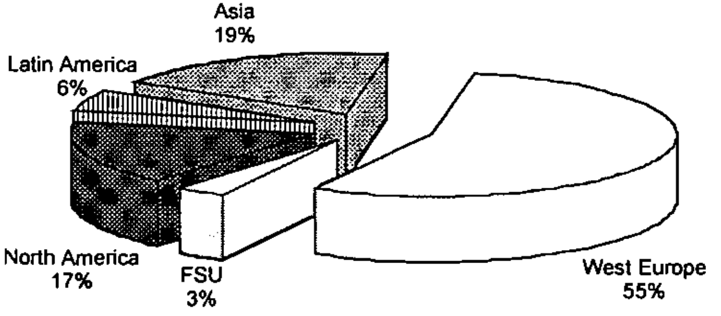
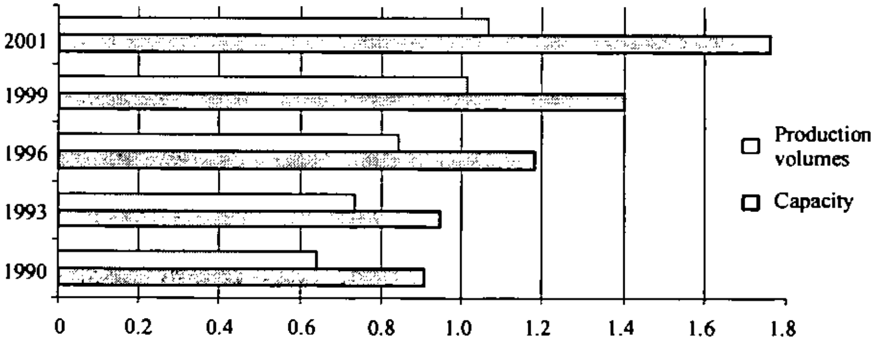


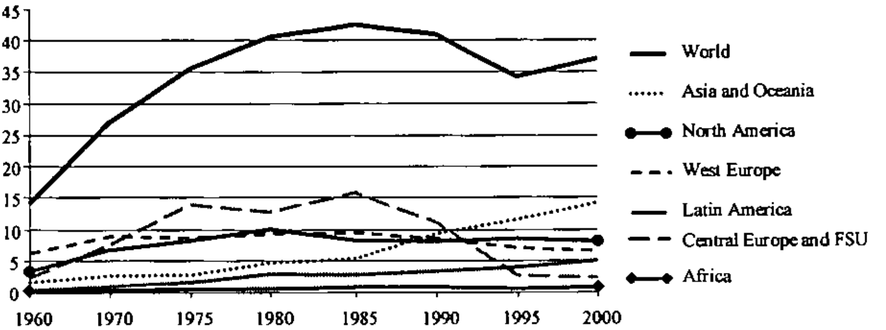
Fig. 6. World production of potassium sulphate by region in 2001 (Source: Fertecon statistics).

Potassium nitrate provides plants with both potassium and nitrogen as nitrate, while its high solubility makes it very suitable for application in irrigation systems. The world potassium nitrate industry consists of 12 producers in several countries with an aggregate capacity amounting to 1.7 Mt of product. Though potassium nitrate has shown a continuous growth both on capacity and production over the last 10 years we should have in mind that the physical volume increased by only 0.4 Mt of product between 1990 and 2001 (Fig. 7).



Source: CRU data

Fig. 7. World capacities vs. production volumes of potassium nitrate in 1990, 1993, 1996, 1999 and 2001 (Mt product).



Source: IFA statistics

Fig. 11. World potassium chloride consumption by region in 1960-2000 (Mt product).

Potash consumption in *West Europe* and *North America* is relatively stable and is not expected to increase greatly as the input of potash fertilizers has already achieved high levels in these regions.

The situation in developing countries is different. On the one hand, countries such as *China* and *India* with a large population are significant consumers of potash fertilizers. These markets are relatively strong though the rate of growth in potash consumption is moderate due to economic constraints. Nevertheless, we expect to see an increased demand in these countries in future.

On the other hand, a number of Asian countries like *Vietnam, Indonesia and Malaysia* are constantly increasing their potash consumption in order to improve their agricultural production. As the greater part of the production is exported, farmers get the financial means to invest in the acquisition of potash fertilizers. Thus, the potash consumption in these countries depends largely on the situation of the world agricultural commodity market.

Latin America is one of the biggest importers of potash fertilizers. As Latin America is a major producer of export crops like soybean, sugarcane, coffee and bananas the development of potash demand there depends highly on the situation on the world market of agricultural commodities. The major potash consuming country in this region is *Brazil*.

To my regret, lack of finance impedes growth of potash consumption in *Central Europe, the FSU and Africa,* which currently demonstrate the lowest level of demand for potash in the world.

As mentioned above, potassium chloride is the most widespread type of potash fertilizer supplying 91% of the total world's requirements. The balance is met by the non-chloride potash products with potassium sulphate and potassium nitrate being most important.

The world demand for potassium sulphate has remained stable in the last five years (Fig. 12), which was mainly due to an expansion of the fruit and vegetable acreage in such developing countries as *China and Brazil*. But we believe that the growing demand will only partially absorb the excessive volumes coming from the new capacities registered in *Asia and Latin America*. Furthermore, a massive reduction of the acreage devoted to tobacco in the key growing countries since 1997, could lead to a decline of demand for potassium sulphate as tobacco growing is one of the most significant consumers of this potash fertilizer.

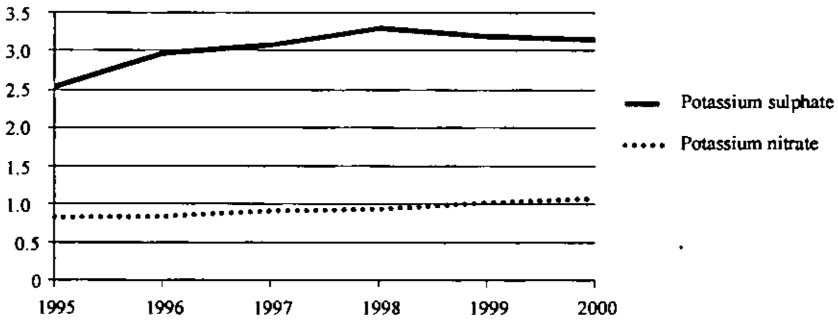


Fig. 12. World consumption of potassium sulphate and potassium nitrate in 1995-2000 (Mt product).

While the demand for potassium nitrate in *West Europe and North America* is relatively stable such regions as *Latin America, Asia and Oceania* have shown a considerable increase in potassium nitrate consumption in the last five years, which is mostly due to its use in the production of complex NPK and bulk-blending mixtures as well as development of irrigation systems in these regions. Nevertheless, the high production cost of potassium nitrate makes it less attractive for farmers who prefer to use less expensive potash fertilizers like potassium chloride or potassium sulphate.

Trends in world and regional supply and demand for major potash fertilizers

It is common knowledge (regretfully, not often used in practice) that balanced fertilization is necessary. Plants are like people: a balanced diet is needed and it is not enough to eat a surplus of one kind of food. But a widespread tendency for farmers is to use a reasonable amount of nitrogen and low or no potassium and phosphorus, which leads to an imbalance in crop nutrient availability in soil and affects crop yields. A small application rate of potash does not meet crops' requirements leaving a huge gap between the input level of nitrogen and phosphorus and the existing use of potash fertilizers, especially in regions like *Africa, Central Europe and FSU* as well as *Asia* (Fig. 13).

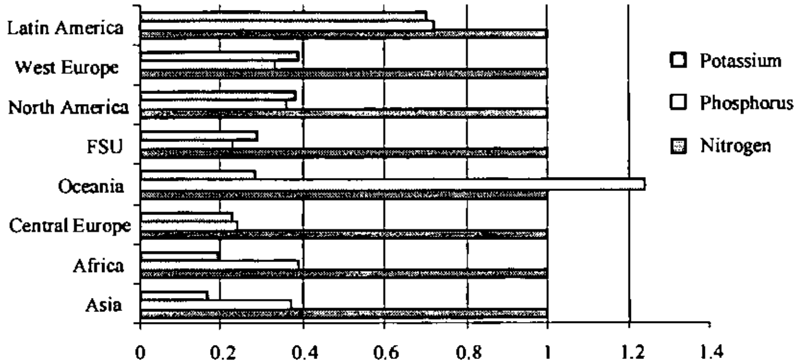


Fig. 13. Fertilizer NPK ratio by region (Source: FAO data).

There is a major difference between the major potash fertilizer producers in the proportion of the product consumed at home or exported. This is because there are only a few major producing countries and countries without a potash industry have to import. Thus, while the domestic market absorbs about 55-65% of the production volumes of the *Canadian and German producers* the potash producers in *Russia* plus *Belarus, Israel and Jordan* are obliged to export the larger part or 83-95% of their production due to a low domestic demand (Fig. 14).

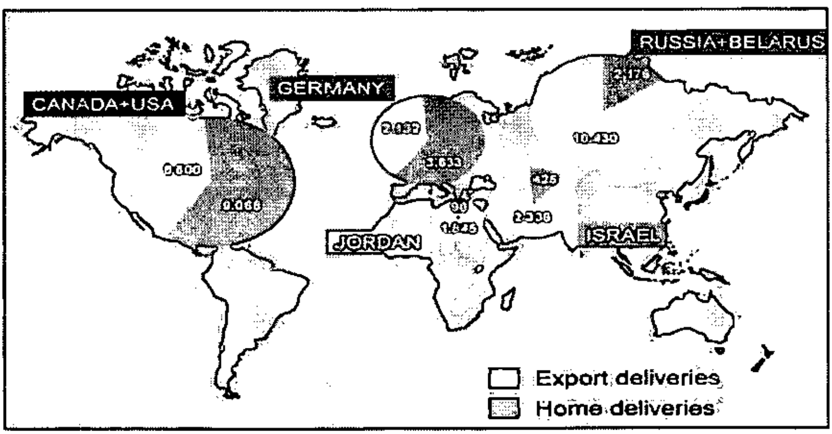
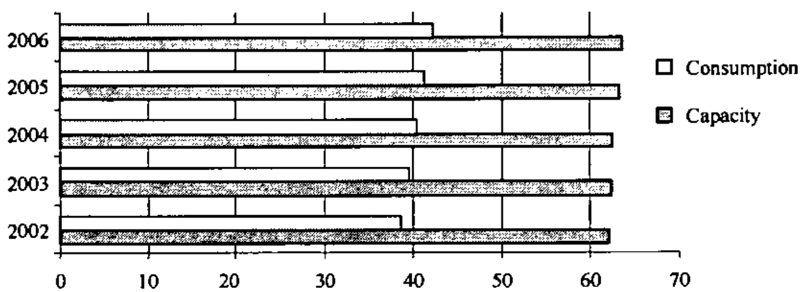


Fig. 14. Home and export deliveries by major potash producers in 2001 ('000 metric t) (Source: IFA statistics).

How do we estimate the outlook for regional potash supply and demand within the next five years? A capacity survey for the medium term till 2006 shows a modest increase of primary potash production capacities by 2% annually with over-capacities declining from 11.3 Mt of product in 2002 to 8.8 Mt in 2006. Though the world potash situation continues to be affected by a large capacity surplus, the world potash market is stable as the major producers continue to adjust regularly their production volumes to match the existing demand. The capacity reserves allow the suppliers to respond with flexibility to fluctuations in the world potash market.

On the other hand, according to IFA estimates, world fertilizer demand is projected to increase gradually in the medium term amounting to about 155 Mt by 2006, an increase of close to 17 Mt nutrients compared with 2001, with the potash demand growing at an annual rate of 2.3% to reach 42.1 Mt of product by 2006 (Fig. 15). Most of the increase is expected to occur in *Asia, Latin America as well as Central Europe and the FSU.*



Source: IFA forecast

Fig. 15. Outlook for world production capacities and consumption of major potash fertilizers in 2002-2006 (Mt product).

Conclusion

In summary, we expect that the main increase in world potash production capacity is likely to occur in *China, Jordan and Brazil* with the total world capacity increasing by 2006 to 63.5 Mt of product or by 2% in comparison with 2002. The future of the potash projects in *Thailand* is still unclear and, according to some experts, production is unlikely to begin before 2007 with other projects also being unlikely as the world potash situation continues to be affected by a large global capacity surplus and production must regularly be adjusted to demand. The main factors defining the world potash consumption will be growth of population, agricultural policies in major consuming countries, world and regional economic development and financial condition of agricultural producers. Increased use rates might be achieved if consumers aim at balanced fertilization and try to overcome the current potash deficit in soils. We do hope that this Congress, along with other IPI activities, will contribute to the global promotion of potash use as the existing production capacities are sufficient to satisfy any future demand for potash fertilizers in the world.

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Potassium in soils: Current concepts

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Abstract

Several comprehensive studies over the years have given us a good conceptual understanding of potassium (K) forms in soils and their availability to plants. However, the precision and consistency with which soil K forms and their availability have been described, particularly recently, is poor, leading to confusion. In this paper a modified K cycle is presented, which is unambiguous with regard to the form of K and its availability to plants.

Four forms of soil K are recognized in this modified K cycle, namely (i) soil solution K, (ii) structural K, (iii) exchangeable K (EK), and (iv) slowly exchangeable K (SEK). From a practical and certainly a quantitative standpoint, only the last two forms are considered to be important. There is controversy surrounding the suitability of EK as a measure of plant-available K in soils. Although widely used, there is abundant evidence to show that it can be unsatisfactory for soils that contain 2:1 layer silicates and have the ability to retain K, for example flooded soils used for rice production. Slowly exchangeable K is retained at wedge sites occurring in weathered micaceous minerals. There is strong evidence for the importance of SEK in many soils and its availability to plants but our inability to determine SEK on a routine basis has largely limited development of a better understanding of its role in crop production. Thus, it is suggested that we have lost sight of the importance of this form of soil K and it may be timely to re-evaluate its significance, involving a revisit of the early literature and the conduct of new work to address the critical issues relating to SEK. A case is made for including an estimate of SEK in calculating soil K stocks to not only improve the precision of K fertilizer recommendations but also predictions of the impact of K depletion on soil K status.

Introduction

Compared to the chemistry of nitrogen (N) and phosphorus (P) in soils, that of potassium (K) is comparatively simple (Syers, 1998). The main reason for this is that K exists predominantly as K ions (K^+), which have a high electropositivity and thus a very weak tendency to form covalent bonds; as a consequence, K does not enter into organic combination to any meaningful extent.

The forms of K in soils have been studied extensively over the years (e.g., Arnold, 1970; Munson, 1985; Sparks, 1987) and it would be fair to say that we have a good conceptual understanding of K forms in soils and their availability to plants. What has occurred more recently, and this seems to have been associated with the increasing involvement of non-specialists, is a progressive deterioration in the precision and consistency with which soil K forms have been described, often causing confusion.

Some 18 years ago, in discussing the dynamics of K in the soil-plant system, Grimme (1985) commented on the liberal use of vague terms such as available K, K availability and K status, and on the fact that they are often used interchangeably, even though they have different meanings. A similar situation exists for the forms of K in soils and as suggested by Syers (1998), it may be timely to re-evaluate the terminology for soil K forms and to integrate this with assessments of plant availability.

This paper briefly considers current concepts of the forms of K in soils and their plant availability, using the K cycle as a conceptual framework. A modified soil K cycle is presented, which is unambiguous with respect to (i) the form of K and (ii) the relative plant availability of each K form. The origin, determination, and importance of slowly exchangeable K (SEK) in soils and the possibility of including estimates of SEK in assessments of K depletion and its impact on soil K status, are also discussed.

The soil potassium cycle

The soil K cycle developed is shown in Fig. 1. This cycle is not original in that several parts of it have been published before (e.g., Kirkman *et al.*, 1994; Syers, 1998; Johnston *et al.*, 2001) but it is different in that the terminology is unambiguous and consistent.

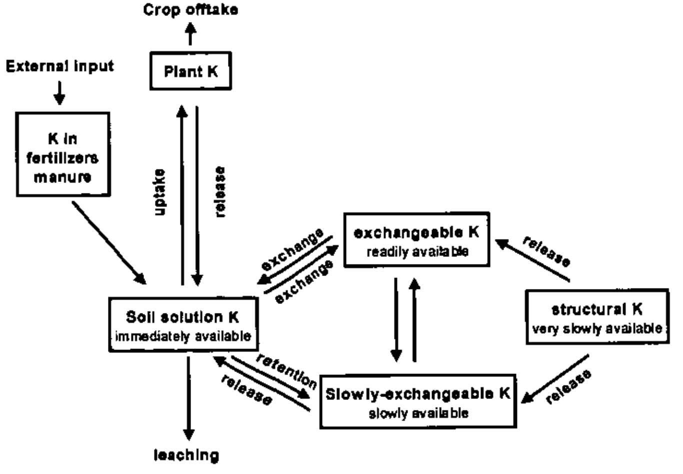

Fig. 1. A modified K cycle for soils.

Four forms of soil K are recognized in this K cycle. These forms and their relative, qualitative plant availability are summarized in Fig. 2. Plant availability increases from bottom to top in the right-hand side of the figure, consistent with an increase in the physical accessibility and chemical reactivity of the K form, shown in the left-hand side of the figure. For ease of presentation in this paper, the four K forms are discussed in the sequence (i) soil solution K, (ii) structural K, (iii) exchangeable K (EK), and (iv) slowly exchangeable K (SEK).

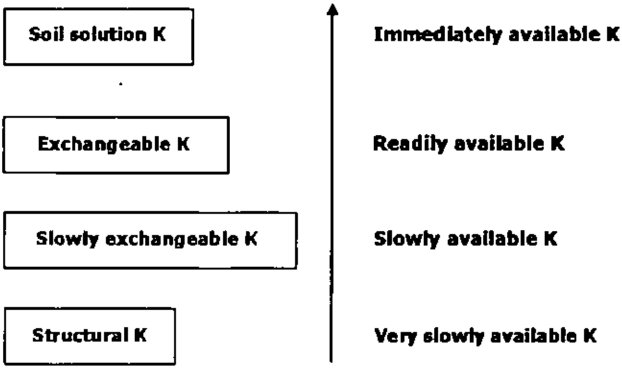

Fig. 2. Four forms of soil K and their relative plant availability.

Soil solution potassium

Potassium ions (K^+) in the soil solution are immediately available to plants. Plant roots take up K^+ and this becomes Plant K in the K cycle (Fig. 1). The concentration of soil solution K^+ can vary appreciably with previous fertilizer and manure applications, and with cropping history. Regardless, the amounts present are always insufficient to meet crop needs, with approximately 5% of the K requirement being in solution at any one time (McLean and Watson, 1985). As pointed out by Johnston and Goulding (1990), however, an estimate of water-soluble K gives no indication of the rate at which K is replenished in the soil solution from soil components. Although vitally important as a pathway for K uptake by plant roots and as the central point in the K cycle (Fig. 1), from a practical standpoint and certainly quantitatively, in terms of crop requirement, soil solution K can probably be ignored. This may appear heretical but the objective in the present paper is to simplify, rather than complicate with unnecessary detail.

Structural potassium

It is not easy to obtain reliable information on the likely importance of the very slowly available K present in the structure or lattice of feldspathic and micaceous minerals in soils. Johnston (1986) presented data, which suggest that between 8 and 47 kg K ha^{-1} was removed by crops from several soils that have not received fertilizer or manure K. These results clearly indicate that structural K can be a source of K for crop growth. However, because most cultivated soils have received fertilizer and manure, forms of soil K other than structural K are likely to dominate K supply to crops (Syers, 1998). From a practical standpoint, structural K can also be ignored.

Exchangeable potassium

Positively-charged K ions can be retained by negatively-charged sites on soil components, particularly on clay minerals and organic matter; this form of K is referred to as EK. The EK fraction is operationally defined as that K which will exchange with an excess of ammonium ions; EK is in rapid equilibrium with soil solution K and is considered to be readily available to plants. In the absence of significant quantities of SEK (discussed below), EK is the predominant source of plant-available K in soils. In such situations, EK is a useful indicator of soil K status and the likelihood of obtaining a response to fertilizer K addition. This is the case for many soils in the UK (Syers, 1998) but interpretations are likely to be soil type specific. For a single soil, the relationship between crop yield and the amounts of exchangeable K can be very close, as shown by the unpublished data of Poulton and Johnston for the yield of winter wheat grain on the Exhaustion Land experiment at Rothamsted Research (Fig. 3). However, much of the reported information for the UK appears to be for single soils or for a rather narrow range of soils and this may influence the conclusion reached as to usefulness of EK.

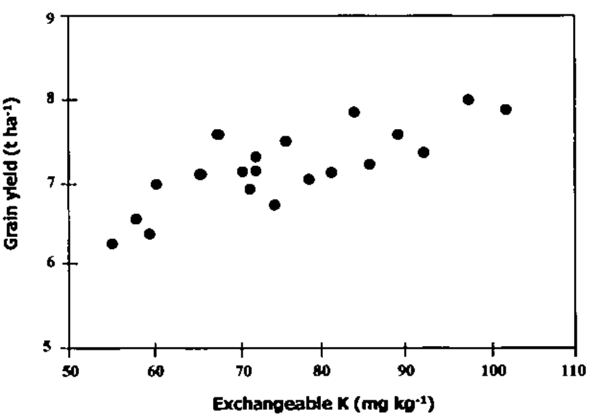

Fig. 3. Relationship between yield of winter wheat grain and exchangeable K in soil on the Exhaustion Land at Rothamsted Research, UK (unpublished data of Poulton and Johnston, used previously by Syers, 1998).

Experience in the USA has been rather different where '... response predictions, using exchangeable K, were wrong about as often as they were right' (Shen and Stucki, 1994). The apparent failure, in some situations, of EK to predict soil K availability or the likelihood of obtaining responses to K fertilizer addition (several such studies are referred to by Eckert (1994), coupled with an interest in improving the precision of K fertilizer recommendations, has largely been responsible for attempts to develop alternative procedures for conducting and interpreting soil tests for available K. However, there are numerous studies in the USA where EK has shown a very good correlation with crop yield (Doll and Lucas, 1973) and the reality is that none of the 'improved' methods appear to have found application in soil testing laboratories. Nevertheless, the suitability of EK as a measure of plant available K remains controversial (Doberman *et al.*, 1996), particularly when soils of different clay content and mineralogical composition are considered together.

The work of Doberman *et al.* (A. Doberman, 2002, unpublished results) for 153 rice farms in seven regions of five countries (China, India, Indonesia, Philippines, and Vietnam) showed no relationship between grain yield and soil EK, and between K uptake by the crop and soil EK, with R^2 values of less than 0.1 in each case (Fig. 4). There could be several reasons for this lack of relationship, including contributions from forms of K other than EK and a decreased availability of K due to the increase in negative charge (and increased retention of K) following flooding (A. Doberman, personal communication), because of the reduction of structural Fe, from Fe^{3+} to Fe^{2+}. It appears that EK has major limitations for predicting grain yield and K uptake on these and perhaps other flooded soils used for rice production.

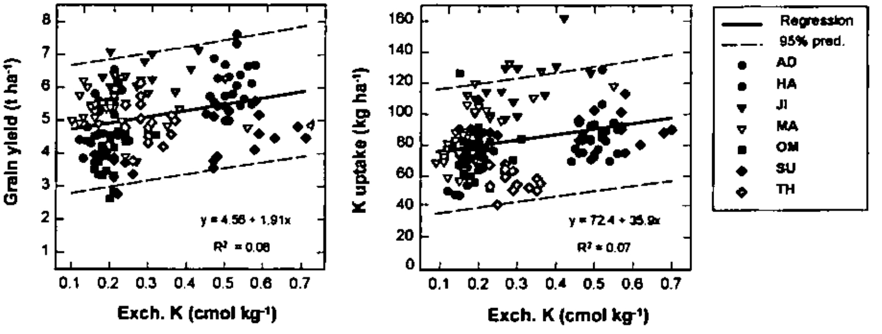

Fig. 4. Relationship between yield of rice grain and soil exchangeable K, and K uptake and soil exchangeable K for 152 rice farms in seven regions of five countries in Asia (unpublished data of Doberman *et al.*, 2002).

Slowly exchangeable potassium

This form of soil K is associated with adsorption sites in micaceous clay minerals which are selective for K^+. These so-called wedge sites, illustrated in Fig. 5, are created as micas weather and partially-expanded (illites) or expanded interlayers (vermiculites) are formed. Wedge sites are primarily responsible for K retention in soils, giving rise to what is usually referred to as 'fixed K.' The term SEK is preferred to fixed K because there is much evidence that added K, which cannot be determined as EK, can be released for crop uptake.

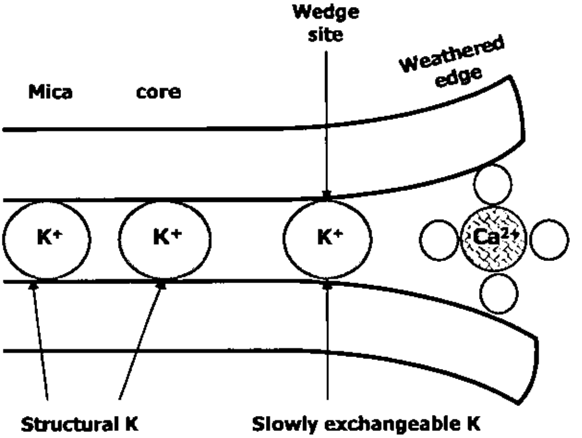

Fig. 5. Occurrence of slowly exchangeable K at a wedge site in a weathered micaceous clay (modified from Rich, 1968).

The retention of K by soils and soil components has been studied extensively, as have possible methodologies for determining SEK (Sparks, 1987; Syers, 1998). Whereas SEK is easy to define and conceptualise, it is more difficult to determine routinely, there being no rapid laboratory method for determining SEK; herein lies the main reason why SEK has not found wide acceptance in routine soil analysis. Extraction of SEK with boiling nitric acid, cation-exchange resins, electro-ultrafiltration, sodium tetraphenyl boron, and by exhaustive cropping have been used (Syers, 1998), but they are all time consuming, particularly the last-named procedure. Also, estimation of the likely contribution of SEK to plant available K in different soils is complicated by the widely different rates of K release which can occur, as shown by results for the release of K over varying periods of time from six soils from the South Pacific (including four from Fiji) to 10^{-3} M HCl containing a H-saturated cation-exchange resin (Tuivavalagi *et al.*, 1996). The release of K from these soils varied by a factor of 66 and there was no relationship between the amount of exchangeable K in the soil and the amount of K released over a given period of time. It was concluded that EK values were of limited value in assessing the capacity of these soils to supply K for sugarcane, consistent with the finding that in some sugarcane areas of Fiji, soil analyses for EK suggest K deficiency, while the sugarcane plants do not show K deficiency symptoms and do not respond to the addition of K fertilizer. The results clearly point to the importance of SEK for plant growth in these soils.

There is abundant evidence in the literature for the importance of SEK in soils and its availability to plants, particularly in the 'older' literature (reviewed, *inter alia,* by Doll and Lucas, 1974; McLean and Watson, 1985). More recently, Doberman *et al.* (1996) have presented interesting data which illustrate the effect of the cation-exchange capacity (CEC) of the clay fraction (usually a good indicator of mineralogical composition) on plant uptake of K by rice in seven-long term field experiments from Asia (Fig. 6). In two soils from China (the Shipai and Jinxian sites) there was a good relationship (r^2=0.75) between K uptake by the plant and K saturation of the soil exchange complex, essentially a read-out on the amount of EK, for soils having low CEC clay fractions, i.e., containing predominantly 1:1 layer silicates. In contrast, for five other soils (two from the Philippines, two from Indonesia, and one from India), which had a high CEC for the clay fraction (>40 $cmol_c\ kg^{-1}$), there was little or no relationship between K uptake by the plant and K saturation, because of the presence of layer silicate minerals able to retain K in non-exchangeable forms. This indicates that EK is unsuitable as a single indicator of soil K status and points to the importance of SEK in supplying plant K in the case of the high CEC soils. In this context, it is important to remember that many rice soils contain 2:1 layer silicates that have the ability to retain K. Doberman *et al.* (1996) concluded that, although extractable soil K (solution + EK) is still the most widely-used measure of available K for rice soils, its suitability is controversial and its reliability unsatisfactory.

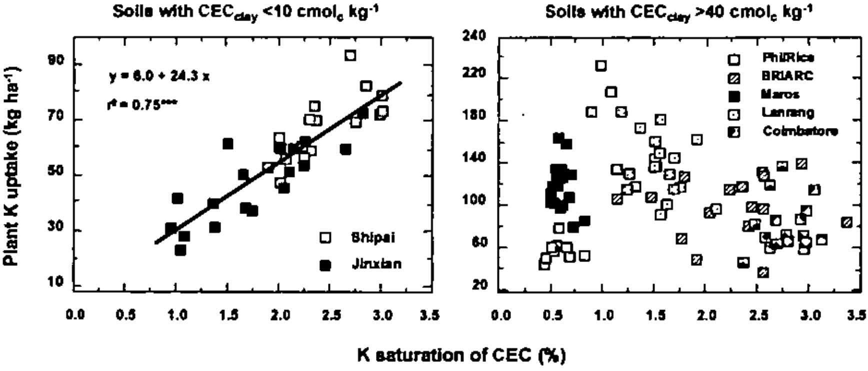

Fig. 6. Effect of CEC of the clay fraction on the relationship between K uptake by rice and K saturation of the CEC of the soil (from Doberman *et al.*, 1996).

It is of interest to consider why there appears to have been a declining interest in the likely contribution of SEK to plant K in different soils. Certainly, difficulties with methodology are one issue limiting a more widespread use of SEK in assessing available K in soils, as outlined in this paper. Also, for agricultural soils in Europe, for example, EK levels can usually be topped up readily by the use of relatively inexpensive K fertilizer and thus a knowledge of reserves of SEK and its rate of release to plants is less important than where K fertilizer is less readily available (Syers, 1998). For such soils, EK is likely to provide a reasonable estimate of soil available K. However, there are many soils where SEK seems to play an important role in meeting plant K requirements, such as rice soils in Asia (Doberman *et al.*, 1996) and some of those studied in the earlier literature (Doll and Lucas, 1974; McLean and Watson, 1985). It may be timely to revisit this earlier literature and plan new work using our improved understanding of K dynamics in soils. Certainly, the accumulation of SEK should be seen as advantageous in that K retained in this way can reduce K leaching losses and maintain K in a slowly exchangeable form. The extent to which SEK can act as an important and dynamic buffer for available K in different soils requires further evaluation.

Assessing potassium stocks in soils and the impact of potassium depletion on soil potassium status

To asses the impact of K depletion rate on soil K status it is necessary to take into account the reserves or stocks of K (Syers *et al.*, 2002). This is illustrated in Fig. 7 for two hypothetical soils, which have the same rate of K depletion because the slopes of the two lines relating soil K stock with time are the same. The impact of the rate of K depletion on soil K status is much larger in soil B, which has a lower (but not K limiting) opening stock, but will become K limiting over the time period considered, whereas soil A does not. This indicates that information on K depletion rate alone is insufficient to determine whether or not a soil will become K deficient.

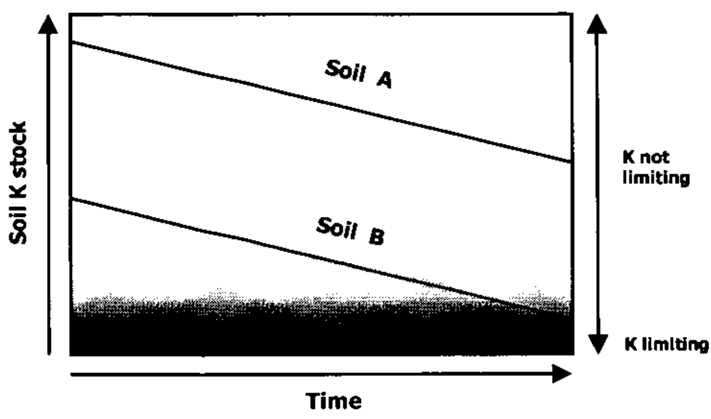

Fig. 7. Impact of initial soil K stock on K limitation over time in two soils with the same rate of K depletion (from Syers *et al.*, 2002).

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Potassium nutrition and crop yield and quality

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Abstract

The dominant mechanism of facilitating K acquisition by plants in response to a low soil K status is to enhance net K influx rate per unit length of roots. No consistent relationship exists between the efficiency of K acquisition and the efficiency of K use in the plant. In many situations, more K fertilizer needs to be applied than is used at present just to replace that removed by the current larger yielding crops and K fertilization should be related to a long-term soil nutrient management policy. Sufficient K fertilization may directly improve crop quality traits, particularly controlled by recessive genes and/or under environmental stress condition. It may also improve crop qualities indirectly by preventing disease infection and controlling of some secondary metabolites in the harvested produce. Understanding the molecular basis and physiological functions of active and passive K transporters in plants has increased enormously in the past decade. However, the physiological functions of K transporters in *planta* need to be elucidated further in relation to the efficiency of K acquisition by roots. Over-expression of *McHAK* and/or inactivation of *AtHKT* genes might be one of the molecular approaches in enhancing crop salt tolerance, thus, increasing the ability to use potassium chloride as a source of K under saline soil condition.

Introduction

Usually present at concentrations on the order of 100 mM in the cells of plants well supplied with potassium (K), K has a number of central roles in promoting plant growth, development and quality, including the maintenance of turgor pressure, leaf and stomatal movements and cell elongation. Potassium has also been described as the "quality element" for crop production (Kafkafi *et al.*, 2001). The essential requirement for K appears to relate to its role as an activator of biochemical processes in the cytosol, particularly protein synthesis (Walker *et al.*, 1998; Leigh, 2001). Its abundance contributes to the electrolyte character of cytoplasm and affects electrostatic interactions between charged entities such as proteins and other biopolymers. The transport of K helps set the electric potential difference across the plasma membrane, which powers the transport of other substances (Maathuis and

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Sanders, 1997). The advancement of characterization of K transporter gene products and identification of their physiological roles in *planta* in the past decade has opened up important new avenues for research on plant K nutrition. This paper will review regulation of K uptake and utilization, discuss current K fertilization for large crop yields and genetically controlled quality, and briefly introduce physiological roles of K transporters in relation to K nutrition and salt tolerance of plants.

Regulation of potassium uptake and utilization

Efficiency of potassium acquisition and utilization

Physiological and morphological mechanisms in facilitating potassium acquisition

Plants have evolved morphological and physiological mechanisms to facilitate K uptake when grown under low K status conditions. Uptake of K by tomato roots was enhanced by temporary removal of the K supply (Fig. 1). Cultivars with a high efficiency for K acquisition have a high net K influx rate by their roots and/or a large root to shoot ratio (Fig. 2 and Table 1).

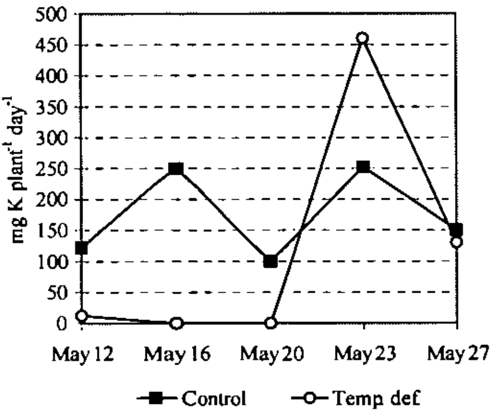

Fig. 1. Comparison of K uptake rate of tomato plants supplied continuously with K and temporarily without K for eight days (Source: Pujos and Morard, 1997).

Chen and Gabelman (1995; 2000) found that among 22 tomato strains with a high K-acquisition efficiency, 18 strains had a high K-influx rate but only four strains had large root lengths. Trehan and Sharma (2002) reported that high K-uptake efficiency of potato cv. *Kufri Chandramukhi* was due to its high K-influx while low K uptake efficiency of cv. *K. Badshah* and cv. *K. Jyoti* was due to a low K-influx which nullified the effect of their large root-shoot ratio.

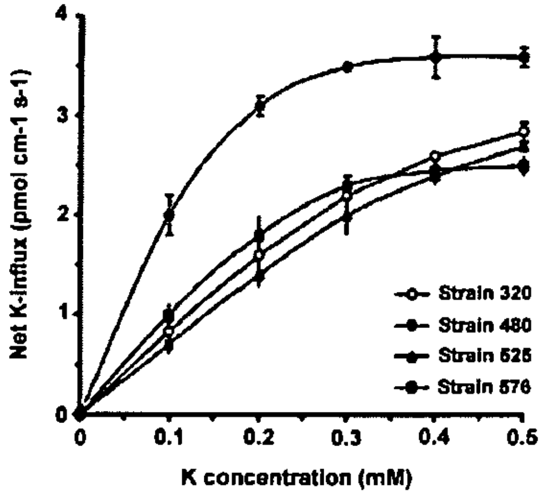

Fig. 2. Average net K-influx rate per unit root length during the third week after seedling emergence as a function of various K concentrations in a sand-zeolite medium. Bars represent standard errors of six replicates. Root length of the strain 320, 525, 480 and 576 was 18.19, 19.14, 19.90 and 45.39 m $plant^{-1}$, respectively. There was no difference of root radius. Therefore 480 and 576 are two strains associated with high K-acquisition efficiency with dominant mechanisms of high K absorption capacity and root length proliferation, respectively (Source: Chen and Gabelman, 2000).

Table 1. The kinetic characteristics of K uptake for three different rice cultivars (Source: Chen *et al.*, 1997).

Cultivar	K uptake capacity	Root length cm $plant^{-1}$	F_{max} $\times10^{12}$ $mol cm^{-2} sec^{-1}$	K_m $\times10^{5}$ $mol L^{-1}$	C_{min} $\times10^{5}$ $mol L^{-1}$
Shanyou64	Strong	125	4.68	4.60	1.28
Tuanji1	Moderate	51	4.58	6.91	4.66
Zhongguo91	Weak	43	2.96	10.50	7.67

The cultivar *K. Chandramukhi* utilized more K from non-exchangeable K in the soil (46%) than did *K. Jyoti* (25%) or *K. Badshah* (17%). Unlike the plant's response to drought stress and P deficiency, namely raising the root-shoot ratio, K deficiency does not affect or even reduce the root-shoot ratio (Table 2). Adequate K nutrition increased root longevity and survival under drought stress, thus improving plant drought resistance (Egilla *et al.*, 2001).

Table 2. Effects of K supply levels on root to shoot ratio of *Hibiscus rosa-sinensis* L. cv. Leprechaum, grown under drought stressed and non-drought stressed conditions (Source: Egilla *et al.*, 2001).

K, mM	Root/Shoot (gDM/gDM)	
	Drought stress	Non-drought stress
0	0.083	0.040
2.5	0.104	0.067
10	0.114	0.061
Source	Prob. > F	
Drought	0.0001	
K	0.0001	
Drought × K	Not significant	

Genotype variation in utilization efficiency of potassium

Nutrient use efficiency is related to the ability of a plant to produce the maximum amount of dry matter for each increment of nutrient accumulated. For 84 genotypes of sweet potato (*Ipomoea batatas* L.), the root K efficiency ratio, i.e, tuberous root yield produced by per unit of K in the whole plant, ranged from 41 to 131 g DW g^{-1} K (George *et al.*, 2002). Highly significant effects of applied K and genotype and their interaction on tuber yield were observed among the genotypes. The whole biomass of tomato seedlings K use efficiency ratio varied between 36.1 and 50.6 g DW g^{-1} K when the K supply was 0.25 mM, and between 23.9 and 40.6 g DW g^{-1} K when the K supply was 1.0 mM (Chen and Gabelman, 1995; 2000). No consistent relationship was found between the K acquisition efficiency and K use efficiency among 22 tomato strains.

Interaction of ammonium and potassium uptake

The physical properties of K and NH_4 in terms of charge and hydrated diameter, as well as their effects on membrane electrical potential and proton extrusion are quite similar (Wang *et al.*, 1996). Many results on the interaction of K and NH_4 in plants, however, are contradictory because in some cases high NH_4 concentration in the nutrient solution inhibited plant growth, thus reduced total K uptake (Xu *et al.*, 2002b). These authors observed that the effect of NH_4 in the culture solution on the utilization of K by sweet pepper plants depended on both the NH_4 and K concentration (Fig. 3). Partial replacement of nitrate in the culture solution by NH_4 stimulated the growth of sweet pepper, and thus increased total K uptake (Xu *et al.*, 2002b). Similar results were also observed for rice cultivated in dryland soil (Xu, personal communication). A functional study of K channels in *Arabidopsis* mutants revealed that external NH_4 inhibits uptake pathway of AKT1, but not of AKT2 (Dennison *et al.*, 2001).

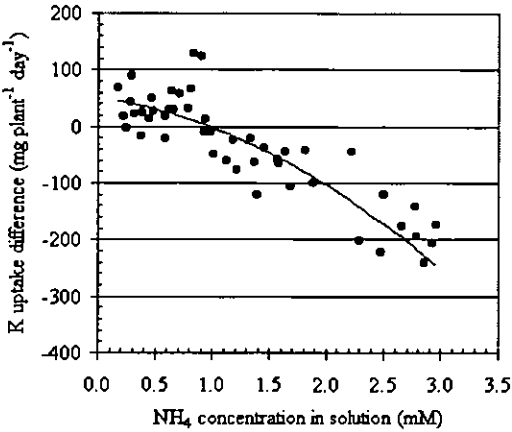

Fig. 3. Difference of K uptake of sweet pepper plants grown in solution culture with either NH_4NO_3 or only NO_3 as the source of nitrogen (Source: based on Xu *et al.*, 2002b).

Potassium fertilization for high crop yield

Potassium nutrition and plant photosynthesis and respiration

Potassium deficiency results in reduced rates of net photosynthesis and translocation of assimilates (Huber 1984; Gupta *et al.*, 1989), which is attributed to many factors, such as an increase in leaf mesophyll and stomatal resistance (Bednarz *et al.*, 1998), an increase of dark respiration (Okamoto, 1969; Peoples and Koch, 1979), and a decrease of leaf transpiration rates (Huber, 1984). The extent to which these factors affect photosynthesis depends on the severity of K deficiency and plant type. Gupta *et al.* (1989) concluded that the bulk of the protective effect of K on photosynthesis in water stressed wheat plants was not by reducing stomatal resistance, but due to an altered cell volume/water potential relationship. Bednarz *et al.* (1998) suggested that the initial decrease in net photosynthesis in cotton resulted from an increase in stomatal resistance with slight K deficiency. When K deficiency becomes more acute, biochemical factors, i.e. decreasing carboxylation efficiency and increasing CO_2 compensation, also contribute to the decrease in net photosynthesis.

Potassium disorder caused by imbalance between source and sink

Because K has a very high mobility in the phloem within a plant, visual symptoms of deficiency would be expected always on the older leaves. If K deficiency is not transient but becomes permanent, the leaves wither and die from the bottom to the top of the plant and the end result is plant death. However, in senescing organs and aged leaves, K is less available for mobilization to the benefit of the actively growing organs (Pujos and Morard, 1997). Under K deficiency, K will be mobilized preferentially from the adult leaves where the first visual symptoms of deficiency will appear. For cotton grown in K rich soil, an unusual disorder called premature leaf senescence, i.e. young leaves with the disorder turn red during boll filling and shed much earlier than is normally observed (Wright, 1999), which is very similar with the late season K deficiency that occurs on strongly K fixing soils (Bednarz and Oosterhuis, 1996). This disorder has now been confirmed as predominantly due to an imbalance between source and sink K (Wright, 1999). The likely explanation is that newer, high yielding cotton cultivars create a very high demand for K (and other nutrients) inducing a K-based problem that appears late in the growing season (Bednarz and Oosterhuis, 1996). The boll load of cotton induced the most striking difference in K composition compared to all the other nutrients between plants with and without the symptoms (Wright, 1999).

Potassium fertilization for crop quality

Potassium requirement for crop quality

The positive effects of applying K on crop quality have been reviewed by Kafkafi *et al.* (2001 and references therein). Potassium fertilization may also improve crop quality indirectly by minimizing diseases. For tomatoes, the exchangeable $K/(Mg)^{1/2}$ ratio was the measure of soil K availability that was most closely correlated with percentage of total color disorders (yellow shoulder plus internal white tissue) (Hartz *et al.*, 1999). Soil application of either K or gypsum ($CaSO_4$) to increase the $K/(Mg)^{1/2}$ ratio reduced yellow shoulder and total color disorders. Because quality varies with the crop, the part to be marketed and the intended use, standards for comparison are needed to evaluate the role of K on quality. Often the amount of K required for optimum yield is also sufficient to secure good quality (Usherwood, 1985). However, the need for K in relation to fruit quality, as in citrus (Koo, 1985), is probably more critical than other aspects of yield. In certain crops, such as tobacco (Colyer and Pohlman, 1971) and tea (Ruan *et al.*, 1999), quality is more important than yield to secure the best financial return. In such cases, more K is needed to ensure quality than is needed for maximum yield.

Recent reports have shown that improvements in some quality traits are unlikely to be gained from increasing the amount of K applied to many crops already adequately supplied with this nutrient. Razmjoo and Kaneko (1993) concluded that for turf-type perennial ryegrass during the winter there were no beneficial effects of K application on turf density, color, growth, and winter hardiness beyond an optimum rate (350 kg K ha^{-1}). Soil application of K_2SO_4 in pear orchards reduced the starch content of the fruit suggesting an advanced state of maturity, but, this was contradicted by the lower soluble solids content and greater firmness of K-rich fruits at harvest (Johnson *et al.*, 1998). An excess concentration of K in sugar beet decreases the amount of sugar crystallized from the extracted juice. However, % K was not greatly affected by large applications of fertilizer K to the sugar but crop was strongly influenced by long-established differences in soil exchangeable K due to soil type, previous cropping and manuring history (Milford *et al.*, 2000). The asymptotic relationship between beet K (kg ha^{-1}) and yield implies that, in many situations, the processing quality of the beet could be improved by increasing yield through better agronomy.

Potassium nutrition and quality traits of seeds

To ensure that narrow-leafed lupin (*Lupinus angustifolius* L.) meets feed quality standards, the concentration of alkaloids must be kept under the maximum acceptable limit of 200 mg kg^{-1} DM (Gremigni *et al.*, 2001). It is very interesting that severe K deficiency resulted in an increase in seed alkaloid concentrations by 205-400% in sweet varieties containing the recessive alkaloid gene (Fig. 4). The amount of K fertilizer required for maximum seed yield and for minimum concentration of alkaloids was 90 and 360 kg K ha^{-1}, respectively. The concentration of alkaloids in a bitter variety (Fest) containing a dominant alkaloids gene was always high regardless of the soil K status. These findings highlighted the need for adequate K fertilization to avoid the risk of producing low quality seeds of sweet lupin varieties with high alkaloid concentrations, especially under climate stress condition (Gremigni *et al.*, 2001).

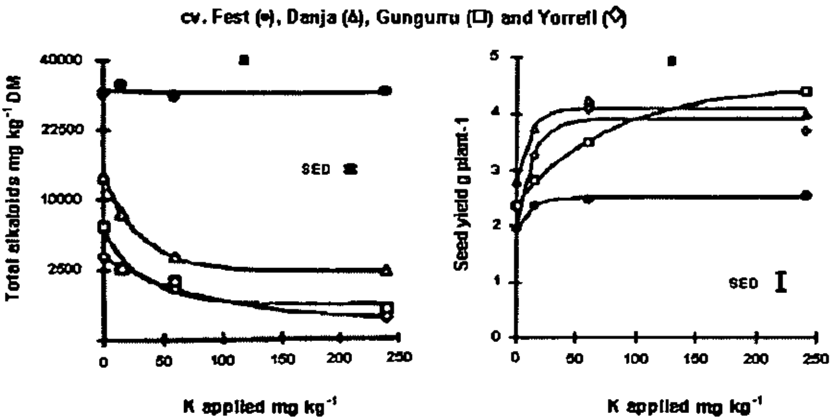

Fig. 4. K nutrition effects on seed yield and total alkaloid concentrations of lupins (*Lupinus angustifolius*) grown in a glasshouse. A low alkaloids concentration in the sweet cultivars (Danja, Gungurru and Yorrell) and a high alkaloids concentration in the bitter cultivar (Fest) is controlled respectively by the recessive *iucundus* gene and dominant *Incundus* gene (Source: Gremigni *et al.*, 2001).

Isoflavones are a group of phytochemicals in some legumes that are thought to contribute to the beneficial health effects of soybean in human and animal diets. Vyn *et al.* (2002) observed a positive correlation between total isoflavone content and seed yield in soybean, suggesting that large yields could be compatible with good quality from an isoflavone-based functional-food perspective. Nevertheless, it is interesting that isoflavone responded positively to K fertilization even when seed yield and/or seed K concentrations themselves were not increased on some of the medium to high K status soils. Significant isoflavone increases were always accompanied by significant increase of leaf K concentration. In a recent genetic mapping study, Meksem *et al.* (2001) confirmed that one quantitative trait locus (QTL) for genistein concentrations was closely linked to a seed yield QTL. The effect of the two linked QTLs for genistein concentrations and yield might be a more universal genetic phenomenon in soybean.

The maturation and premature germination (i.e., vivipary) of sweet pepper seeds are another example of a quality trait that is significantly influenced by the leaf K concentration (Marrush *et al.*, 1998). The K concentration of fruit flesh significantly affected the total emergence percentage of sweet pepper seeds developed in the summer season (Fig. 5), but not in the winter season. It is K in fruit flesh rather than K in seeds that seems to be important for the seed emergence quality (Xu *et al.*, 2002a) although K nutrition may have more of an effect on vivipary of pepper seeds than by simply altering ABA levels in the seed (Marrush *et al.*, 1998). A deficiency of K would be expected to result in the malfunction of a whole series of metabolic process, among which could be the synthesis and metabolism of ABA and other plant growth regulators (McCarty, 1995; Marrush *et al.*, 1998).

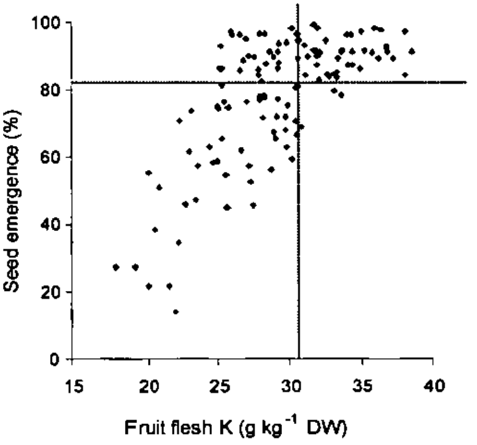

Fig. 5. Relationship between the K concentration of fruit flesh and emergence percentage of corresponding seed samples of sweet pepper grown in a summer season (Source: Xu *et al.*, 2002).

Physiological functions of potassium transporters

Potassium transporters are required for the uptake of K from soil and for its distribution through the diverse plant tissues. The generally accepted model of high and low affinity sites for K uptake into roots was presented by Epstein in the early 1960s (Epstein *et al.*, 1963). This model is now being elucidated, helped by powerful electrophysiological and molecular techniques.

Functions of high affinity potassium transporters

Massthuis and Sanders (1997) concluded that high affinity K^+-H^+ symport was dominant in the mediation of K uptake by plant roots when $[K]_{ext} < 0.5$ mM. The first high affinity transporter, HKT1, was identified by complementation of a mutant yeast strain defective for K^+ uptake with a wheat root cDNA expression library (Schachtman and Schroeder, 1994). It is the generally accepted dogma that ion uptake mechanisms should be localized to the epidermis (e.g. for nitrate and phosphate), however, the *HKT1* gene was expressed in the root cortex and in cells bordering the vascular tissue of leaves (Schachtman and Schroeder, 1994). The function of HKT1 in plants remains to be elucidated (Schachtman, 2000). A family of K transporters known as the HAK/KT/KUP family might catalyze the high affinity transport (Schachtman, 2000). Plant HAK transporters expressed in yeast mediate both high- and low-affinity K^+ uptake (Su *et al.*, 2001).

Roles of higher plant potassium channels

Low affinity K transport occurs at mM external K concentrations that are not saturating at physiologically relevant K concentrations (Fox and Guerinot, 1998). It is carried out mainly by voltage-gated K channels that allow the passive flow of K down an electrochemical gradient. By functional complementation of yeast mutant strains defective for K transport, the first two K channels in plants, AKT1 and KAT 1 were identified from *Arabidopsis* 10 years ago (Sentenac *et al.*, 1992; Anderson *et al.*, 1992). Recently using reverse genetic strategy and comparative functional studies, Dennison *et al.* (2001) confirmed that the growth rates of *Arabidopsis* plants supplied with rate-limiting concentrations of K depended on the presence of AKT1 but not AKT2 channels (Fig. 6), indicating that AKT1 but not AKT2 mediates growth-sustaining uptake of K into roots.
Since a range of transporter families, with each family comprising many members, can transport K, it is likely that parallel pathways exist, and that no one transport system will dominate (Schachtman, 2000). Fu and Luan (1998) suggest that conformational changes in the transporter protein might be responsible for switching between the high and the low affinity mode for a single protein. Changes in the external K concentration or membrane potential might trigger such a

conformational switch. If the difference in membrane potential is lower than the reversal value (zero current) in response to the negative membrane potential generated by the H^+-pump, the passive channel transporter may also mediate what has previously been termed "high-affinity" uptake. AKT_1 channels mediate K uptake from solutions that contain as little as 10 µM K (Hirsch *et al.*, 1998).

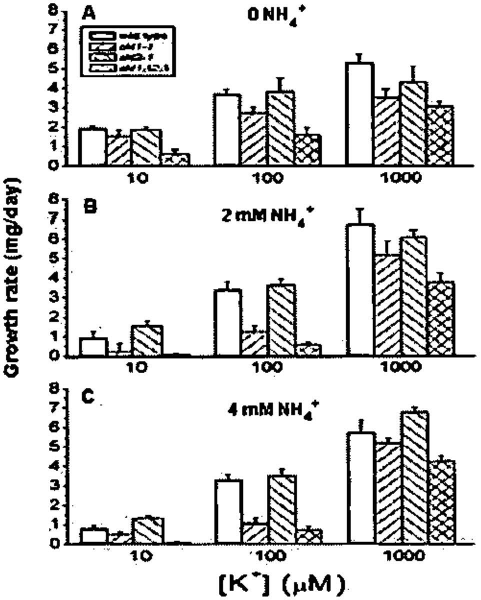

Fig. 6. The K dependence and NH_4 inhibition of growth rate in seedlings of single and double mutations of two K channel genes (*akt1 and akt2*) and their wild type of Arabidopsis. A, 0 mM NH_4 B, 2 mM NH_4 C, 4 mM NH_4. Each bar represents the mean of three independent experiments ± SE. (Source: Dennison *et al.*, 2001).

Relationship between potassium transporter and salt tolerance

HKT1 may function as a K^+-Na^+ symport and contribute to salinity stress in a variety of plant species (Rubio, 1995; Gassmann *et al.*, 1996; Box and Schachtman, 2000). AtHKT1 may have both a channel and a transporter function that facilitates downhill transport of Na^+, as well as a H^+-energized K transport (Uozumi *et al.*, 2000). Rus *et al.* (2001) found that AtHKT1 is a salt tolerance determinant that controls Na entry into the roots of *Arabidopsis*. Mutation (inactivation) of HKT1 improves K selectivity under salt conditions, thus improving salt tolerance (Rubio *et al.*, 1995; Rus *et al.*, 2001). In contrast, in the halophytic common ice plant, both K starvation and salt stress strikingly increased the expression of the transcript and highly abundant protein of the root-specific, inward-rectifying K^+ channel McHAK

(Su *et al.*, 2001; 2002). In addition, McHAK is highly selective for K^+ over Na^+ and is likely to transport specifically K^+ while excluding Na^+ in the common ice plant. Thus, the McHAK genes are considered to be major contributors to K homeostasis under high-salinity conditions both by facilitating uptake and transport through the vasculature. By their up-regulation, they seem to alleviate K starvation. The different discrimination of Na^+ observed for Arabidopsis and for the common ice plant could be attributed to differences in the primary amino acid sequence of the transporters that might influence selectivity (Su *et al.*, 2002). A possible impact of transgenic salt tolerant crops in the future would be the ability to use KCl under saline soil conditions.

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The role of potassium in alleviating detrimental effects of abiotic stresses in plants

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Abstract

Plants exposed to environmental stress factors, such as drought, chilling, high light intensity, heat and nutrient limitations, suffer from oxidative damage catalysed by reactive oxygen species (ROS), e.g., superoxide radical ($O_2^{\cdot-}$), hydrogen peroxide (H_2O_2) and hydroxyl radical ($OH^{\cdot}$). Reactive O_2 species are known to be primarily responsible for impairment of cellular function and growth depression under stress conditions. In plants, ROS are predominantly produced during the photosynthetic electron transport and activation of membrane-bound NAD(P)H oxidases. Increasing evidence suggests that improvement of the potassium (K) nutritional status of plants can greatly lower ROS production by reducing activity of NAD(P)H oxidases and maintaining photosynthetic electron transport. Potassium deficiency causes severe reduction in photosynthetic CO_2 fixation and impairment in partitioning and utilization of photosynthates. Such disturbances result in excess of photosynthetically produced electrons and thus stimulation of ROS production by intensified transfer of electrons to O_2. Recently, it was shown that there is an impressive increase in the capacity of bean root cells to oxidize NAD(P)H when there was a deficiency of K. An increase in NADPH oxidation was up to 8-fold higher in plants with low K supply than in K sufficient plants. Accordingly, K deficiency also caused an increase in NADPH-dependent $O_2^{\cdot-}$ generation in root cells. The results indicate that increases in ROS production during both photosynthetic electron transport and NADPH-oxidizing enzyme systems may be involved in membrane damage and chlorophyll degradation in K deficient plants. In good agreement with this suggestion, increased severity of K deficiency was associated with enhanced activity of enzymes involved in detoxification of H_2O_2 (ascorbate peroxidase) and utilization of H_2O_2 in oxidative processes (guaiacol peroxidase). Moreover, K deficient plants are highly light-sensitive, and very rapidly become chlorotic and necrotic when exposed to increased light intensity. Because ROS production by NADPH oxidases and photosynthetic electron transport is especially high when plants are exposed to environmental stress conditions, it seems reasonable to suggest that, under such conditions, improvement in the K nutritional status of plants might be of great importance for the survival of crop plants. Several examples are presented here emphasizing the role of K in alleviating the adverse effects of different abiotic stress factors on crop production.

Introduction

The world population is expanding rapidly, and is expected to be around 8 billion by the year 2025 (Pinstrup-Andersen *et al.*, 1999). This represents an annual addition of nearly 80 million people to the present population of about 6 billion. This increase in world population will occur almost exclusively in developing countries where serious nutritional problems exist at present, and population pressure on agricultural soils is already very great.

To feed the increasing world population and sustain the well-being of human kind, food production must be increased by up to 100 % over the next 25 years (Borlaug and Dowswell, 1993; Dyson, 1999; Tillman, 1999). The projected increases in food production must be achieved on the already cultivated land because the potential for an appreciable expansion in the area of agricultural soils in most parts of the world is very limited. In addition, recent trends indicate that the productivity and fertility of soils globally are declining due to degradation and intensive use of soils without consideration of proper soil management practices (Gruhn *et al.*, 2000; Cakmak, 2002). An inadequate and unbalanced supply of mineral nutrients and impaired soil fertility are particular problems causing decreases in global food production, especially in the developing countries. It is estimated that around 60% of cultivated soils have growth-limiting problems associated with mineral nutrient deficiencies and toxicities (Cakmak, 2002). According to Byrnes and Bumb (1998), in the next 20 years fertilizer consumption has to increase by around 2-fold to achieve the required increases in food production. It seems that, in the coming decades, research in plant nutrition will be a high-priority research area contributing to crop production and sustaining soil fertility.

Environmental stresses (e.g., water deficiency, extremes of temperatures, salinity, flooding, soil acidity and pathogenic infections) are increasing and they contribute significantly to decreasing crop yields below the potential maximum yield of many crops. According to Bray *et al.* (2000), the relative decreases in potential maximum crop yields (i.e., yields under ideal conditions) associated with abiotic stress factors vary between 54 to 82% (Table 1). Most of the yield decreases caused by abiotic stresses result from drought, salinity, high or low temperatures, excess light, inadequate mineral nutrient supply and soil acidity. Therefore, for sustaining food security and the well-being of humankind, a high priority should be given to minimizing the detrimental effects of environmental stresses on crop production by (i) applying modern breeding techniques and biotechnological tools, and (ii) increasing soil physical and chemical fertility as well as maintaining the productivity of cultivated soils by an adequate and balanced supply of mineral nutrients.

Plants have developed a wide range of adaptive/resistance mechanisms to maintain productivity and ensure survival under a variety of environmental stress conditions. Increasing evidence suggests that the mineral nutrient status of plants plays a critical role in increasing plant resistance to environmental stress factors (Marschner, 1995).

Table 1. Average yields and record yields of maize, wheat, soybean and potato and the losses in record yield caused by abiotic stresses. Record yield is assumed to represent crop production under ideal conditions. Abiotic stress factors include, but not limited to, drought, salinity, extreme temperatures, flooding and nutrient deficiencies (adapted from Bray *et al.*, 2000).

Crop	Record yield	Average yield	Average losses by abiotic stress	Losses by abiotic stress
		$t\ ha^{-1}$		(%)
Maize	19.3	4.6	12.7	65.8
Wheat	14.5	1.9	11.9	82.1
Soybean	7.4	1.6	5.1	69.3
Potato	94.1	28.3	50.9	54.1

Of the mineral nutrients, potassium (K) plays a particular role in contributing to the survival of crop plants under environmental stress conditions. Potassium is essential for many physiological process, such as photosynthesis, translocation of photosynthates to sink organs, maintenance of turgidity, activation of enzymes, and reducing excess uptake of ions such as Na and Fe (Marschner, 1995; Mengel and Kirkby, 2001).

This review deals with the roles of K in minimizing adverse effects of environmental stress conditions on crop production, with a particular emphasis on abiotic stress factors. The beneficial effects of K on enhancing plant resistance to biotic stress factors (e.g., diseases, insects...) are described by Haerdter (This volume).

Protective role of potassium against light-induced cell damage

Chloroplasts are the major organelle producing reactive O_2 species (ROS), such as the superoxide radical ($O_2^{\cdot-}$), hydrogen peroxide (H_2O_2) and singlet oxygen ($^1O_2$) during photosynthesis (Asada, 2000). Production of ROS in chloroplasts can be particularly great when plants are exposed to environmental stresses such as drought, chilling, nutrient deficiency and salinity (Foyer *et al.*, 1994; Marschner *et al.*, 1996; Asada, 2000; Vranova *et al.*, 2002). Reactive O_2 species are highly toxic, causing membrane damage and chlorophyll degradation, and are thus responsible for development of leaf chlorosis and necrosis. Under normal conditions, up to 20% of the total photosynthetic electron flux is transferred to molecular O_2, forming $O_2^{\cdot-}$ and other $O_2^{\cdot-}$-driven reactive O_2 species (Robinson, 1988; Biehler and Fock, 1996; Cakmak, 2000). When utilization of absorbed light energy in CO_2 fixation is limited by biotic or abiotic stresses, the electron flux to O_2 is intensified, resulting in a large accumulation of ROS in chloroplasts. Under these conditions excitation energy is also transferred to O_2 to form highly toxic $^1O_2$. Production of ROS in chloroplasts becomes more pronounced when plants grown under an environmental stress are exposed to high light intensity, resulting in the occurrence of photooxidative damage to the chloroplasts. There are several examples showing that combination of high light intensity and an environmental stress causes very rapid development of leaf chlorosis and necrosis (Cakmak and Marschner, 1992; Foyer *et al.*, 1994; Wise, 1995; Huner *et al.*, 1998; Cakmak, 2000; Choi *et al.*, 2002).

Plants suffering from K deficiency are extremely sensitive to increasing light intensity. At the same small supply of K, leaf chlorosis and necrosis occurred in plants growing under high light intensity, but not in plants under low light (Marschner and Cakmak, 1989; Marschner *et al.*, 1996). Partial shading of the K-deficient leaves also prevented development of leaf chlorosis and necrosis. Such marked effects of high light intensity on the occurrence of chlorosis were not related to K concentrations in leaf tissues: shaded and non-shaded parts of K-deficient leaves had a similar K concentration (Marschner and Cakmak, 1989). These observations support the idea that photooxidative damage to chloroplasts catalysed by ROS plays a critical role in occurrence of leaf symptoms characteristic of K deficiency.

There are several reasons for the high sensitivity of K deficient plants to increasing light intensity. Potassium plays a central role in the maintenance of photosynthesis and related processes. In many different plant species, K deficiency results in severe decreases in net photosynthesis (Fig. 1). The decrease in photosynthesis with K deficiency becomes more distinct when plants are exposed to elevated atmospheric concentrations of CO_2 and O_3 (Barnes *et al.*, 1995), indicating an increased K requirement when plants grow in a CO_2-enriched atmosphere.

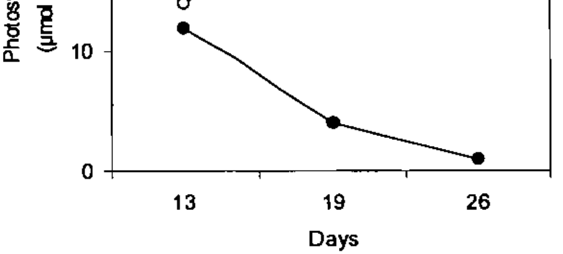

Fig. 1. Photosynthesis rate in leaves of cotton plants grown in pots over 26 days with adequate and deficient supply of K (redrawn from Bednarz and Oosterhuis, 1999).

This effect of K is important and needs further investigation in view of the fact that the global atmospheric CO_2 concentration has increased and possibly will be doubled by the end of 21st century (Bolin, 1986). The decreases in photosynthesis by K deficiency appears to be related to reduced stomatal conductance, increased mesophyll resistance and lowered ribulose bisphosphate carboxylase activity (Peoples and Koch, 1979; Cakmak and Engels, 1999; Zhao *et al.*, 2001a; and references therein). Maintenance of photosynthesis at a high rate is also dependent on export and utilization of photoassimilates within plants. In plants poorly supplied with K, there is several fold more sucrose in source leaves and a marked reduction in roots compared with plants well supplied with K (Cakmak *et al.*, 1994a, b; Huber, 1984; Marschner *et al.*, 1996; Bednarz and Oosterhuis, 1999; Zhao *et al.*, 2001a). These findings are consistent with results showing that K deficiency causes a severe decrease in phloem export of sucrose from source leaves (Fig. 2; see also Mengel and Viro, 1974; Mengel, 1980; Cakmak *et al.*, 1994b).

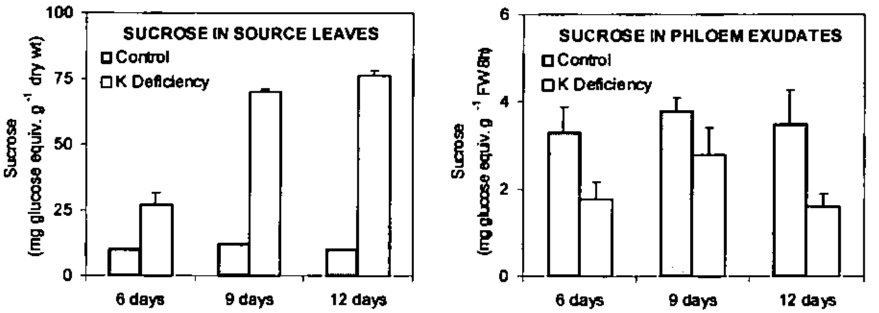

Fig. 2. Sucrose concentrations in source leaves and phloem exudates collected from source leaves of bean (*Phaseolus vulgaris*) plants over 12 days of growth in nutrient solution with adequate (2000 μM) and deficient (50 μM) K supply (redrawn from Cakmak *et al.*, 1994b).

Due to such a distinct impairment of photosynthetic CO_2 fixation, as well as reduced utilization of photoassimilates in K-deficient leaves, enhanced production of ROS is unavoidable, which in turn leads to photooxidative damage (Fig. 3). Increases in the severity of leaf chlorosis by K deficiency were associated with enhanced activities of enzymes involved in detoxification of H_2O_2 (ascorbate peroxidase) and utilization of H_2O_2 in oxidative processes (guaiacol peroxidase) (Cakmak, 1994; Fig. 4). The rise in H_2O_2 detoxification capacity of K deficient leaves supports the suggestion that the production of ROS is intensified in K deficient leaves at the expense of CO_2 fixation. It can be concluded that plants exposed to high light intensity or grown under long-term sunlight conditions, as occurs like in southern countries of the Northern Hemisphere, have much larger K requirements than plants grown under low light intensity. Increased requirement for

K by high light intensity is needed for an efficient utilization of absorbed light energy in photosynthetic CO_2 fixation and transport of photosynthates into sink organs.

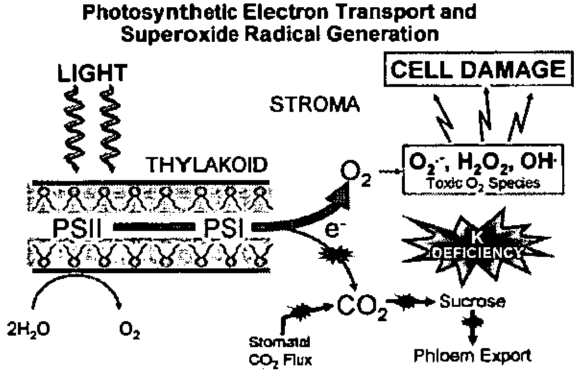

Fig. 3. Schematic representation of superoxide radical production in chloroplasts of K deficient leaves. Refers the inhibition of the corresponding reaction by K deficiency.

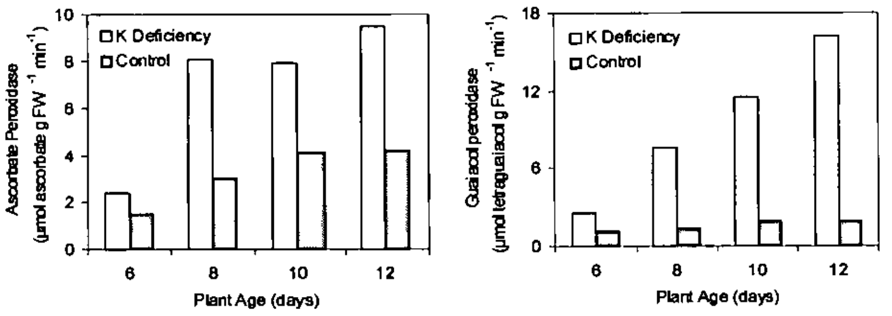

Fig. 4. Activities of ascorbate peroxidase and guaiacol peroxidase in leaves of bean (*Phaseolus vulgaris*) plants over 12 days of growth in nutrient solution with adequate (2000 µM) and deficient (50 µM) K supply (redrawn from Cakmak, 1994).

Potassium-induced plant resistance to drought

There is increasing evidence that plants suffering from environmental stresses like drought, chilling and salinity have a large requirement for K. Environmental stress factors that enhance the requirement for K also cause oxidative damage to cells by inducing the formation of ROS, especially during photosynthesis (Bowler *et al.*, 1992; Elstner and Osswald, 1994; Foyer *et al.*, 1994).

The reason for the enhanced need for K by plants suffering from environmental stresses appears to be related to the fact that K is required for maintenance of photosynthetic CO_2 fixation. For example, drought stress is associated with stomatal closure and thereby with decreased CO_2 fixation. Based on the model given in Fig. 3, formation of ROS is intensified at the expense of inhibited CO_2 reduction by drought stress. Obviously, formation of ROS under drought stress would be dramatic in plants exposed to high light intensity, with concomitant severe oxidative damage to chloroplasts. Increases in ROS production in drought-stressed plants are well known and related to impairment in photosynthesis and associated disturbances in carbohydrate metabolism (Seel *et al.*, 1991; Quartacci *et al.*, 1994; Jiang and Zhang, 2002). These results indicate that when plants are grown with a small supply of K, ROS production induced by drought stress can be additionally enhanced, at least due to disturbances induced by K deficiency in stomatal opening, water relations and maintenance of a high photosynthesis rate (Marschner, 1995; Mengel and Kirkby, 2001). In addition, most importantly, under drought conditions chloroplasts lose large amounts of K to further depress photosynthesis (Sen Gupta and Berkowitz, 1987) and induce further ROS formation. These results strongly support the idea that increases in the severity of drought stress result in corresponding increases in K demand to maintain photosynthesis and protect chloroplasts from oxidative damage. The results presented in Fig. 5 for wheat are in accordance with this suggestion, and show that decreases in photosynthesis caused by drought stress are particularly large in plants with little K, and are minimal when K is sufficient (Sen Gupta *et al.*, 1989). Alleviation of detrimental effects of drought stress, especially on photosynthesis, by a sufficient K supply has also been shown in legumes (Sangakkara *et al.*, 2000).

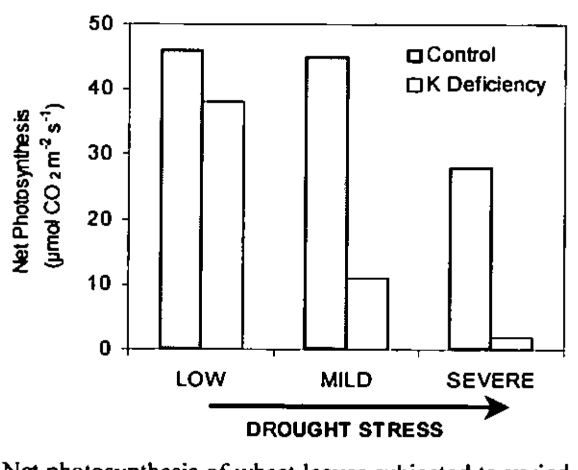

Fig. 5. Net photosynthesis of wheat leaves subjected to varied drought stress and K supply (data calculated from Sen Gupta *et al.*, 1989).

In field experiments conducted in Egypt, it was found that decreases in grain yield resulting from restricted irrigation could be greatly eliminated by increasing the K supply (Abd El-Hadi *et al.*, 1997). In view of these results it can be concluded that the improvement of the K nutritional status of plants seems to be of great importance for sustaining high yields under rainfed conditions.

Enhanced resistance of plants to low temperature stress by potassium supply

Like drought stress, chilling stress is also responsible for photooxidative damage to chloroplasts due to the impairments in photosynthetic C metabolism. Generally, in chilling-stressed plants, absorbed light energy exceeds the capacity of chloroplasts to use it in CO_2 fixation, and the excess energy is alternatively used for activation of O_2 to ROS (Huner *et al.*, 1998; Foyer *et al.*, 2002). Increases in the activity of enzymes scavenging for H_2O_2 and $O_2^{\cdot-}$ in plants upon exposure to chilling or freezing temperatures indicate the participation of ROS in chilling-induced cell damage (Foyer *et al.*, 1994; Lee and Lee, 2000; Allen and Ort, 2001). Photosynthetic electron transport, stomatal conductance, Rubisco activity and CO_2 fixation are the major targets impaired by low temperature stress in plants (Allen and Ort, 2001). These cellular targets are also adversely affected by K deficiency. Therefore, with a small supply of K, chilling-induced photooxidative damage can be exacerbated causing more decreases in plant growth and yield. It seems highly possible that the supply of large amounts of K to plants growing under chilling temperatures can provide protection against chilling damage. In accordance with this suggestion, it has been shown that increasing K concentration in the irrigation water provided important protection against stem damage from low night temperatures in carnation plants (Kafkafi, 1990). Similarly, decreases in yield and increases in leaf damage induced by frost in potato plants under field conditions could be alleviated by large applications of K fertilizer (Table 2). Improving chilling tolerance of plants by increasing K supply was also shown in tomato, pepper and eggplant seedlings growing outside, with temperatures ranging from 4C° to 16°C. Depending on the source of K fertilizers, K supply enhanced total plant yield by 2.4-fold, 1.9-fold and 1.7-fold in tomato, pepper and eggplant, respectively (Hakerlerler *et al.*, 1997). Although the effect was not significant, K supply also reduced the rate of seedlings death due to low temperature.

Table 2. Influence of potassium supply on tuber yield, potassium concentration of leaves, and leaf damage caused by frost in potato (Grewal and Singh, 1980).

Potassium supply (kg ha^{-1})	Tuber yield (t ha^{-1})	Potassium concentration (mg g^{-1} dry wt)	Leaf damage (%)
0	2.39	24.4	30
42	2.72	27.6	16
84	2.87	30.0	7

NADPH-dependent $O_2^{\cdot -}$ formation

Beside the photosynthetic electron transport, NADPH-dependent oxidases represent another major source for production of ROS in plant cells (Cakmak, 2000; Jones *et al.*, 2000; Vranova *et al.*, 2002). Superoxide-generating NADPH-oxidases are generally localized in plasma membranes, and are activated by a number of biotic and abiotic stress factors, such as chilling (Shen *et al.*, 2000), ozone treatment (Pellinen *et al.*, 1999), wounding (Orozco-Cardenas and Ryan, 1999), Zn deficiency (Cakmak and Marschner, 1988), drought (Zhao *et al.*, 2001b; Jiang and Zhang, 2002), pathogenic attacks (Lamb and Dixon, 1997; Bolwell and Wojtaszek, 1997), and salt treatment (Kawano *et al.*, 2002). As shown schematically in Fig. 6, NADPH-oxidizing enzymes catalyse one-electron reduction of O_2 to $O_2^{\cdot -}$ by using NADPH as an electron donor. Reactive O_2 species produced by NADPH oxidases are involved in peroxidation of vital cell constituents and programmed cell death (Jones *et al.*, 2000; Neill *et al.*, 2002). It is generally accepted that $O_2^{\cdot -}$-generating NADPH oxidases play a major role in cell damage and associated decreases in growth by abiotic stresses. For example, preventing NADPH oxidation or NADPH-dependent $O_2^{\cdot -}$ generation in cucumber plants under chilling stress reduced chilling-induced leaf necrosis and lipid peroxidation (Shen *et al.*, 2000).

Potassium Deficiency-Induced NADPH-Dependent Superoxide Radical Generation and Membrane Damage

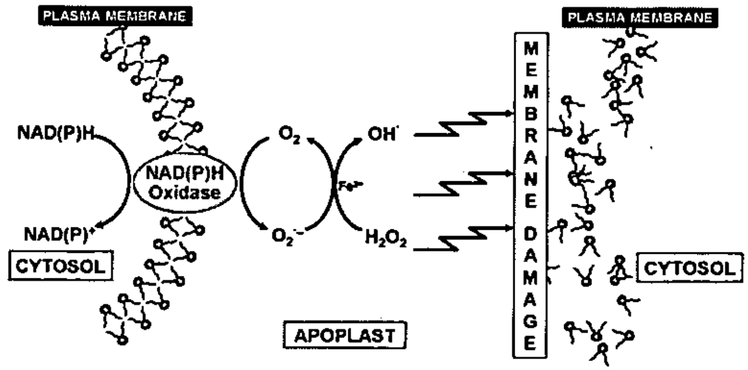

Fig. 6. Model of the K deficiency-induced NADPH oxidase, superoxide radical production and membrane damage in root cells.

Very recently, we found that activity of NADPH oxidase increased in cytosolic fractions of bean roots with the increasing severity of K deficiency (Table 3). The increases in NADPH oxidation due to K deficiency were up to 8-fold. Such marked increases have not been reported in the literature, for example neither in the case of chilling (Shen *et al.*, 2000) and water stress (Zhao *et al.*, 2001b; Jiang and Zhang,

2002) nor in Zn deficient plants (Cakmak and Marschner, 1988). Potassium deficiency also resulted in an increase in NADPH-dependent $O_2^{\cdot-}$ generation; however, the extent of $O_2^{\cdot-}$ generation was much lower as compared with the level of NADPH oxidase activity (Table 3). It seems possible that K deficiency can activate $O_2^{\cdot-}$-generating NADPH oxidase in plants suffering from biotic and abiotic stresses. As mentioned above, $O_2^{\cdot-}$-generating NADPH-oxidase is activated by different stress factors such as drought (Jiang and Zhang, 2002; Zhao *et al.*, 2001) and chilling (Shen *et al.*, 2000). The well-described protective roles of K against drought and chilling stresses might also be explained by the stimulatory effect of K deficiency on the activity of NADPH oxidase. Moreover, $O_2^{\cdot-}$-generating NADPH-oxidases could also be involved in K deficiency-induced blackspot browning formation in potato tubers. The reason for the blackspot pigmentation in K deficient tubers is not well understood, and has been attributed to the enhanced activity of polyphenoloxidase by K deficiency (McNabnay *et al.*, 1999).

Table 3. Effect of increasing K supply on NADPH oxidase and NADPH-dependent $O_2^{\cdot-}$ production in the cytosolic fraction of bean roots grown for 8 days in nutrient solution. Values in parentheses show the percentage of those in K-sufficient (2000 μM) plants (S. Eker, personal communication).

K supply (μmol)	NADPH oxidase (μmol NADPH.g FW.min)		$O_2^{\cdot-}$ - concentration (nmol $O_2^{\cdot-}$ .g FW.min)	
10	191± 7	(817)	138± 9	(124)
25	170±11	(723)	130±14	(117)
50	61± 3	(254)	154±14	(139)
100	53± 9	(225)	151± 6	(136)
200	30± 1	(128)	133±11	(120)
2000	24± 4	(100)	111±11	(100)

The reason for the increases in NADPH oxidase by K deficiency is not known; and needs to be investigated in future studies. Abscisic acid (ABA) is known to induce activity of NADPH oxidase and NADPH-dependent formation of ROS (Zhao *et al.*, 2001b; Jiang and Zhang, 2002; Neill *et al.*, 2002). Irrespective of NADPH oxidase, ABA has also been shown to be effective in increasing H_2O_2 and $O_2^{\cdot-}$ accumulation in roots or leaves (Jiang and Zhang, 2001; Lin and Kao, 2001). The increase in $O_2^{\cdot-}$-generating NADPH oxidase by K deficiency might be related to ABA, because ABA accumulates in plants suffering from K deficiency. For example, in *Ricinus communis* K deficiency strongly enhanced biosynthesis of ABA in roots and resulted in 4.6-fold increase in ABA transport from roots to shoots (Peuke *et al.*, 2002). Large increases in peroxidase activity in K deficient plants (Cakmak, 1994) can be also explained by high ABA accumulation, because increasing concentration of ABA induces activity of peroxidase in rice roots (Lin and Kao, 2001). Based on these results, one may speculate that NADPH oxidase activity induced by K deficiency is possibly related to enhanced accumulation of ABA. This point needs to be clarified in future studies.

Role of potassium in alleviating detrimental effects of salt stress

Soil salinity is an increasing constraint threatening crop production globally. Around 30% of cultivated soils are affected by the accumulation of salts (Epstein *et al.*, 1980; Zhu *et al.*, 1997). Soil salinity generally results from excess accumulation of NaCl, and exerts detrimental effects on crop production by causing ion toxicity and inducing osmotic stress (water deficiency) in both the root environment and in plants (Zhu *et al.*, 1997; Zhu, 2001).

Like most of other environmental stresses, salt stress also strongly affects photosynthesis and causes oxidative stress by inducing water deficiency (stomatal closure), ion toxicity and K deficiency. Consistent with this result, most salt-tolerant genotypes respond to salinity by increasing the antioxidative defence systems for detoxification of ROS (Rodriquez-Rosales *et al.*, 1999; Sudhakar *et al.*, 2001; Zhu, 2001). The critical role of antioxidative defence in expression of high salt tolerance was demonstrated in the *Arapidopsis* mutant line (*pst 1*). This mutant line has an impressive tolerance to NaCl (up to 400 mM) and also to excess light intensity. High salt tolerance of this *Arabidopsis* mutant line was associated with enhanced activities of enzymes scavenging for $O_2^{\cdot-}$ and H_2O (Tsugane *et al.*, 1999). The *pst* seedlings were also highly tolerant to the treatment by $O_2^{\cdot-}$-producing herbicides. These results support the idea that salt stress reflects an oxidative stress, and induction of antioxidant defence system is critical for development of salt tolerance. Similar conclusions were also reached by Hernandez *et al.* (2000) and Sudhakar *et al.* (2001) in the studies with sensitive cultivars of pea and mulberry, respectively.

In view of the fact that high NaCl treatments impair K nutrition of plants, it is suggested that K deficiency at the cellular level might be a contributory factor to salt-induced oxidative stress and related cell damage. Therefore, improving K nutrition of plants under salt stress could be essential to minimizing oxidative cell damage, at least in part by reducing ROS formation during photosynthesis (Fig. 3) and inhibiting activation of $O_2^{\cdot-}$ -generating NADPH oxidase (Shen *et al.*, 2000; see also Fig. 6). Consistent with these suggestions, Kaya *et al.* (2001) showed that stress induced by salinity increases chlorophyll and membrane damage and decreases biomass production in tomato. These effects could be significantly inhibited by foliar application of K fertilizer in the form of KH_2PO_4. In this work, salinity caused not only K deficiency but also P deficiency, and applying KH_2PO_4 as a foliar spray was effective in correcting both nutrient deficiencies.

Accumulation of Na and impairment of K nutrition is a major characteristic of salt-stressed plants. Therefore, the K/Na ratio in plants is considered a useful guide to assessing salt tolerance. Selection or breeding genotypes with high K/Na ratios is an important strategy to minimize growth decreases in saline soils (Deal *et al.*, 1999;

Santa-Maria and Epstein, 2001; and references therein). Rascio *et al.* (2001) identified a wheat mutant with an appreciable ability to accumulate K in the shoot, and showed that this mutant, compared to other wheat genotypes, greatly improved tissue hydration, seed germination and seedling growth under increasing concentrations of NaCl.

The importance of K nutrition in salt tolerance was also shown in studies with *Arabidopsis* mutant lines. Mutant lines showing hypersensitivity to NaCl were also hypersensitive to low K supply. High salt sensitivity of the *Arabidopsis* mutant line was found to be associated with extremely poor capacity to take up K from a growth medium (Liu and Zhu, 1997; Zhu *et al.*, 1998). Similarly, in tomato the salt-hypersensitive mutants were defective in K uptake and had an impaired K nutrition (Borsani *et al.*, 2001). These results again highlight the critical importance of adequate K nutrition in alleviation of detrimental affects of salinity in plants.

Alleviation of iron toxicity by potassium

Potassium interacts not only with the uptake of Na, but also of Fe, especially in rice. Iron toxicity is a common nutritional problem in wetland rice, resulting in severe losses in growth and yield (Neue *et al.*, 1998). Iron toxicity is ascribed to the formation of ROS, especially hydroxyl radical ($OH^{\cdot}$), which is the most toxic ROS to aerobic cells (Becana *et al.*, 1998). There are some Fe species which are also very toxic, and produced by the reaction of Fe^{+2} with molecular O_2, forming ferryl ($Fe^{+2}O$) and perferryl ($Fe^{2+}O_2$) species (Grotti, 1985; Cakmak, 2000).

Iron toxicity in rice generally occurs in soils containing low levels of K, Zn and P (Benckiser *et al.*, 1984; Neue *et al.*, 1998). Accumulation of Fe in rice plants and development of Fe toxicity symptoms in shoots is particularly aggravated by K deficiency (Li *et al.*, 2001). In rice, increasing K supply reduced the Fe concentration in leaves by at least 2-fold and improved plant growth (Li *et al.*, 2001). The reason for the ameliorating effect of adequate K supply on Fe toxicity is not well understood. It was proposed that adequate supply of K enhances root-oxidizing capacity for Fe, thereby preventing its uptake (Neue *et al.*, 1998). Alternatively, K deficiency can result in exudation of organic compounds that facilitate reduction and uptake of Fe. Regardless of the reason, however, a sufficient K supply appears to be beneficial in alleviating Fe toxicity in wetland rice, and therefore improvement of the K nutritional status of rice plants is of great importance in soils containing excess levels of soluble Fe.

Conclusions

Potassium deficiency is an important nutritional problem affecting crop production and quality. Potassium deficient plants are very sensitive to high light intensity, rapidly becoming chlorotic and necrotic. Partial shading of leaves prevents development of chlorosis and necrosis, indicating that photooxidative damage to chloroplasts is a major contributory factor in the development of K deficiency symptoms. Shaded (green) and not-shaded (chlorotic and necrotic) parts of the same leaf had the same K concentration, or the necrotic parts even tended to contain more K. These results suggest that crop plants grown under conditions of high light intensity over a long period have a much higher requirement for K than the plants exposed to lower light intensities during growth.

The susceptibility of K deficient plants to high light intensity can be ascribed to the generation of ROS during photosynthesis. In K deficient plants, photosynthetic CO_2 fixation is substantially limited due to impairment in i) stomatal regulation, ii) conversion of light energy into chemical energy, iii) phloem export of photosynthates from source leaves to sink organs. At the expense of such disturbances in photosynthetic CO_2 fixation, molecular O_2 is activated leading to extensive generation of ROS, and thereby oxidative degradation of chlorophyll and cell membranes. Enhanced production of ROS by K deficiency is not confined only to impaired photosynthetic electron transport. It also appears likely that an NADPH-dependent oxidase is another important source of ROS in K deficient plants. Potassium deficient plants show a substantial increase in capacity to oxidize NADPH. Consistent with enhanced activity of NADPH oxidase, NADPH-dependent $O_2^{\cdot-}$ generation was increased by K deficiency. Reactive O_2 species produced by NADPH-oxidase or during photosynthesis are a major mediator of cell damage by different environmental stresses such as chilling, drought, ozone treatment, wounding, and salinity. When the K supply is limited, plants can become very sensitive to environmental stresses. Several examples have been presented here showing that improving the K nutritional status of plants greatly minimizes detrimental effects of drought, salinity and chilling on plant growth. The larger K requirement of plants under different abiotic stresses appears to be related to the inhibitory role of K against ROS production during photosynthesis and NADPH oxidase.

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Potassium and biotic stress of plants

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Abstract

Various examples presented in this paper show that potassium (K), besides its essential functions in most metabolic processes of plants, plays a crucial role in reducing or overcoming the impact of biotic stress. For rice, an adequate supply of K is not only important for yield formation but also reduces the incidence of lodging, even at soil K contents that are regarded as not limiting for yield. Furthermore important rice diseases, e.g. stem rot, brown leaf spot (*Helminthosporium oryzae*), rice blast (*Piricularia oryzae*), sheath blight (*Thanatephorus cucumeris*) are reduced with an adequate K supply. For green tea, which is an increasingly popular beverage due to its beneficial effects on human health, supply of K limits leaf diseases, for example anthracnose, grey blight and brown blight. The paper also aims to suggest some mechanisms that are involved in the complex interactions between host, pathogen and environment. Understanding these relationships, may offer perspectives with regard to replacing pesticides by better nutrition, especially to organic growers, who supply an ever growing number of consumers.

Introduction

Biotic stress generally describes the negative impact caused by pests and diseases on plant growth and crop production. Krauss (2001), presenting the overall situation for food supply and the need for increased crop production in the future, highlighted that the required increase is often jeopardised by pests and diseases. Nevertheless, in the past, with the availability of a great number of effective pesticides, growers could often simply control biotic stresses with chemical measures. This however, has greatly changed with stricter pesticide residue regulations for food and the increased awareness of consumers, demanding healthier and residue-free food (Ruan *et al.*, 2000). There is a change towards more sustainable, integrated pest management systems (IPM) with emphasis on crop varieties with a high resistance to pests and diseases. An integral part of IPM is that cultural practices should minimize damage caused by pathogens. Among these practices, crop nutrition plays a key role, because it affects plants' metabolism and their susceptibility to all kinds of stress (Marschner, 1995). The available information on the subject indicates that the positive effects of fertilization result from a balanced supply of nutrients (Härdter, 1997). However, looking at the current consumption of nutrients worldwide, it is evident that in certain regions and countries there is a dramatic imbalance in the demand and supply of nutrients. Whereas nitrogen (N) is usually abundantly supplied, in the agricultural land-use systems in these regions/countries, there is an inadequate supply of potassium (K) (Krauss, 2000). This paper discusses the physiological aspects involved in the interaction between plant nutrition and plant / pathogen interactions. In addition, the economic impact of integrated plant production systems, including balanced nutrition with more emphasis on K, is discussed, using mainly examples for rice and tea.

The size of crop losses by biotic stress

The worldwide losses in eight major crops (barley, coffee, cotton, maize, potatoes rice, soybean and wheat) caused by biotic stress have been estimated by Oerke *et al.* (1995). During the period 1988-90 of the attainable production of USD 580 billion, about USD 240 billion (41%) are lost due to pests (15%), pathogens (13%) and weeds (13%) (Figure 1).

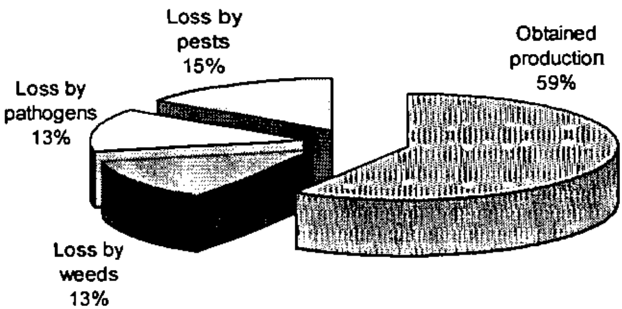

Fig. 1. Value of crop lost due to pests, diseases and weeds in comparison to the total attainable value of production. The obtained production of $ 580 billion is only 59% of the attainable production (Oerke *et al.*, 1995).

The situation may have changed since 1988-90, especially due to the increased inputs of plant protection reagents. In 1998, farmers worldwide spent a total of USD 34 billion to protect their crops from pests and diseases, and the annual growth rate in pesticide consumption indicates a further stable growth of 4.4% annually (Yudelman *et al.*, 1998).

In India, for example, tremendous progress in becoming self-sufficient in food production has been made during the past two decades but this has only been achieved by improved plant protection. India has dramatically intensified its use of pesticides as is evident from the considerable increase in fungicide imports in the 1990s. Fungicide imports today are almost eight times larger than in 1990 (Figure 2). Assuming that domestic fungicide production has also increased during this period, the change in fungicide consumption is probably even greater. In comparison to fungicide imports, the use of potash fertilizer has increased only modestly during the same period. Similar observations were made by Härdter (1997) for Thailand, the world's largest rice exporter and one of Asia's biggest importers of pesticides. Therefore, it may be justified to ask whether better crop nutrition could have helped to reduce the use of pesticides without sacrificing yield.

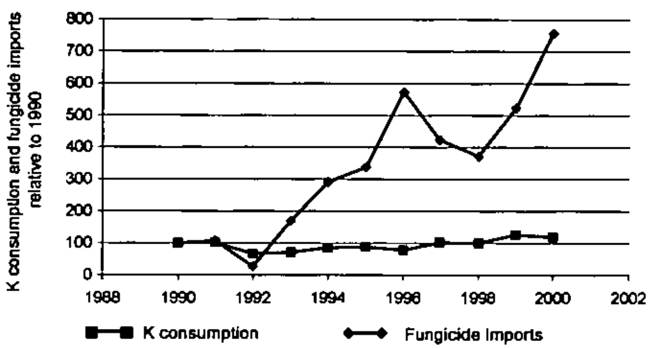

Fig. 2. Percentage change in fungicide imports and K consumption relative to 1990 in India (based on FAO yearbooks, 1991-2001).

Alternative strategies to pest and disease control

In integrated pest management systems, growers have several options to control pests and diseases: 1) selection of a resistant/tolerant variety, 2) chemical control, 3) the use of predators, 4) improved cultural practices (crop rotations, tillage systems, etc.) and 5) plant nutrition.

Nutrition of plants has a substantial impact on the predisposition of plants to be attacked or affected by pests and diseases. By effecting the growth pattern, the anatomy, the morphology and particularly the chemical composition, plant nutrition may contribute either to an increase or decrease of the resistance and/or tolerance to pests and diseases (Krauss, 1969; Graham, 1983; Perrenoud, 1990; Marschner, 1995; Ruan *et al.*, 2000). However, unlike human nutrition, where the effect of nutrition on "health" has gained considerable importance, the implementation of proper plant nutrition to improve plant resistance and tolerance to pests and diseases appears to lag far behind its potential. Effects on plant health caused by mineral nutrition are generally small in either resistant or highly susceptible crops, but may be considerable in moderately susceptible to partially resistant crops. For such crops, an adequate nutritional status, ensuring optimum plant growth, increases resistance and tolerance against pests and diseases.

During their life cycle, plants may encounter attacks from mainly four groups of organisms, fungi, bacteria, viruses and pests. The principles of infection, the damage caused and the protective mechanisms adopted vary.

The severity of attack by fungal diseases depends on the presence of plant exudates on leaf and root surfaces and low molecular weight substances are preferred by

these micro-organisms. Balanced plant nutrition, especially with K, contributes to the synthesis of high molecular weight compounds and to the integrity of cell membranes favoured by boron (B) and calcium (Ca) reducing exudate flow and hence limiting fungal attacks.
Parasites responsible for bacterial diseases mainly enter the host plant through stomata, and spread and multiply in the intercellular spaces of leaves, stems and roots. Mineral nutrition, in particular the K and Ca supply, is crucial to minimize the damage caused by bacteria.
Regarding viruses and mineral nutrition there is little information available. However, since the multiplication of viruses in an organism is confined to living cells, all factors favouring growth are also favouring viral infection. Plants well supplied with nutrients may, however, grow out of the disease. On the other hand, 60% of all viruses are transmitted by vectors, e.g. leaf hoppers are a serious threat to rice as vectors of viruses. Management practices may therefore concentrate on the protection against these vectors (see below).
Pests in contrast to fungal, bacterial and viral parasites are generally less specific in their dietary requirements. However, certain visual (e.g. colours of surfaces) and sensual (e.g. odours) factors influence the attack of the host plants by certain pests.

Pest attacks

Pests generally attack young or rapidly growing plants. Nitrogen, which promotes growth, therefore increases the susceptibility of plants to pest attacks, and K deficient plants suffer more from the attack of pests. This was shown by Vaithilingam *et al.* (1982) for rice grown on a soil low in K, which was attacked by the rice leaf folder (*Cnaphalocrocis medinalis*) and the damage was significantly reduced by K application (Figure 3).

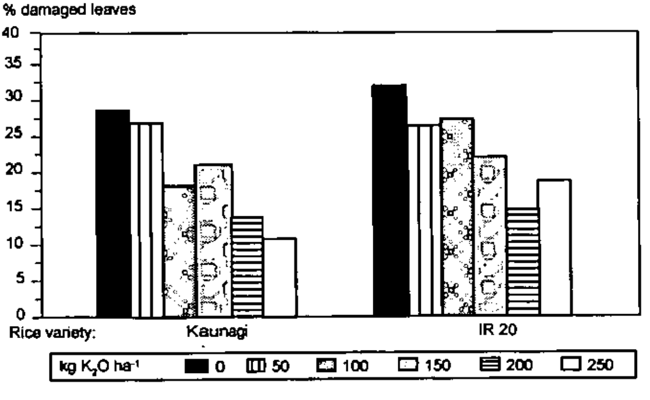

Fig. 3. Effect of potassium on leaf damage caused by rice leaf folder on two rice varieties (Vaithilingam *et al.*, 1982).

In this experiment, there was little difference between the two rice varieties in the percentage of damaged leaves and K had a similar effect on reducing damage in both varieties with a positive response up to 250 kg K_2O per hectare.
Similar observations were made by Adiningsih *et al.* (1994) in West Java. They found a significant reduction in damage caused by white stem borer, which is a major pest in intensive rice cultivation in Java (Figure 4).

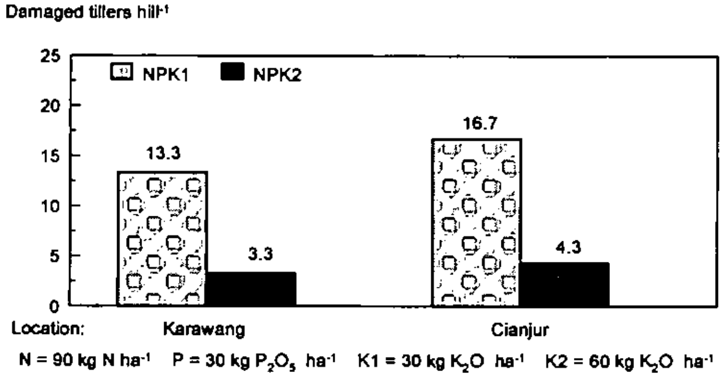

Fig. 4. Effect of potassium on rice plant damage by white rice stem borer (*S. innotata* Wlk.) at two locations in West Java (1991/92) (Adiningsih *et al.*, 1994).

Increasing the potassium rate from that usually recommended, 30 kg, to 60 kg K_2O ha^{-1} reduced the percentage of damaged tillers attacked from stem borer by more than 10% on average.

Fungal diseases

Next to pests, fungal diseases cause considerable damage and yield loss to crops (see Figure 1). There are a number of host-parasite interactions which can be influenced by mineral nutrition. A knowledge of these effects is important to demonstrate the potential possibilities that balanced nutrition can offer in reducing the impact of fungal attacks on crop production.
Brown leaf spot (*Helminthosporium oryzae*) is one of the most important parasitic attacks affecting rice production. The disease occurs mainly where plant nutrition is unbalanced owing to excessive applications of N (partly also with too much P) and inadequate supply of K, silicon (Si), magnesium (Mg), manganese (Mn) and zinc (Zn).
Increasing the K supply to rice in Indonesia reduced leaf damage caused by brown spot disease significantly (Figure 5). The main effects of K on brown spot disease in this experiment occurred between 0 and 90 kg K_2O ha^{-1}, whereas the percentage of filled grain increased up to the largest application, 150 kg K_2O ha^{-1} (Adiningsih,

1994). According to Ismunadji (1976), spores originating from K deficient host plants appeared to be more virulent, whereas an adequate K supply reduced the germination rate of conidospores. Furthermore, in plants which were well supplied with K, the spread of the disease within the plant was reduced owing to restricted hyphal infection.

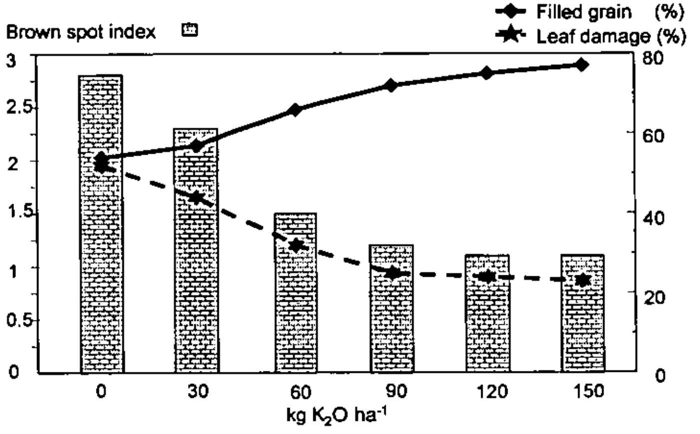

Fig. 5. Effect of potassium on brown spot damage and grain filling of rice (Adiningsih *et al.*, 1994).

Ruan *et al.* (2000) studied the relationship between K nutrition and resistance of tea plants (cv Lonjing 43) to three fungal diseases which differ largely in their mode of infection and damage caused. *Gloeosporium theaesinensis* (anthracnose) invades the tea plant at the base of leaf hairs located in the lower surface of younger leaves. *Guignardia camelliae* (brown blight) invades mature and old leaves directly through the epidermis and primarily reduces the production of new shoots. *Pestalotiopsis theae* (grey blight) is a weak parasite that invades leaves mainly *via* wounds and may pose serious damage especially when tea is mechanically harvested.

Plants inoculated with the pathogen that causes anthracnose initially showed 9 leaves or 4 seedlings with symptoms of anthracnose in the control treatment (without K application) while with 250 mg kg^{-1} K_2O, no plants were affected (Figure 6). The number of leaves/seedlings infested increased rapidly with the duration of the experiment. At 36 DAI, the number of leaves and seedlings with symptoms of anthracnose in the control treatment were 2.8 and 3 times larger than those with K, respectively.

The strong suppression of the anthracnose outbreak with K may be due to the small amount of exchangeable K in the soil. Perrenoud (1990) concluded that disease suppression by K is usually confined to soils deficient in this nutrient. A causal reason for this observation could be that K increases the hardness and thickness of the leaf surface. On the other hand, an alteration of the leaf's chemical composition could have played an important role. With K low-molecular substances, e.g. soluble nitrogen fractions, amides and amino acids that are usually preferred as "food" by the pathogens are synthesized to polymeric substances such as proteins, mismatching the dietary requirements of the pathogens.

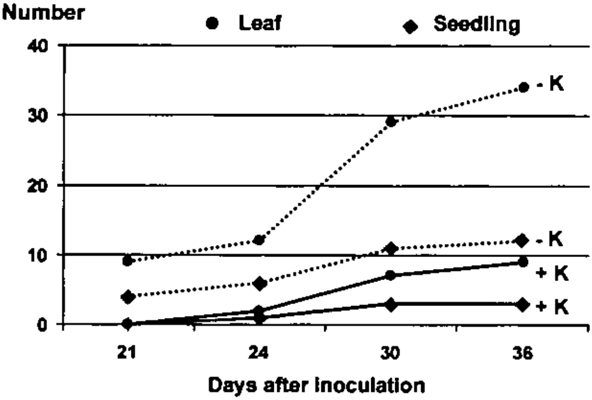

Fig. 6. Effect of potassium on the reduction of anthracnose infection on tea leaves and seedlings. The experiment was on a red earth soil with 35 mg kg^{-1} exchangeable K (Ruan *et al.*, 2000).

Similarly, the infestation rates of grey blight increased gradually with time and continued to increase until 37 DAI. During all stages recorded, the disease was significantly reduced in the treatments receiving K (Figure 7).

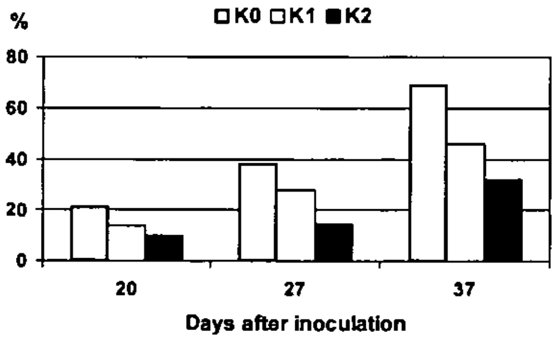

Fig. 7. Effect of potassium on grey blight infestation of tea grown on a red earth soil plus quartz with 71 mg kg^{-1} exchangeable K (Ruan *et al.*, 2000).

Increasing the rate of potassium application from K1 to K2 further decreased infestation. The most drastic effects of K on the depression of grey blight was observed at 37 DAI with a reduction in infestation of 33 and 54% with the K1 and K2 treatments, respectively.

The mechanisms involved in reduced susceptibility of plants to pathogens through applying K are discussed below but, besides changes in morphology, the reduction of damage by fungi may be also due to enhanced synthesis of certain organic compounds. These latter may act as phytoalexins, inhibiting growth and spread of the pathogens. Chakraborty *et al.* (1994) found that higher contents of certain polyphenols may exert such antifungal effects in plants. Recent results by Lang'at *et al.* (1998) confirm the close negative correlation between polyphenol contents and the incidence of grey blight.

Bacterial attacks

Bacterial diseases are caused by various facultative parasites which can be divided into leaf spot diseases, soft rots and vascular diseases. The main bacterial disease in rice is bacterial leaf blight caused by the facultative parasite *Xanthomonas oryzae*. According to Marschner (1995) this type of pathogen usually enters the host plant through the stomata, multiplying and spreading in the intercellular spaces of the leaves. Calcium (Ca) and K are important factors limiting the susceptibility of plants to this disease.

The infection by *Xanthomonas oryzae* is enhanced by N and reduced by K application. **Devadath and Padmanabhan (1970)** found that besides numbers of leaves affected, N also increased the length of the lesions caused by this parasite (Table 1).

Table 1. Effect of different amounts of nitrogen and potassium on the length of lesions of bacterial leaf blight infested rice leaves (Devadath and Padmanabhan, 1970).

Potassium rate, kg K_2O ha^{-1}	Nitrogen rate, kg N ha^{-1}			K effect
	60	120	180	
60	11.4	12.7	16.3	
120	10.1	11.7	14.4	
180	9.1	10.3	6.8	
N effect				

Figures denote length of lesions in cm.

The effect of the nutritional status of the host plant affected the multiplication and severity of the disease which was obviously enhanced by excessive N and insufficient K. The impact of N on leaf damage is reversed as soon as K is in ample supply. That these two nutrients modulate disease infestation not only for bacterial attack but also for facultative fungal parasites is important for fertilizer application strategies and is discussed in the next section.

The potassium : nitrogen interaction

Data in the literature with respect to whether N or K have either negative or positive effects on plants' susceptibility are often inconsistent. This may be explained by the level of nutrient supply at which the experiments were carried out. On the other hand the kind of parasite attack, i.e. whether the plants were affected by facultative or obligate parasites plays an important role for the observation and the action to be taken by the grower. Whereas obligate parasites rely on assimilates supplied by living cells, facultative parasites prefer senescing tissue or release toxins which kill the host plant. The response of these different types of parasites to the N and K supply varies accordingly; a large N supply increases the severity of infection by obligate parasites but generally has an opposite effect on facultative parasites (Figure 8). To the group of obligate pathogens belong rust diseases and powdery mildew, whereas the group of facultative pathogens consists of the major leaf spot, stem rot, as well as bacterial spot and wilt diseases. In contrast to N, K depresses both types of pathogens.

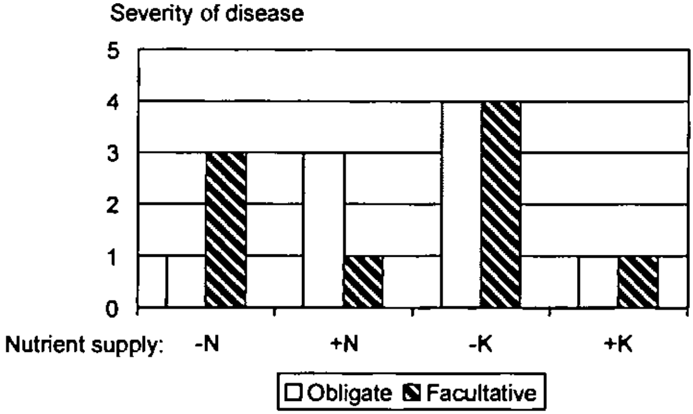

Fig. 8. Severity of effects caused by obligate and facultative parasites as affected by the nitrogen and potassium supply (1 = mild; 5 = very serious) (based on Marschner, 1995).

The ratio between N and K obviously plays a dominant role in the relationship between the host plant and the parasite. The K supply seems to be crucial for the modulation of the disease infection. In his review, Perrenoud (1990) pointed to the magnitude of this effect and concluded that the use of K decreased the incidence of fungal diseases in 70% of the cases he quoted. The corresponding decrease in bacterial infestation was 69%, pests 63% and viruses 41%. Simultaneously, K increased the yield of plants infested with fungal diseases by 42%, with bacteria by 57%, with pests by 36% and with viruses by 78% (Figure 9).

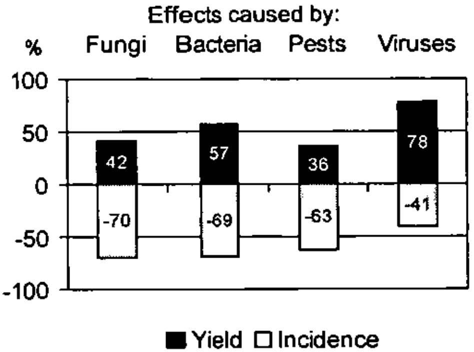

Fig. 9. Reduction of pest and disease incidence and corresponding yield increases by K application in 2450 studies with various crops (Perrenoud, 1990).

Mechanisms

Modifications in the host/parasite interaction caused by crop nutrition may be the result of a combination of factors, e.g.:

- host/pathogen coincidence,
- host's anatomy and morphology,
- host's metabolism and chemical composition.

A prerequisite for a successful infestation is the coincidence of certain developmental stages of both host and pathogen. The use of fertilizers can affect this coincidence by either accelerating or slowing down the development of the host plant relative to that of the pathogen. Furthermore, the occurrence and disease pressure caused by certain pathogens is closely linked to environmental conditions (temperature, humidity). Pathogens which like humid and warm climates are likely to be more aggressive if these conditions occur compared to pests which prefer a dry climate.

Environment

Suparyono *et al.* (1992) studied the occurrence of various rice parasites in both wet and dry seasons at various levels of soil K supply (Table 2). Their observations show distinct differences in disease incidence with K between the seasons. For the pathogens studied, the effects in the wet season were generally more pronounced than in the dry season. The effect of K application during the wet season, however, seemed to be confined to soils with low and medium K status. At the site rich in K, soil K was obviously sufficient to reduce overall disease incidence during the wet season. In contrast, K application had a more significant impact on the reduction of the major observed diseases in the dry season. This could be due to temporary depletion of soil K, caused by larger K uptake during the dry season, explained by greater biomass accumulation promoted by the higher light intensities. Despite the fact that the soils had been classified as rich in K, the greater disease incidence during the dry season indicated that the indigenous K supply was not sufficient to supply enough K for biomass accumulation and to increase the crops' resistance to pathogens.

Table 2. Disease suppression of rice affected by various parasites in plots receiving 90 kg K_2O ha^{-1} (Suparyono *et al.*, 1992).

Location Disease	Disease suppression (%) WS 89-90	 DS 90
Jakenan (poor in K)		
Stem rot	42	32
Sheath blight	19	20
Brown spot	69	43
CLS	-	51
Singamerta (medium in K)		
Stem rot	37	22
Sheath blight	50	21
Brown spot	-	-
CLS	64	13
Ngale (rich in K)		
Stem rot	29	14
Sheath blight	-	16
Brown spot	-	29
CLS	-	32

- = very low disease intensity, WS = Wet season,
DS = Dry season, CLS = Cercospora leaf spot

Morphology and anatomy

A change in morphology and anatomy of plants after nutrients are applied is an essential aspect with regard to the infestation by pathogens. The walls of the cells in the cuticule and the epidermis are the major physical barriers to parasites, restricting penetration into the host plant. Nutritional impact on plant resistance to parasites may therefore primarily be expected from alterations of these barriers. Potassium has been found to improve physical properties of culms (Table 3).

Table 3. Effect of potassium on the hardness, thickness and lignin content of rice culms (Noguchi and Sugawara, 1966).

Treatment	Hardness of the culm*				Thickness of the culm (mm)			Lignin content (% DM)
Internode	1	2	3	4	1	2	3	
NP	3.0	2.2	1.5	1.4	0.84	0.49	0.37	26.9
NPK1	6.0	4.0	3.0	2.5	0.86	0.55	0.40	27.5
NPK2	6.5	4.6	4.0	2.6	0.92	0.59	0.42	29.3

*Force required to crush 1 cm of the main culm

When K was applied, the thickness, hardness and the lignin content of the rice culms was increased and rice plants well supplied with K are less susceptible to stem rot. Noguchi and Sugawara (1966) found that K also has a positive effect on the silica (Si) content of rice plants (Table 4). Because Si is essential for the improvement of structural strength, it protects rice plants especially from fungal diseases, e.g. leaf spot disease and rice blast. Large amounts of N generally decrease whereas K increases the Si content of all plant parts.

Table 4. The effect of potassium application on the silica content (% in dry matter) of rice plants (Noguchi and Sugawara, 1966).

Treatment	Leaves	Stem	Ear	Root
	% Si			
NP	14.1	4.7	3.4	3.0
NPK1	18.0	5.9	3.9	3.9
NPK2	17.8	6.1	4.1	4.1

On soils with very limited Si availability, the Si content in the dry matter of plants may further decrease, probably due to dilution by growth. Therefore, an application of this nutrient under conditions of low soil supply is advisable because Si is also an important factor enhancing the physical barrier against pests, e.g. stem borers.

Calcium (Ca) is another nutrient that is important for the formation of physical barriers against penetration of pathogens into plants. Calcium is essential for both the stability of bio-membranes, controlling the efflux of low-molecular substances, and as a structural constituent of the middle lamella, where it is required for cell wall stability. Many pathogens invade plant tissue by producing extra-cellular pectolytic enzymes that lead to disintegration of the middle lamella. A decrease in the damage caused by such enzymes can thus protect plants from an infestation by parasites and Ca has a strong inhibiting effect so that the susceptibility of plants to parasites, using such enzymes for invasion, is very much reduced by adequate supply of this nutrient. Because K may act as an antagonist to Ca, decreasing its concentration in the plants, it may be expected that K reduces the inhibitory effects of Ca on pectolytic enzymes produced by pathogens.

Prabakar (1991), however, found that K significantly reduced the activity of various enzymes produced by the pathogen *Pyricularia oryzae* and significantly reduced the incidence of rice blast. The maximum inhibition on the production of the enzymes occurred at 125 kg K_2O ha^{-1} (Figure 10) probably because K raised the β-glucosidase activity contributing to an increase in the phenolic levels, building resistance towards invading pathogens.

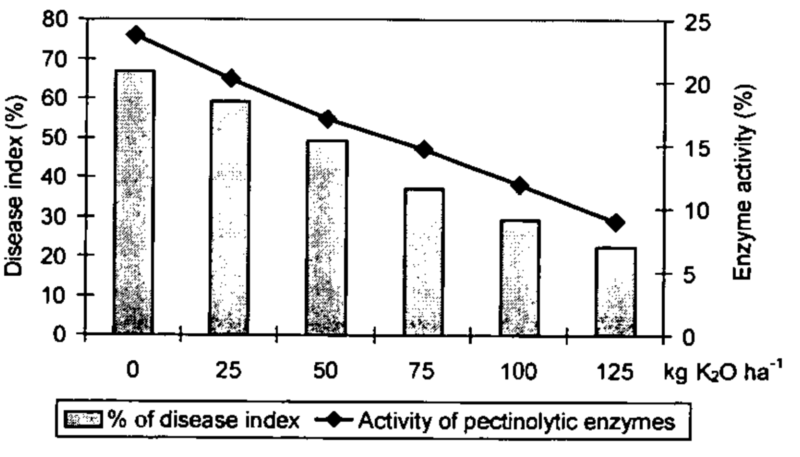

Fig. 10. Influence of a potassium application on rice blast incidence due to reduction of pectinolytic enzymes produced by *Pyricularia oryzae* (Prabakar, 1991).

Our own field experiments (Ruan *et al.*, 2000) indicate that such an inhibition of fungal infection in tea may be caused by an enhanced synthesis of polyphenols, which were increased in the leaves of plants adequately supplied with K.

Metabolism and chemical composition of the host plant

Once a pathogen has crossed any physical barrier and entered the plant, the damage caused depends largely on the dietary preferences of the parasite and the biochemical composition of the host. Generally, parasites prefer low-molecular weight, soluble substances, e.g. amino acids and sugars. Robinson and Hodges (1981), reported that amino acids have a strong influence on the development of fungal conidia.

The effect of balanced nutrition of rice on the content of soluble N and sugars in relation to total N and carbohydrates, respectively, was studied by Noguchi and Sugawara (1966). Their results clearly show effects of K on the composition of leaf sheaths (Table 5).

Table 5. Composition of leaf sheaths of rice as influenced by K nutrition (Noguchi and Sugawara, 1966).

Treatment	Total N* (%)	Soluble N* (%)	Soluble N : total N-ratio (%)	Total Carbohydr.** (%)	Sugar** (%)	Sugar : carbohydr.-ratio (%)
NP	0.98	0.45	45.9	23.2	2.43	10.5
NPK1	0.61	0.21	34.4	24.3	1.79	7.4
NPK2	0.57	0.18	31.6	24.5	1.52	6.2

* at heading
** at panicle initiation

Potassium application decreased total N in the dry matter of leaf sheaths. But the most important result with regard to susceptibility is the fact that the content of soluble N decreased more, so that the ratio of soluble N to total N declined. The decline in both soluble and total N may be explained by a dilution effect due to improved growth as consequence of the better K supply.

A more drastic effect was observed with regard to carbohydrates. Potassium application slightly increased total carbohydrate content whereas it drastically reduced the soluble sugar fraction.

Carbohydrate metabolism also influences the synthesis of phenols which are known as being toxic for many pathogens (Goodman *et al.*, 1967). On the other hand, phenols are important precursors in the biosynthesis of lignin (Marschner, 1995), being important physical barriers for attacks by parasites. In most of the biochemical and biophysical processes directly or indirectly related to the resistance of plants against parasites, N and K clearly appear as antagonists. Because large yields normally require large amounts of N, adequate amounts of K need to be applied. This would lead to increased yields of crops with a better resistance to pathogens, whilst also decreasing the requirements of pesticides.

Conclusions

The role of mineral nutrition, and particularly that of K, is usually explained by its role in the physiology and metabolism of the plant. Its effect on the expression of biotic stresses, whether reducing or enhancing plants' susceptibility to certain diseases, depends, in addition to the nutrient itself, on internal and external factors. The internal factors can be described by resistance, e.g. the ability of a host to restrict penetration, development and reproduction of a pathogen or tolerance which allows the host to maintain its own productivity despite infection (Figure 11). Resistance and tolerance are generally caused by escape from the attack (apparent resistance), anatomy, and inhibitory substances produced by the host plant.

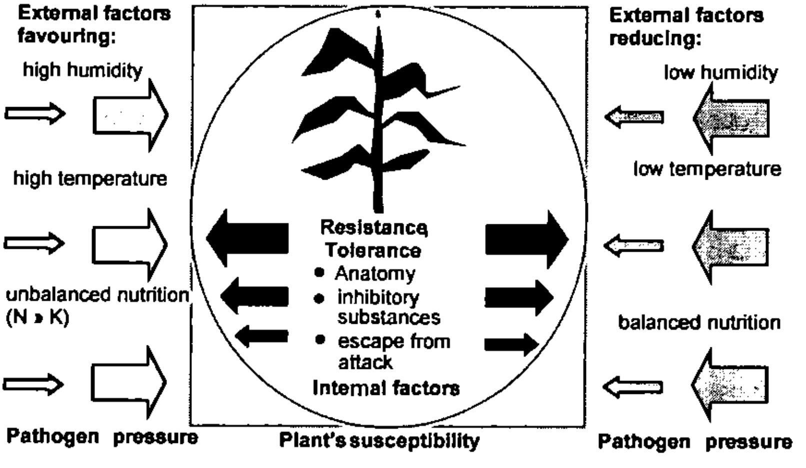

Fig. 11. The interaction of internal and external factors on the expression of damage caused by a pathogen or pest.

Considerable progress has been made in breeding and selection for resistance and tolerance against pests and diseases. Although genetically controlled both resistance and tolerance are strongly influenced by external or environmental factors as shown in Figure 11. Besides humidity and temperature, nutrition plays an important role in modulating the susceptibility of a host plant to a pathogen attack. In this respect an unbalanced supply of N and K in favour of N often promotes the penetration (softer tissue) and spread of a pathogen (low molecular organic compounds). A sufficient supply of K has been shown to inhibit infestations by various pests and diseases and offers a potential to increase the plants tolerance and resistance to withstand an attack. Various mechanisms have been discussed, including the influence of K on anatomical and chemical properties of plants.

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Acquiring and putting knowledge into practice – the role of IPI

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Celebrating 50 years of IPI, or 50 years of promoting balanced fertilization may raise certain questions. For example, whether world agriculture has not yet accumulated enough knowledge and done enough promotion to make further effort obsolete. If further research and promotion is necessary, what form should it take?

World agriculture is confronted with a rapidly changing demand situation

The global population is still growing and might reach a plateau of eight to ten billion in some thirty years from now. More people need more food. Most of the population growth will occur in developing countries. But the natural resources of land, water and energy are becoming scarce and thus expensive, especially in the densely populated regions of Asia. Population pressure together with restricted availability of resources will require increased productivity from those resources which are already being used.

However, it is not only the increasing number of people who need more but affordable food, it is the changing food habits which are a challenge to world agriculture. Driven by an advancing urbanization, especially in developing countries, people look for more diverse and easily managed food rich in protein, vitamins, functional food components etc. Satisfying these changes will impact on the crop spectrum because the increasing demand for animal protein will stimulate the production of feed grains, particularly maize and soybean.

Additionally, the demand for more and diverse food is increasingly complemented by the demand for quality and safe food. Recent food crises in Europe question the trustworthiness of conventional agriculture. Many consumers and politicians especially in developed countries see an alternative in organic agriculture. But, can farming based on recycling with restricted external inputs be sustainable, can low-input agriculture produce enough food at affordable prices? Equally is it possible to expect communal farmers in Africa to adopt high-input agriculture without ensuring that they have available affordable inputs and a market for their produce at fair prices and importantly the necessary knowledge to make the appropriate changes?

Equally importantly today, consumers expect something more than food from agriculture, they require a clean and healthy environment. The conceptual integration of agriculture into the needs of an acceptable environment has become a major issue in agricultural policies in industrialized countries. Policies that boosted, through support prices and market intervention, the production of agricultural goods is over. Milk lakes and butter mountains belong to the past. The farmer will sooner or later be liable for the cost of environmental damage resulting from bad farming practices, the polluter-pays principle. On the other hand, it is still an open question as to how to pay farmers when they maintain and contribute to the environment and landscape for the benefit of others.

The background to environmental needs differs in developing countries and industrialized countries. In the former, the top priority is to produce enough food, feed and fibre with available resources, the current price/cost relationship for production, market access and infrastructure. Food must be made available at affordable prices. Hunger is still prevalent in many parts of the world. However, it is not necessarily lack of food which makes more than 600 million people go hungry to bed, it is poverty first of all, it is powerlessness, civil conflict and also environmental degradation.

Of course, agriculture in developing countries cannot be seen in isolation. Globalization, access to world markets, compliance with the rules and regulations of importing countries are some of the policy issues relevant for developing countries which may slow or restrict their development. Without producing enough top quality agricultural products to satisfy export markets, developing countries will not be competitive.

Knowledge transfer – the basis for a competitive agriculture

To repeat, today we need food security, food diversity, food quality and food safety from farming systems that comply with the needs of the environment, that safeguard natural resources and that must be sustainable. In this context, the World Commission on Environment and Development interpreted sustainability as a "*Development which meets the needs of the present without compromising the ability of future generations to meet their own needs*".

One of the key elements to achieve this goal is appropriate fertilizer use and nutrient management because without adequate nutrients plants cannot grow. Scarcity of land and water forces farmers to produce more from the same area of land or volume of irrigation water. Traditional practices to fertilize a crop yielding 2 t/ha are not applicable if a yield of 20 t/ha is achievable and required.

Achieving food diversity with a wide crop spectrum that includes oilseeds, like soybean, or vegetables demands a different nutrient management strategy compared to a cereal dominated mono-culture. Root patterns, and hence the spatial exploitation of soil for nutrients, the nutrient content of the harvested produce and genotype nutrient requirements are some of the factors that will determine the nutrient management of different cropping systems.

Food quality, whether constituents, like protein and sugar, or other desirable traits like taste, appearance and freedom from pests and diseases, are closely linked to the nutrient supply of the plant. Unbalanced nutrition spoils quality and farmers lose their competitiveness in the market.

Food safety refers to contamination with compounds and elements that can affect the health of the consumer, both humans or animals. Appropriate balanced nutrition of crops for example can improve their resistance to pests and diseases and thus lower the requirement for crop protection products. This reduces the risk of producing contaminated food while, at the same time, improving acceptance in the market.

The increasing awareness of the multifunctionality of agriculture, in not only producing enough food, feed and fibre but also maintaining the landscape, to give pleasure and recreation to urban people, will also have an impact on nutrient management, especially to minimize losses of nutrients from agriculture. Nitrogen (N) use efficiency of 25-50% and P rich runoff water are a waste of natural resources including energy. To counter these losses requires a break with traditional thinking and the adoption of modern nutrient management systems and models. For example, nutrient auditing can make crop production more transparent, both to legislative bodies and consumers.

Larger crop yields and better quality with appropriate use of fertilizers aid rural development provided appropriate economic structures are in place to give farmers sufficient incentives to try for greater productivity and quality. With increasing purchasing power, farmers spend more money on non-agricultural products and they are more inclined to re-invest into soil fertility. This attracts other business and creates jobs. Furthermore, appropriate fertilizer use according to the site and crop specific needs supports the sustainability of crop production and protects the environment.

On the other hand, poor infrastructure, inaccessible markets, non-tariff barriers in international trade, lack of credit, powerlessness, unclear land title and last but not least, lack of knowledge are some of the obstacles to increasing yields and generating income. These are also the conditions that create a lack of interest in the environment and the fertility of the land on which sustainable crop production depends. Unproductive land leads to farmers being caught in the poverty trap.

Results from field trials and research work on the effect of plant nutrition on yield and quality are numerous. There is also an increasing number of decision support systems, planning tools, qualitative and quantitative soil and plant test procedures available to assist and guide the farmer in nutrient management. Nutrient accounting helps the farmer to comply with legislative requirements while, at the same time, being an essential tool to monitor the sustainability of a production system. The crucial point, however, is to bring this information and experience to the farmer, especially in regions with limited communication systems.

The role of IPI in knowledge transfer

The working philosophy of IPI is to transfer knowledge "*from the lab to the land and from the land to the lab*". As an intermediary between the farmer and researcher, IPI aims to inform farmers about the latest knowledge concerning the effect of balanced fertilization, with adequate potash, on the yield, quality and stress tolerance of crops. On the other hand, IPI aims to stimulate research on the behaviour of potassium (K) in soil and its function in the plant, in order to explain and understand observations in the farmers' fields and give appropriate fertilizer recommendations.

Also, IPI wants to make the input sector aware of the market opportunities, and inform decision-makers and politicians about the status of soil fertility, crop production, especially the impact of improved practices, and the economic situation of farmers.

Why the focus on K and balanced fertilization? It is because fertilizer use has become more and more unbalanced especially with regard to K. The current use of potash, especially in developing countries, is far less than the removal of K by the harvested crops. This implies considerable soil K mining with serious consequences for the sustainability of soil fertility. Furthermore, unbalanced fertilization also leads to decreased use efficiency of fertilizers, especially of N fertilizers. Apart from the negative effect on the environment and sustainability, inefficient fertilizer use with unbalanced fertilization decreases farmers' income because of under-utilization of the applied nutrients and the loss of crop yield.

There are many reasons for the increasing imbalance in fertilizer use. For example, N fertilizers are readily available and have an immediate effect on the crop's growth so they are used in preference to P and K fertilizers, especially in times of economic constraints. Furthermore, K is an ecologically friendly nutrient and thus not subject to research for environmental reasons.

Another factor responsible for unbalanced fertilization is simply lack of knowledge on the behaviour of K in soils and its effect on plant growth. In the soil, K is subjected to dynamic exchange processes between four pools that differ in their K release characteristics, namely rapidity, intensity and capacity. Routine soil tests usually consider only partially the availability of soil K, methodological constraints prevent examination of other soil K pools. Therefore, response predictions based on routine soil test values can be as often wrong as right. More research is needed to better understand the underlying processes in the soil to develop more reliable soil tests leading to more precise fertilizer recommendations. Another shortcoming is the absence of any practicable method to predict the stock of K in soil and its availability over time.

In plants, K is a multifunctional and highly mobile nutrient. Very many biochemical and biophysical processes are directly or indirectly affected by K. It catalyzes numerous enzymatic reactions, it is involved in assimilate formation and translocation and controls the water status of plants. Due to the versatile and central role of K in crops, their yield, quality and stress tolerance can be related to their K status. This is especially so in relation to their tolerance of biotic and abiotic stress, i.e., to pests, diseases, climatic and soil-borne calamities such as frost, heat, drought, salinity. Unfortunately, due to their lack of knowledge, farmers seldom relate stagnating yields, poor crop quality and/or increasing susceptibility to stress to an imbalance in nutrition and K deficiency.

The Three pillar approach of IPI

To collect and distribute information on the effect of balanced fertilization with K, IPI has adopted its "Three pillar" approach, namely:

- On-farm activities: simply designed field trials executed by the participating farmer, and supervised by a professional advisor of the cooperating scientific institution, aim to demonstrate the beneficial effects of balanced fertilization. These trials are complemented by local field days to inform a larger group of farmers by "learning by seeing", and not only farmers but fertilizer distributors and extension workers. The trials may also initiate further scientific research when need arises.
- Seminars and workshops: These are mainly scientific gatherings with participants from a particular agro-ecological region. They serve as a platform to exchange views and experiences in research related to K. Country reports on the status of soil fertility, crop responses and fertilizer use provide valuable information to planners, decision-makers and to the fertilizer sector. All contributions during these events are published as "proceedings" for further dissemination of the findings.

  More recently, IPI has started to conduct training programs on certain issues such as fertigation or fertilizer marketing.
- Publications: IPI produces publications for different stakeholders.
  - Leaflets: crop-specific information for farmers and extension workers in a particular country, in the local language, easy to read, with local results and recommendations.
  - Country reports: in English and the local language, to inform about the situation of crop production and fertilizer use in general, and crop responses to potash in particular. The target groups are local extension agents, the fertilizer sector and decision-makers.
  - International Fertilizer Correspondent, *ifc*: published twice a year with about 5,000 addressees worldwide ranging from farmers to scientists and decision-makers, it informs in a popular way the achievements of IPI and others with respect to soil fertility and fertilizer use.
  - Crop Bulletins: 60-80 page booklets on a specific crop, written by a prominent expert/scientist, which describes the botany, economic importance, function of nutrients, nutrient demand and fertilizer recommendations for that crop. It is meant as a reference for students, scientists and planners in advisory services.

- Research Topics: Booklets of 60-80 pages on an issue related to soil fertility and/or fertilizer management relevant to a particular region. Also written by a prominent expert/scientist, they target extension agents, students and scientists.
- Proceedings: all oral and poster presentations at major IPI workshops and symposia are published as proceedings of the meeting.
- IPI website: it contains information on IPI, more recent results and publications, a calendar of forthcoming events related to soil fertility and fertilizer use, and is linked to its member companies and major fertilizer associations.

Current projects

IPI is currently conducting projects in China, Vietnam, India, West Asia North Africa, Central/Eastern Europe, the FSU, Argentina and Brazil. These activities are managed by "IPI-Coordinators" and supervised by local scientists from universities or research institutions such as ICAR in India, ISSAS in China, SWRI in Iran or EMBRAPA in Brazil.

Do we still need promotion of balanced fertilization as done by IPI?

The dynamic processes in agriculture are subjected to demands for continuous change to adapt to rapidly changing market situations. New issues such as sustainability, environment, multifunctionality are further challenges which confront crop production around the world and both advisors and farmers must be in a permanent learning process to cope with each new development.

Of course, farmers in industrialized countries have, in most cases, easy access to all kinds of information and the latest recommendations. Not so the farmers in developing countries. Often handicapped by illiteracy, devoid of information and ignored by inefficient advisory services in many countries, these farmers need knowledge. They are eager to learn and to adopt the idea of balanced fertilization, provided on-farm demonstrations can convince them and the market situation can supply the inputs and incentives.

Extension workers from both the public and private sector are also interested to receive information, even from other regions, in order to compare and to readjust their own systems. This group of IPI customers is indispensable to communicate and disseminate results and experiences at the local level.

The fertilizer sector is interested in feed back on fertilizer use and optimum applications on crops. This helps to develop new products and market strategies that improve the availability of appropriate fertilizers. IPI maintains close contacts with fertilizer associations in all parts of the world.

Scientists in developing countries seldom have the opportunity to interact directly with farmers. Lack of funds also prevents them meeting colleagues from other institutions and countries. With joint research programs and through sponsored regional and international seminars and workshops, IPI creates the opportunity to meet and stimulate research activities.

Last but not least, IPI tries to attract senior officials, local decision-makers and politicians to address its regional IPI conferences. Attending such events provides them an inside view of the situation concerning soil fertility and crop production prospects.

IPI, which is a service of the European and Near East potash industry, will continue its commitment to food security and the environment to the benefit of farmers, consumers and national economies.