Proceedings of the 13th IPI-Congress

Nutrient Balances and the Need for Potassium

International Potash Institute 1986

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CH - 3048 Worblaufen-Bern/Switzerland
Phone 031 58 53 73 Telex 33430 ipibe ch
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Contents

Introductory Address

L. Gachon, Director of Research, I.N.R.A., Clermont Ferrand/France; member of the Scientific Board of the International Potash Institute; chairman of the 13th I.P.I. Congress

In the name of the Organising Committee of the 13th Congress of the International Potash Institute, I would like to associate myself with *President Celio* in extending the most cordial welcome to the delegates from the 34 countries who honour us by their presence and their interest in the theme of the Congress.

Farmers and agronomists alike are much concerned with nutrient balances whatever may be the local ecological, economic and social conditions. It is accepted that those engaged in agriculture should achieve a standard of living enjoyed by those in other professional occupations. While this is without doubt a worthy objective it is also of prime importance that it should be realised without risk to the environment. Rational fertilizer usage is central to the solution of the problem. In profiting from the new methods placed at his disposal, the farmer can improve the efficiency of his enterprise but he must also show concern for the future and concern for the effects of the cycling of nutrients in the system he adopts. He needs a thorough understanding of the fluxes of nutrients in time and space in order to improve management.

The fluxes with which we are concerned take place within the soil-plant system and result from the global potential of the soil to supply «assimilable» ions and the potential of the root system to take advantage of the supply which are integrated in the processes of ionic equilibria and changes of state and also in growth and functioning of the root system. We are also concerned with interactions between the soil-plant system and the environment; in inputs and outputs of nutrients in solid, liquid or gaseous form.

In the course of this Congress, specialists will describe the present state of knowledge of the various components of nutrient balances in relation to cultural methods and agricultural systems. As is customary in the Congresses of the *International Potash Institute,* scientific aspects will be discussed in relation to case studies with particular attention to potassium.

This Congress is in effect the conclusion of a series of three colloquia devoted to nutrient balances in the 3 main climatic zones of the world the conclusions of which will be summarised in the opening session by the 3 colloquium chairman.

It is perhaps significant that Reims is situated at the geographical centre of the European Community near to the political and administrative centres in Strasbourg, Luxembourg and Brussels. The congress is being held at a point in time when the *EEC,* formerly a net importer of agricultural produce, is cracking under the strain of surplus production notably of milk, beef, wheat and sugar.

The result of the joint effects of the growth of international exchanges, a sharp increase in the cost of labour and consumption of intermediates in relation to the value of agricultural produce is that the European agricultural market finds itself locked in pitiless world competition which some have gone so far as to describe as economic warfare. From the strictly economic point of view, such a situation must have inevitable consequences for the progress of agricultural intensification which involves increase in the productivity of labour by the injection of capital and the adoption of the most recent techniques.

Such development – which might well be called industrialisation – nevertheless has its limits because farming is, and will always remain, an activity subjected to the constraints of soil and climate, that is if we exclude the small areas under glass in the temperate zone and the outer limits of the irrigated areas of the arid and sub-arid zones. While there is progressive intensification in the geographically favoured parts of the *EEC* there is also to be noted an extension of the areas classed as less favoured and, on this account, qualifying for aid from the Community. The process is not specific to Western Europe and is most noticeable in tropical countries where are to be found striking contrasts even within one territory.

At this point I will interrupt my thoughts to tell you something about the Champagne region where we find ourselves today. Here also there are marked contrasts which the organisers originally intended to demonstrate to you in the course of the excursions, but the distances to be travelled and constraints of available time meant that this plan had to be abandoned. On the excursions you will visit only two geographical areas near to Reims; one representing agriculture firmly wedded to the course of increased productivity, the other more traditional and devoted to high quality. Both illustrate the contributions of science and technological development; both pay attention to the conservation of the rural environment.

Central Champagne through which you will travel on Thursday is situated on the chalk, a parent material containing an average of 95% calcium carbonate and extremely low in plant nutrients. Fifty years ago it was the home of a depressed population, a country of scrubby pines and poor downland traversed by sheep which the ecologists called the «alliance du Mesobromion», an area much favoured for military encampments. It was called the «wretched Champagne» an expression of the extreme poverty of the soil. Today, thanks mainly to fertilizers, these rendzina soils have become some of the most productive in Western Europe.

To the west, the chalk is overlaid by the tertiary sediments of the Paris basin giving rise to a «cuesta» relief. Here is the home of the vine and that wine, the famous champagne, such an excellent drink for the celebration of social contacts and for the toasting of success whether it be a wedding, a birth or a Congress. So this congress will not fail to honour the tradition and furthermore you will tomorrow afternoon have the opportunity for some contact with viticulture and the mystique of champagne manufacture.

Finally, you will recall from your knowledge of history that it was at Reims in the magnificent gothic cathedral that the first kings of France were crowned. The organisers of the 13th Congress had the happy idea to offer you a spectacle at this heart of French history which I strongly advise you not to miss.

I hope – and I am confident – that, through participation of each one of you in our discussions, this scientific pilgrimage to Reims will be a success.

13th Congress of the International Potash Institute
August 1986 in Reims/France

1st Session

NPK nutrient balances in different climatic regions and production systems based on IPI-Colloquia 1983–1985

Co-ordinator: *Prof. Dr. H. Laudelout,* Soil Science Dept., Catholic University of Louvain/Belgium; member of the Scientific Board of the International Potash Institute

Nutrient Balances and the Need for Fertilizers in Arid and Semi-Arid Regions**

H. Laudelout, Soil Science Dept. Catholic University of Louvain/Belgium*; member of the Scientific Board of the International Potash Institute*

If we can say that in the humid tropics agriculture is able to exploit the climate in spite of the soil, the contrary is the case in the arid and sub-arid regions. Whatever the parent material, a long history of pedogenesis in the tropics has produced strongly leached soils with very low concentrations in the soil solution, where aluminium occupies many of the exchange sites, where phosphate levels are very low and held very strongly and irreversibly. While such conditions are unfavourable for the growth of higher plants they apply similarly to microorganisms resulting in low bacterial and fungal biomass. Despite these unfavourable conditions however, generally high temperatures, which do not exceed the optimum for photosynthesis, and abundant rainfall allow active photosynthesis virtually throughout the year.

The situation is quite otherwise in the arid and sub-arid regions where we are concerned with soils having abundant mineral reserves but a too dry climate and ruling temperatures often unduly high and where also soil physical properties are far from the ideal. It was essentially with the latter problem that the *17th IPI Colloquium* at Rabat and Marrakesh was concerned. The set of papers and communications presented gave an excellent theoretical and practical basis for the formulation of sound fertilizer policies for these areas.

Emphasis was placed on an important eco-climatic characteristic of these regions: the period of maximum rainfall, winter as in the Mediterranean areas or summer as in the tropics. The options which these climatic differences present are fundamentally dissimilar. Irrigation is obviously necessary in the Mediterranean climate but very often much more expensive than the adaptation of crops to shortage of available water. Avenues of approach in this area are extremely diverse: development of a root system which will guarantee maximum utilisation of water reserves, physiological adaptation of the plant's water economy, the effects of different nutrients on tolerance of drought stress.

* Prof. *H. Laudelout*, Dépt. Science du Sol, Faculté d'Agriculture, Place Croix du Sud 2, B-1348 Louvain-la-Neuve/Belgium

** This paper summarizes and concludes those presented on occasion of the 17th Colloquium of the International Potash Institute (IPI) in Morocco: *Nutrient balances and the need for fertilizers in semi-arid and arid regions*, pp. 1-394 (1983).
These proceedings are available at the rate of US-$ 25.80 + *mailing charges* at IPI in Bern/Switzerland (see address on the fly-title page of this book).

Nutrient balance under irrigated crops in an arid region is significant from two points of view: concentration by evapotranspiration of the soil solution constantly enriched in salt originating from the irrigation water and the removal of nutrients in increased plant material. The nutrient turnover is very rapid as compared with rain-fed cropping.

The potassium balance is often overlooked in these soils partly because soil potassium reserves are over-estimated but mainly because of over-estimation of the capacity for mobilisation of these reserves. Study of the nitrogen balance is no less necessary; the stumbling block here is underestimation of the increase in soil metabolism and, consequently, mineralisation capacity caused by irrigation.

The increased mineralisation of organic matter, through irrigation or fluctuation in climate, is necessarily accompanied by soil acidification which results in a loss of calcium and magnesium ions for which the nitrate ion plays the role of transporter. Movement of cations into the subsoil is accompanied by downward migration of nitrate. Cations enter the soil solution by exchange with H^+ ions liberated by respiration or nitrification. If the turnover of elements is very active as is the case in forest soils, they can migrate in the form of bicarbonate. If this is not the case, the anion transporter is in 80 % of cases nitrate as was shown by results from Senegal presented by *Piéri*.

The capacity for mineralisation of organic matter seen in arid and semi-arid soils appears to differ considerably from that to which we are accustomed in temperate zone soils. Figures as high as 25% in Moroccan soils and even 50% in Senegal have been quoted for the fraction of organic nitrogen which is mineralizable. Furthermore, this mineralisation proceeds at an excessive rate with the return of the rains causing losses of nitrogen and equivalent quantities of calcium and magnesium. Here there is probably justification for the traditional system of farming using mixed cropping, as, for instance, sorghum and cotton. Reduction in yield of the cotton is largely compensated by improved nutrient and water utilisation by the sorghum. The traditional technique of farming in arid regions is thus similar to that used in the tropics, where after clearing and burning the forest, a whole range of crops are planted together in order to draw the maximum profit from the «flash» of fertility produced by burning. Study of the ionic balance gives a glimpse of the reason for such practices.

Concerning the nitrogen balance of arid soils, it seems that additions from the atmosphere are negligible and that additions from symbiotic fixation are short-lived, at least according to Senegalese experience.

So far as concerns potassium, balance studies show that maintenance of the level requires both the conservation of crop residues and the application of fertilizer. In the case of the mixed cropping of cereals and cotton, one must remember that the grasses compete strongly with the dicotyledon for K.

The different authors' conclusions regarding the movement of potassium in the profile are most variable; if it is true that leaching from crop residues is very rapid, the final destination is less certain. One is tempted to think that in light soils potassium moves at a rate comparable with that of calcium and magnesium, but in fact this does not seem to be so.

One general conclusion from balance studies would appear to be that as well as maintaining equilibrium between gains and losses of potassium and nitrogen, it is most important to pay attention to losses of calcium and magnesium caused by nitrification and respiration of the soil biomass.

It hardly seems that soil analysis is an adequate substitute for balance studies. To quote the opinion of one contributor: «the determination of available K in soil is beset with two problems: (i) there may be a lack of response to applied K on soils containing low or medium levels of exchangeable K. (ii) very considerable response to applied K may be obtained on soils that are very high in K.»

Despite, or because of, pessimistic conclusions, research on methods for diagnosing nutrient requirements continues and some papers in the Colloquium clearly described new avenues which are being explored. As shown by *Marschner* it has become possible to measure and even to calculate the interaction between soil water content, root growth and movement of nutrient ions by mass flow and diffusion. The part played by each flux in the transport of different elements is known and while mass flow is of negligible importance for phosphorus and potassium, it is sufficient for calcium and magnesium. The contribution of mass flow varies greatly with climate and seasons, and the effect of soil moisture content on the contribution from mass flow has been analysed. The main conclusions are that a reduction in soil moisture reduces mass flow but, as it is accompanied by change in ionic exchange equilibria, with, generally speaking, an increase in selectivity for monovalent ions, and thus potassium, the ionic composition of the solution is subject to appreciable quantitative and qualitative variations. Similarly, dilution of the solution reduces by the exclusion of anions the volume accessible to anions and especially to nitrate and this increases convective flux of anions.

If one considers the accumulation of nutrients brought by convective flux to the root surface, local accumulation will depend primarily on evapotranspiration by the plant; thus recorded differences in accumulation of sodium and chloride have varied by a factor of three.

One participant in the colloquium concluded that the mean value for electrical conductivity of the soil solution did not accurately reflect salt concentration at the root surface and consequently the availability of water in the rhizosphere. On the other hand, soil exploration by the root system through root elongation or by extension of the zone containing root hairs would greatly affect relations between mineral nutrition and the diffusive or convective fluxes. The same would apply to mycorrhizal associations which are known to extend considerably soil exploration and also to the microbial population of the rhizosphere which owes its existence to root exudates and also modifies the root environment.

This series of observations explains and justifies the pessimistic conclusion to which reference is made above in connection with the problem of predicting response to potassium fertilizer in arid region soils. If our approach to the problem is not modified, it certainly seems that pessimism will always rule and that conclusions drawn from an isolated analytical result should only be used in conjunction with a consideration of the relationships mentioned above and in the light of the agronomist's experience. While waiting for this integration of results, knowledge and expertise, use of the nutrient balance approach remains a safe haven based on restoration to the soil of losses through crop uptake, leaching, regression or volatilisation. In other words we have to estimate as closely as possible all the items in the nutrient balance sheet.

NPK Nutrient Balances in Different Climatic Regions and Production Systems – Temperate Regions**

A. Malquori, Institute of Agricultural and Forest Chemistry, University of Florence/Italy; member of the Scientific Board of the International Potash Institute*.

The IPI-Colloquium at Gardone-Riviera/Italy in 1984 brought the topic of nutrient balances to the temperate region. The material presented referred essentially to farming in Central Europe which was one of the first regions to see the introduction of fertilizers and their use in increasing crop and animal production. This is a region with a long farming history and where there is much accumulated knowledge of the pedological, physical, chemical and biological properties of the soils. In this region, with rare exceptions, climatic factors have no very great influence on crop production; this is in marked contrast with the hotter regions whether wet or dry.

There have been many changes in the relationship of man with the soil in the temperate regions since the end of World War II; crop yields and the economic returns to farmers have kept pace with the increase in world population and continue to do so. These improvements result from progress in mechanisation, genetic improvement of crops and livestock and in general standards of cultivation (irrigation, fertilizers, plant protection). The introduction of varieties of higher potential has led to refinement in fertilizer recommendations adapted to soils, crops and farming systems. Adjustment of N:P:K ratios has come about through research to improve economic returns with attention to the need to preserve the environment which could be compromised by chemical pollution.

The colloquium was organised in five sections which dealt with:

a) Nutrient balances in farming systems,
b) Evaluation of nutrient balances,
c) Building yields by fertilizer input in temperate agricultural systems,
d) Fertilizer needs in temperate ecosystems,
e) Agricultural productivity in ecosystems.

* Prof. Dr. *A. Malquori*, Istituto di Chimica agraria e forestale, Università di Firenze, Piazzale Cascine 28, I-50100 Florence/Italy

** This paper summarizes and concludes those presented on occasion of the 18th Colloquium of the International Potash Institute (IPI) held in Gardone-Riviera/Italy: *Nutrient balance and fertilizer needs in temperate agriculture;* pp. 1-360 (1984).
These proceedings are available at the rate of US-$ 26.90 + *mailing charges* at IPI in Bern/Switzerland (see address on the fly-title page of this book).

In the 1st Session, *van Diest* showed how the efficiency of fertilizer depended upon general fertility conditions and that in livestock husbandry, the efficiency of N and P fertilizers was inferior to that in stockless farming. Apart from interactions between N, P and K, the efficiency of fertilizer is always affected by supplies of other nutrients, by the availability of water and by the efficiency of plant protection.

According to *Toderi* and *Giordani*, fertilizers are always more efficient in rotational cropping than in monoculture. While nitrogen induces an increase in potassium uptake by the plant, the cultural system has a great effect on removals of phosphorus and potassium.

So far as concerns the effect of irrigation on the yield of mixed grass-legume swards, *McEwen* and *Johnston* found it to exceed that of applying 200-400 kg/ha nitrogen (N) according to circumstances. Nutrient removals were closely related to water availability, *i.e.* greatly increased by irrigation.

In mixed husbandry systems, well developed in N. Europe, *Murphy* showed that nutrient losses were closely related to the method of dealing with slurry and manure. Exports in animal products sold have to be added to these losses. Because of frequent rainfall and the generally light texture of soils, losses of calcium, leading to soil acidity, are important. The control of pH by liming encourages the growth of legumes and hence enrichment of the soil in nitrogen, especially important when N fertilizer use is moderate.

Dealing further with mixed systems, *Walther* indicated that nutrient balance depends mainly on the number and housing of stock, feeding and cultural practices. The phosphorus, potassium and magnesium in farm manures are in forms available to plants and so can enter into the balance as equivalent to fertilizer P, K and Mg. The same does not hold for nitrogen whose efficiency varies greatly between different farm manures. The balance is also affected by storage and distribution methods which should be arranged to minimise losses and the danger of pollution.

From the various papers, it appears that nutrient balances in temperate systems can be established taking into account all factors which are controllable such as amounts and availabilities of the main nutrients, first and second order interactions between N, P and K and the K×Ca and K×Mg interactions plus the interactions between fertilizers and soils as concern availability and uptake by the crop. In addition, there may be considerable fixation of P and K. Thus, in considering balances, the soil has fundamental importance and this can be assessed from analytical data, its physical, chemical and biological characteristics while it may be possible to improve soil structure and pH. It is important to consider the clay mineral composition of the soil and this is not always sufficiently emphasised. For example, in speaking of K fixation, the valuation of non-exchangeable reserve K may need to be modified in the light of knowledge of clay mineral composition *(e.g.* dominance of 2:1 or 1:1 clay minerals).

Other factors which should not be overlooked are: organic matter content, water holding capacity, disease and pest control and control of pollution. It is clear that the element which presents the most problems is nitrogen of which losses can be severe unless steps are taken to minimise them. Gaseous N loss (denitrification and volatilisation) are considered to be more important than leaching losses. It is estimated that in general, some 50% of fertilizer N is lost to the air and drainage. In the final analysis, nutrient balance must conform to the demands of economic farming.

The results of long-term experiments are particularly relevant in a consideration of nutrient balance. According to *Beringer*, it is only such experiments which can provide reliable information as they take into account the magnitude and pattern of nutrient uptake in the course of a succession of crops. Plant-soil relationships in the early stages of growth must also be considered. Knowledge of the interactions between the various elements, as indicated above, aids the interpretaion of analytical results. *Droeven* and *Rixhon* also confirm the value of long-term experiments in assessing nutrient balances, principally of P and K.

In evaluating losses by leaching and erosion in the course of a rotation, important factors according to *Chischi* and *Spallaci* are intensity and distribution of rainfall, pedological characteristics (behaviour of the various horizons), topography and plant cover.

It is necessary to take into account the abilities of different crops to extract the less available forms of potassium *(Ryser* and *Köchl)*. K in biotite is more easily attacked than that in muscovite, as confirmed by *Edelstein* and *co-workers*. In some soils, deep cultivation without mixing surface and lower soil layers can increase yields *(Johnston* and *McEwen)* through increasing the volume of soil accessible to plant roots and this is important in dry periods. Further investigation is needed to establish in which soils this may be important.

Again on the subject of analysis, it appears that determination of soil N by EUF according to *Németh* is well correlated with the N supplying ability of the soil.

In the Session on building yields with fertilizers, *Tinker* introduced a conceptual distinction between «genetic potential», closely related to photosynthesis, «site potential» depending on local soil conditions and climate and «actual yield» realised by the farmer in practice. The difference between site potential and actual yield is a measure of potential progress achievable maybe through choice of rotation, cultivation technique and nutritional, biological and physical factors. These latter can be controlled and adjusted with fertilizer, paying attention to time of application, which in the case of nitrogen can be critical. As to control of nitrogen losses by using nitrification inhibitors, it is necessary, according to *Sequi* and *Nannipieri* take note of crop, soil pH, temperature, the type of fertilizer and biological activity in the soil. Especially in alkaline soils the main loss is by NH_3 volatilisation and the use of inhibitors should be avoided in soils where N losses through leaching and denitrification are small and limited to short periods.

Fertilizer use has implications for plant protection. For instance, according to *Trolldenier* take-all in wheat can be limited by correct N-K balance in the fertilizer. K reduced infection in mild attacks though not in severe. Fertilizer increased tolerance of water stress with favourable effects on affected plants.

Mme Blanc reported on reduction of attack by *Fusarium oxysporum* on carnation and *Coryneum cardinale* on cupressus by both Ca and K in hydroponic culture and with young plants. Consequently as well as achieving N:P:K balance it is necessary to take account of the K:Ca ratio especially if the disease is aggravated by high nitrogen. In such cases an element may have a phytosanitary significance as well as its nutrient importance.

Hébert reviewed the pattern of fertilizer use in the Common Market, relating differences to cultural systems practised in each region. From the economic point of view loss of income through too low fertilizer usage is usually greater than any possible loss caused by excess fertilizer. Nitrogen is always the most critical element while its effects are more easily seen in the behaviour of crops than are those of P and K. N losses are highest in livestock enterprises which, on the other hand, show a positive K balance since K is not a constituent of organic plant material and is returned to the soil in the same ionic form as in fertilizer. *Thévenet* had investigated interactions between irrigation and nitrogen for winter wheat underlying the necessity to consider soil moisture content in the period just before shooting to minimise the danger of pollution.

Mantinger described post-war changes in fruit culture in the South Tyrol/Italy where livestock, and in consequence farmyard manure have virtually disappeared. Orchards now carry grass covers which are cut and mulched and receive moderate dressings of N and K, with care to avoid excess. A new equilibrium has now been established and a surplus of fertilizer would carry risks of pollution of the subsoil. Dealing with vines, *Fregoni* described the value of nutrient maps which along with soil and leaf analysis give a good indication of nutrient requirements with allowance for losses by erosion, denitrification and fixation.

Overrein dealing with European forests, pointed out the dangers of atmospheric pollution which cause soil acidification, especially if Ca is low, increase leaching losses and have toxic effects due to the mobilisation of Al and toxic microelements. Forests become less drought tolerant and more prone to attack by nutrient deficiency and disease. In recent years, air pollution has led to a reduction in photosynthesis with accumulation of toxic materials in the apices and, consequently, a depression in root development by many forest species. The main difficulty in research is the long-term nature, and consequent expense, of such work.

In a concluding paper, *Mengel,* dealing with nutrient availability drew attention to biological factors relating to the root system of crops, such as rate of elongation of the root, and conditions in the rhizosphere which affect uptake of P and K. These are often more important than physico-chemical factors even if it is not easy to demonstrate the effects experimentally. Nitrogen losses by denitrification far outweigh losses by leaching, especially as concerns organic N. Leaching of K can be appreciable, but some control is possible through adjusting times of application. Phosphorus losses are related to ageing of phosphates with progressive reduction in solubilty.

A final impression of this colloquium is that of the importance of losses from the pool of nutrient ions in the soil and the need to quantify these: losses of nitrogen by denitrification and volatilisation; losses of potassium by leaching and irreversible fixation; losses of phosphorus by ageing of fertilizer phosphates ...

Nutrient Balances and the Need for Potassium in Humid Tropical Regions

G. W. Cooke, Rothamsted Experimental Station, Harpenden, Herts/United Kingdom; member of the Scientific Board of the International Potash Institute*

1. The potentials of the humid tropics for crop production

The humid tropics have very great potentials for agricultural production because the solar radiation received, and the high temperatures, promote good growth of all plants. In many areas rainfall is sufficient for rain-fed crops and also to maintain the reserves needed for irrigation systems. Therefore these regions have the potential to feed large local populations and to export food and products for industrial processing to other less-favoured regions. An example of a high potential was given to the *IPI-Colloquium in Bangkok* (1985)** by *van Keulen* in his discussion of this topic, continuous growing of four rice crops in one year resulted in a total grain yield of 33 000 kg/ha.

These high potentials can only be achieved, or even be approached, when all constraints to crop growth are identified and overcome by inputs and/or improved management. The most important constraint is that imposed by inadequate nutrition which is overcome by the use of fertilizers. The weights of N and K taken up by most crops are comparable and the weights of P are generally less. When crops are removed from the farms on which they are grown large amounts of nutrients are removed so that soil fertility is diminished. Therefore there is need to examine nutrient balances at both farm and national levels to assess the need for fertilizers to maintain the productivity required and to prevent the deterioration of soil fertility.

2. The intensification of agriculture

In many countries increased production from agriculture is required to feed the local population more adequately and to provide for the exports that improve national prosperity. Generally expansion of output will depend on increasing the production from land that is now cropped since the areas of land available for conversion to agriculture are limited.

* Dr. *G. W. Cooke,* Honorary Scientist, Rothamsted Experimental Station, Harpenden, Herts. AL5 2JQ/United Kingdom

** This paper summarizes and concludes those presented on occasion of the 19th Colloquium of the International Potash Institute (IPI) in Bangkok/Thailand: *Nutrient Balances and the Need for Potassium in Humid Tropical Regions.* These proceedings are available at the rate of US-$ 29.— + *mailing charges* at IPI in Bern/Switzerland (see address on the fly-title page of this book).

Improvement will require effective management of water and land resources, the use of improved varieties of crops in appropriate cropping systems, and the use of fertilizers and pesticides. Certainly the increased yields needed will not be achieved unless the supplies of nutrients are adequate and the amounts needed must be assessed by considering the factors involved in intensification which are considered here:

2.1. High-yielding varieties

The improved varieties of plants with greater potentials for yield generally take up more K than traditional varieties do and they require a correct balance between NP and K fertilization. An example of differences in nutrient uptakes between a high-yielding rice variety «TNI» and the old local variety which it replaced was reported by *Kemmler [1972]:*

	Grain yield t/ha	Nutrients taken up kg/ha N	P	K
Local variety	2.8	82	10	100
TNI	8.0	152	37	270

The normal practice in introducing the new variety would be to supply more N to achieve the larger yield but, in such circumstances, it must be recognised that the amount of K needed by the new cultivar is nearly three times as much as was sufficient for the traditional variety.

2.2. Mixed and multiple cropping systems

These systems hold great promise of increased production in the tropics. *Ismunadji and his colleagues* showed the Bangkok Colloquium how important mixed cropping was for diversifying cropping and producing more food. In their experiments in Indonesia mixed crops of maize and soybeans produced much more grain than when each crop was grown alone, but adequate supplies of potassium were essential to achieve this greater potential. *Li Shi-ye* and *Zhan Chang-gung* discussed the soil characteristics which affect the supply of K in south China where multiple cropping is applied on more than two-thirds of the total area of paddy. They emphasised that soil alone cannot supply all the K needed by three crops in a year and that other sources (fertilizers and organic manures) are essential to make up the balance in K.
Deka et al. [1984] described an experiment at Pantnagar in India which tested six crop rotations over four years; all the crops received recommended fertilizer dressings. Table 1 shows the highest economic returns were from the rice-wheat-maize-cowpea rotation, but the highest return per rupee invested was from a rice-berseem rotation. *Deka* and *Singh [1984]* reported the nutrient balances established over a two-year period of this experiment shown in Table 1 (balances were calculated from additions in fertilizers minus removals in crops). Only the rice-wheat rotation showed a gain in

N (in the other rotations the legumes fixed their own N and the crops removed were rich in N). All the rotations gained in P, but the balance for K was negative in all rotations and the maximum deficit was in the rice-wheat-maize + cowpea rotation which was also the most profitable overall. This lack of balance for K indicates that there should be a reassessment of the fertilizer recommendations for crops in such a rotation since the negative K balance occurred when the standard recommendations were applied.

Table 1. Nett returns from different crop rotations over a four-year period and the nutrient balance over two years of this period (from *Deka et al [1984]* and *Deka* and *Singh [1984]*)

Rotation	*Nett Returns, mean/year*		*Nutrient balance per year (kg/ha)*		
	Rs/ha	Rs/Re invested	N	P	K
Rice-wheat	3919	0.54	+ 44.2	+19.4	−106.2
Rice-lentil	2919	0.54	− 51.9	+19.1	− 77.6
Rice-berseem	5426	0.86	−133.6	+13.0	−141.4
Rice-wheat-green gram	4705	0.53	− 20.6	+31.3	−142.6
Rice-wheat-maize+cowpea	6345	0.73	− 24.8	+ 7.7	−173.3
Rice-mustard-green gram	4067	0.53	− 7.9	+39.7	− 87.1

2.3. Tropical root crops

These crops are an important means of storing the energy from the sun for use as food; they are being increasingly grown in the tropics as they have a very high potential for yields of starch, in addition some, such as potatoes provide good quality protein and vitamins and minerals. In the present context these crops are important because they take up large amounts of potassium and most of this K is in the tubers which are removed from the farm. Cassava is the important root crop in many tropical regions. The country with the largest annual production is Brazil (24.5 million tonnes), this followed by Thailand (14.5 million tonnes) and Indonesia (13.7 million tonnes). Although cassava grows well on poor soils and often receives no fertilizer the large amounts of potassium it removes deplete the reserves in soils so that responses to K-fertilizer occur when cropping is continued, and the depletion of soil-K means that other crops which follow will yield badly unless they receive K-fertilizer.

2.4. Crops for export

Experience in many countries with crops intended for export shows that there is a need to maintain sound fertilizer practices to improve productivity, this improvement is needed to increase the bulk of crop available for export and also to lessen the cost of unit produce and so improve competiveness. Most exported agricultural products remove large amounts of plant nutrients from the country and it is essential that they should be replaced by fertilizers. Both employment prospects, and foreign earnings should be protected by adequate nutrition of the crops on which the trade depends. In some tropical countries tea is very important source of foreign earnings and a recent discussion on this subject is noted below:

Kemmler [1984] discussed the N and K nutrition of tea in South India and in Sri Lanka – the two most important tea exporting countries. Recent average yields have been 1748 kg/ha of made tea in South India but only 832 kg/ha in Sri Lanka. Experiments in Sri Lanka in the 1940s showed that after several pruning cycles the response to K could be as large as to N. Research in India in the same period indicated that K was a yield stabilising factor. *Kemmler* also illustrated the stagnation and then the recent decline in yields in Sri Lanka since the peak period in the early 1960s. By contrast yields in all of India have increased by about 40% in this period; these changes in yields and differences between the two countries were associated with differences in practical fertilizer policies which are shown in Table 2.

The changes in both total quantities of fertilizers and in the $N:K_2O$ ratios applied are associated with considerable increases in yields in India, and with the failure to increase yields in Sri Lanka since the 1960s. The average use of fertilizer in South India in 1977-81 was 406 kg/ha (of $N + P_2O_5 + K_2O$) with a $N:K_2O$ ratio of 1:1. The comparable average in Sri Lanka for 1979-81 was only 141 kg/ha with a ratio of $N:K_2O$ of only 1:0.52.

Kemmler concluded that differences between yields of tea in Sri Lanka and in South India may be due in part to other factors such as soil and climatic conditions and to management of the crops. While the supply of potassium may not be the major factor limiting yields in Sri Lanka, where much N-fertilizer is being applied an increase in the amount of K applied should aid the crops tolerance to drought and recovery after pruning so leading to higher and more stable yields.

Table 2. Estimated annual fertilizer use for tea in Sri Lanka and in South India (amounts of nutrients in kg/ha)

	Sri Lanka			*South India*		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1955	60	28	34	67	34	34
1961-65	87	22	60			
1970*	74	14	42	108	34	54
1980**	82	16	43	180	42	184

* Sri Lanka: 3-year average
** Sri Lanka: 3-year average, South India: 1977-81

2.5. Clearing of forests for cropping

Nutrient balances must be considered when tropical forest is cleared for crop production. Fertilizer recommendations are developed by following nutrient dynamics through the year. When this is done and recommendations for correct fertilizing and satisfactory agronomic practices are applied continuous cropping produces satisfactory yields and improves soil fertility.

Von Uexküll presented to the Bangkok Colloquium a very thorough account of how the acid soils under tropical forest can be managed so that soil fertility is improved and continuous cropping becomes possible. He described how the original topsoil fertility is maintained by improved clearing methods and how subsoil properties are improved. Continuous cropping is then possible, provided that large amounts of potash (500-600 kg K_2O/ha) are applied, 15-20 t/ha of grain can then be grown annually in a three-crop rotation. To achieve this the nutrient cycle of the cropping system must be evaluated so that adequate fertilizer dressings are used. He concluded that a full effort with high inputs is required; minimum input systems will result in the deterioration of these tropical land resources and may possibly lead to their destruction.

2.6. Interaction of plant nutrients with other inputs

Changes in other inputs that are applied to overcome constraints and to intensify production will always require a reassessment of nutrient cycles. Where irrigation provides the extra water needed for full crop growth the uptake of nutrients needed by the larger crop will require the use of more fertilizers. These fertilizers will increase water use efficiency and the water will increase the efficiency of the fertilizer *(Cooke [1986])*.

A good example of the interaction of another input with fertilizer is provided by the use of stimulants in rubber production; the stimulants improve yields but also increase the nutrients removed in the latex. *Von Uexküll* and *Cohen [1979]* quoted results obtained in Malaysia: With a yield of 2000 kg/ha of dry rubber the K removed was only 20 kg/ha; where stimulants were applied the yield was raised to 5796 kg/ha of dry rubber in 10 months of tapping but the K removed increased to 63 kg/ha. In another example they quoted, the application of Ethrel as stimulant increased the yield by about 50% but the N and P drained were increased by about 2½ times and the K lost was increased by 3 times.

3. Nutrient balances

It is clear from the previous Section that it is essential to calculate nutrient balances to determine the amounts of fertilizers needed to secure the level of production that is required and to ensure that soil fertility is at least maintained, and preferably improved. Local balances are required for cropping systems to provide good advice to farmers that has a sound scientific and economic basis. In addition nutrient balances for a country are needed to develop a national fertilizer policy.

3.1. Local nutrient balances

Extension workers should prepared to calculate nutrient cycles for the cropping systems on farms in the areas they serve. Guidance in constructing balance sheets will be obtained from the results of long-term field experiments in the area. In addition local farming practices and marketing policies and other local factors such as soil type and climate should be taken into account.

3.1.1 Re-use of crop wastes and residues

Particular attention should be paid to the use of fractions of the crop or their fate on the farm. Where the straw or stover of grain crops is ploughed in or burned on the field the P and K contained in these fractions will be returned to the soil, but if they are removed from the land extra nutrients must be applied to balance these losses. The ashes of straw used as fuel should be returned; similarly efforts should be made to return to the land the residues left after plantation crops have been processed.

3.1.2 Potassium in irrigation waters

The quality of irrigation water affects the fertility of paddy soils. On average the world's rivers contain 2.3 mg/l of K^+ and many publications indicate that about 20 kg/ha of K may be supplied when a rice paddy receives 1000 mm of water. The actual amount of potash supplied depends on the concentration of K^+ in the water and the amount and frequency of the irrigation, in some areas 30-70 kg/ha of K_2O could be supplied in a year.

Although much potassium is supplied by irrigation water, the movement of this water down the soil profile leaches away much of the K^+ present in the soil solution. In Taiwan, *Feng* and *Chang [1965]* found that where lowland rice soils are maintained in flooded conditions most of the added K was leached away during the four-month growing season. Where reserves of K in the soil were small the K-fertilizer that was required needed to be applied in split dressings to avoid losses by leaching. *Sequi [1981]* reported that irrigation water supplied 222 kg/ha of K_2O to rice paddies in Italy, but the drainage water removed 132 kg/ha of K_2O, so during the course of a year of irrigation 90 kg/ha of K_2O was lost from the system.

3.2. National nutrient balances

National fertilizer policies will be developed from scientific and agronomic evidence discussed against the background of economics and public policy. The overall need for the production of crops to provide food for the local population, for industrial processing, and for export, will indicate the yields that are required. Soil capability assessments will show where these crops are best produced. Studies on the crops and soils, together with the results of long-term field experiments, will show how much fertilizer is required to initiate the improvement in productivity which is needed. To ensure that the fertilizers are used efficiently, and that soil fertility is maintained, will require more detailed and continued studies on the nutrient balances and work on soils and crops which is noted later. Exports of agricultural produce have large effects on national nutrient balances. These balances will guide decisions on investment in fertilizer factories, on imports, and the exploitation of local resources and minerals to supply nutrients.

3.2.1 Nutrient balance in Thailand

As the *19th IPI-Colloquium* met in Bangkok it was appropriate to examine some aspects of the nutrient balance in Thailand which has a very important industry in exporting food and other agricultural products. The amounts of nutrients leaving the country in exports of agricultural products in 1982 are shown in Table 3. The fertilizers applied in the whole country in the following year (1983/84) provided about 60% more N than was exported and nearly twice as much P_2O_5, but the K_2O supplied by fertilizer was less than one quarter of the amount exported. Of the total amount of K exported two-thirds was contained in tapioca products made from cassava. It is clear that exports from Thailand must be resulting in the depletion of potassium reserves in the soils to an extent that the yields of crops that follow the export crops will be seriously reduced. Many other countries of the humid tropics are also involved in considerable exports of agricultural produce which remove large amounts of nutrients from the national cycles.

Further information on the national balance was obtained by calculating the amounts of nutrients in the harvests of the major crops grown in Thailand. *F.A.O. [1985]* published the areas of crops grown and the production of each crop which were used in the calculations. These calculations were restricted to the ten arable crops which occupied more than 100000 ha each in 1984; these crops are rice (paddy), maize, sorghum, cassava, (dry) beans, soybeans, groundnuts, seed cotton, sugar cane, and fibre crops (jute and others). These ten crops occupy 14588000 ha, which is 84% of the arable area of Thailand. The total nutrient uptakes are summarised in Table 3. The fertilizers used in the whole country supplied nutrients equivalent to 37% of the N, 48% of the P, and only 4% of the K, taken up by these 10 crops. The risk of serious nutritional deficiency causing reductions in yields is much greater for K than for N and P while fertilizer use continues at the present levels. The total nutrients which would be applied to these crops if current recommendations were put into practice were calculated using the crop areas published by *F.A.O. [1985]*. The recommendations made for the crops would have supplied more N and P than the total amounts taken up, but only 83% of the K uptake (Table 3). Comparing the total amounts of the recommendations with the amounts of fertilizers used in Thailand in 1983/84 shows that the fertilizers used in the country would have supplied only 19% of the N, 35% of the P, and 5% of the K that would be recommended.

The calculations noted above ignore the minor arable crops (which occupy 16% of the arable area) and the plantation crops which occupy 1970000 ha (equivalent to

Table 3. Some aspects of the plant nutrient balance in Thailand: amounts of nutrients in produce exported in 1982, the total amount of nutrients applied in fertilizers in the country in 1983/84, amounts taken up by the ten most important arable crops and the amounts which would be recommended for these crops, and the amounts removed in the harvests of perennial crops grown in 1984.

	N	P_2O_5 tonnes	K_2O
Removed in crops exported in 1982	159788	72658	156498
In fertilizers used in 1983/84	255000	135500	36800
Removed by 10 arable crops in 1984	683861	282409	940726
Recommended for 10 arable crops	1323845	381740	784415
Removed in harvests from perennial crops in 1984	18864	7181	28982

11% of the arable area). The nutrients removed in the 1984 harvest of copra, oil palm, bananas, pineapples and natural rubber were calculated; the total amounts are shown in Table 3. They are only small fractions of the amounts removed by the arable crops shown in Table 3; nevertheless these removals are important in the areas where the perennial crops are grown.

4. Gains from potassium fertilizers

4.1. Increases in grain yields

The papers presented to the Bangkok Colloquium showed that the supplies of potassium in the soils of southeast Asia are rarely sufficient for the continuous production of yields that approach the economic maximum that is required. Responses to K-fertilizers had been recorded in most of the countries for which there were reports to the Colloquium.

De Datta reported typical results showing the responses by grain crops; examples given here are in terms of kg of grain per kg of K_2O applied: In China increases in rice yields averaged 9.3 kg of grain. Average responses by wheat were 8 kg of grain in India and 6 kg of grain in Pakistan; in some areas of India very high responses had been recorded – 25 kg of grain in the Punjab and 14 kg in Delhi. In early experiments in India maize yields were increased at an average rate of 8 kg of grain, more recently responses on the black soils of Coimbatore had been 26 kg of grain.

Ho reported on the responses to K-fertilizer and the value/cost ratios (VCRs) relating to the applications to rice, wheat, maize and sorghum in the five countries of southeast Asia where *F.A.O. Fertilizer Experiments* had been made. Most of the responses and VCRs were positive; some VCRs were quite large indicating that using K-fertilizers would bring much profit to the farmers. The responses were related to measurements of available K in the soils and to soil classification.

4.2. Gains from the use of potash fertilizers in China

Lin Bao and his colleagues reported that as Chinese agriculture has been intensified K-fertilizers have been increasingly needed because the N and P fertilizers used had increased yields. The yields and qualities of the following crops were all increased by K-fertilizers at these returns per unit of K_2O:

	Kg product per kg of K_2O
Wheat	6.3 (grain)
Maize	8.4 (grain)
Potatoes	15.8 (tubers)
Sweet potatoes	51.4 (tubers)
Cotton	1.3 (lint)
Jute	4.6 (fibre)
Peanuts	8.4 (unshelled nuts)
Rape	2.4 (seed)
Soybean	3.5 (soybeans)
Sugar cane	3.1 (cane)

There are many indications that responses to K have increased greatly in areas where cultivation has been continuous and where HYVs and multiple cropping systems are introduced. A good example was provided by *Lin Bao [1985]* for wetland rice in China. He gave these average figures for a series of 62 experiments in 1958 and 260 experiments in 1982:

	Percentage of trials showing marked responses to			Response to a unit of applied nutrient (kg grain per kg nutrient)		
	N	P	K	N	P	K
1958	82	50	29	16.5	5.5	3.8
1982	95	50	63	10.1	3.5	5.8

In the 1950s responses to K were much less frequent and smaller than to N and P. In 1982 average responses to N and P were less than in 1958 but the response to K was greatly increased. In the mid-1960s K-deficiency symptoms appeared in rice in a large area of China.

4.3. Gains in animal production

There is an increasing interest in many countries in increasing the production of animals to provide milk and/or meat for the population. At present the average production of food from each animal in developing countries is very much smaller than from animals in developed countries. The reason is mainly because both the quantity and the quality of food available to the animals is poor in developing countries. Production from the animal population will be increased by work to improve local grasslands and forage crops and to utilise the wastes from crops grown for human food (straw etc). Pastures to feed the animals can conveniently occupy land that is difficult to cultivate or which is liable to erode when under arable cultivation. Improved production from such pastures will often require lime to neutralise acidity and to supply calcium for both plants and animals. In addition the supplies of P and K must be made adequate for the legumes which are essential for increasing the nitrogen status of the pastures. Work in Thailand has shown that any reserves of K in the soil under such pastures are quickly depleted; in some experiments there was no response to K-fertilizers in the first year but significant responses were measured in the second year. Introduced legumes have given considerable responses to potash.

Some pastures are established under perennial plantation crops, such as coconuts; for such conditions adequate fertilizing is very important. Both the coconut palms and the grasses have high requirements for K, deficiencies will result in poor yields of nuts and poor growth of grass.

5. Economic aspects of the use of potassium

That the increases in yields from the use of K-fertilizers which have been recorded are profitable to farmers is well illustrated by a report by *Ho* and *Sittibusaya [1984]* made to the *Fifth Asean Soil Conference* held in Bangkok in 1984. They used the results of the *F.A.O./Thai Fertilizer Programme Project* in which 271 experiments had been made on farmers' fields covering the main soil and climatic conditions of the country. Responses to K-fertilizer varied according to the K-status of the soils and other factors such as organic matter contents. The experiments defined the levels of K needed for near maximum yields and the fertilizer recommendations (some of which were used in the calculations made here for Table 3). The VCRs (ratios of $\frac{\text{value of extra crop from fertilizer}}{\text{cost of fertilizer applied}}$) were calculated.

A summary of some of the results from whole groups of experiments on particular crops is given here:

	No. of experiments	K_2O applied kg/ha	Return, kg of yield/kg of K_2O	VCR
Sorghum (grain)	21	31	8.4	2.3
Soybeans (beans)	33	38	6.8	5.0
Groundnuts	29	38	4.7	3.9
Mung beans	25	38	4.7	3.9
Cassava (tubers)	26	100	25.0	2.1
Cotton (lint)	7	75	3.8	5.9
Kenaf (fibre)	39	50	12.0	6.0

All the VCRs were positive so that for all these crops farmers would profit from applying potash fertilizer. In some subsections of each group of trials K-fertilizer was even more profitable than the averages shown above. These results show that K-fertilizer is essential for satisfactory economic yields of crops in Thailand. *Ho* showed that a similar situation prevails in other countries of southeast Asia in the paper he presented to the IPI-Colloquium in Bangkok. He gave the results of experiments on rice, wheat, maize and sorghum in Bangladesh, Indonesia, Philippines, Sri Lanka and Thailand. In all the series listed in the paper the lower rates of K applied increased yields and gave positive VCRs. In a few series very large dressings of K depressed yields and gave negative VCRs. Gains from potash were recorded in all the experiments on grain legumes, root crops, sugar cane, fibre crops, and vegetables. The higher rates of K were also profitable in many of the experiments on root crops, fibre crops and vegetables, and in practically all the experiments on maize/legume intercropping.

6. Pricing policies

When Governments have reviewed the scientific evidence on the need for fertilizers to be used in their countries to achieve economically the production levels required for home consumption and for export they will develop their national fertilizer policy. It then remains to arrange that farmers receive advice on the fertilizers that they should use. Whether they accept this advice and maintain appropriate levels of fertilization will depend on the economics of the situation which is determined by the costs of the fertilizers and the prices farmers receive for the crops that they grow. Therefore the success of the fertilizer policy, and the acceptance of its practical aspects by farmers, will depend on establishing fertilizer and crop prices which ensure that farmers receive a return on their spending on fertilizers. Examples have been published of the effect of these price relationships on national use of fertilizers and average crop yields in the country. An example, as published by *Couston [1984]*, is in Figure 1, the highest national yields of paddy, in the Republic of Korea and in Indonesia, were associated with small amounts of paddy needed to buy 1 kg of fertilizer. In countries where the price ratio was less favourable to the farmer much less fertilizer was used and national average yields were much smaller.

Ho reported to the Colloquium that the VCR should be at least 2 to ensure that new technology is adopted by farmers in a developing country. Small farmers with little capital are generally more interested in treatments giving a high VCR than in obtaining very high nett returns. He showed that, with few exceptions, in Thailand where the crop/fertilizer price ratio is one of the least favourable applying 30-40 kg/ha of K_2O gave a VCR of more than 2.

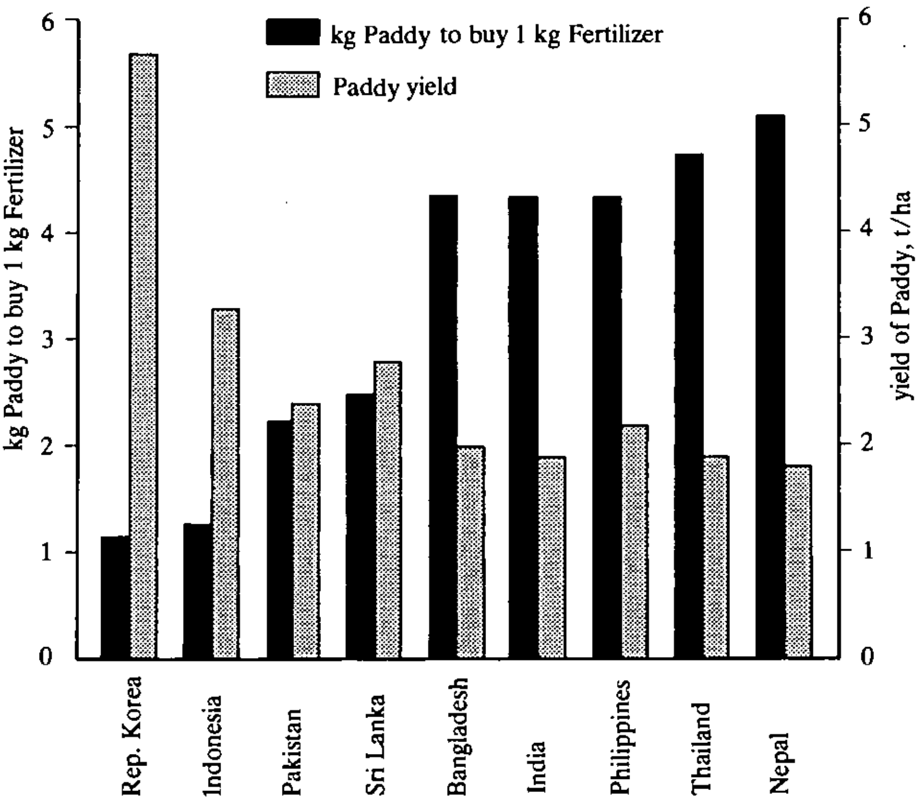

Fig. 1 The relationships between the prices of crops and of fertilizers and the yields of paddy rice in countries of South East Asia (From: *Couston [1984]*).

N-fertilizers may have an immediate effect on crop growth which impresses farmers and which is usually more striking than the immediate effect of K-fertilizers; but it does not follow that applying N is more profitable than applying K-fertilizer. A study by the *Fertiliser Association of India [1984]* showed that less than half as much paddy was needed to buy 1 kg of K_2O as was needed to buy 1 kg of N or P_2O_5. Consequently the financial return per rupee invested in fertilizer was almost identical for N and for K_2O over the period from 1971/72 to 1984/85. The same study reported the economics of applying N, P and K for paddy, wheat, gram, and sorghum for the same period. For both paddy and wheat the returns per rupee invested in N and K_2O were very similar and returns from P_2O_5 were smaller. For both gram and sorghum the returns from expenditure on K_2O were several times larger than the returns from expenditure on N (and applying P_2O_5 tended to be less profitable than applying N). The results of such studies are important and should be widely disseminated among farmers so that they can make rational choices on the fertilizers to be applied which will lead to maximum returns from their spending on these inputs.

7. The present and future use of fertilizers

Previous sections have shown that fertilizers are essential for the development of agriculture in the tropics and that there is a great need to use more potassium; it is also proved that the use of fertilizers is economic to farmers. Therefore it is appropriate to examine the current use of fertilizers in the humid tropics and to note the estimates that have been made of the likely future use of potassium fertilizers.

Very large increases in fertilizer use have occured in the last 30 years and these are shown in Table 4 which gives *F.A.O. [1954 and 1984]* data for the amounts used in two temperate regions and in three regions which encompass humid tropical countries. In the period from 1953 to 1983 the amount of N used in the world increased by about 12 times, but the K used increased by only 5 times. This raises the question of balance in the amounts of nutrients applied; this is examined in Table 4 by giving the ratios of $N:P_2O_5:K_2O$ used. Only in South America are the weights of N and K_2O used roughly equal; the very low amounts of K_2O used relative to N used in Asia and Africa are a cause for concern that should be discussed.

7.1. The history of fertilizer use in Thailand

Thailand provides an example of the changes in the use of fertilizers in a country of the humid tropics. Fertilizers have been a major input to agricultural development in Thailand for many years. The changes that have occured in the total amounts of nutrients used during the last 20 years are shown in Figure 2. The amounts of nitrogen used have increased greatly and the phosphate used has also increased considerably, but the increases in the potash used have been much smaller and the amounts now used are much too small to match the large amounts of nitrogen that are available. *F.A.O.* reports that in 1982 the amounts of fertilizers applied in Thailand on average of the whole area of arable and permanent crops were 9.5, 6.9 and 1.9 kg/ha, respectively of N, P_2O_5, and K_2O; the average figures for Asia as a whole were 50.0, 16.9, and 5.6 kg/ha, respectively of N, P_2O_5, and K_2O.

Table 4. Amounts of nutrients applied as fertilizers in several regions of the world in 1952/3 and 1982/3. *(FAO [1954 and 1984])*

	N	P_2O_5	K_2O	$N{:}P_2O{:}K_2O$		
	thousands of tonnes used			ratio of amounts used		
1952/3						
Europe	2 108	2,658	2,862	100	126	127
North and Central America	1 738	2,331	1,688	100	134	97
South America	79	104	33	100	132	42
Asia	800	343	256	100	43	32
Africa	146	181	38	100	124	26
The world	4 891	6,107	4,896	100	125	100
1982/3						
Europe	14 767	8 244	8 508	100	56	58
N. and Central America	11 140	5 075	5 110	100	46	46
South America	1 108	1 508	1 036	100	136	94
Asia	22 819	7 689	2 544	100	34	11
Africa	1 865	1 147	426	100	62	23
The world	61 021	30 833	22 844	100	51	37
	FAO's classification of regions for 1982/83					
All developed countries				100	61	56
All developing countries				100	37	14
Developing market economies in:						
Africa				100	71	41
Latin America				100	75	48
Near East				100	54	3
Far East				100	34	18

Table 5. Amounts of potash used in 1982 in eight countries of Southeast Asia and estimates of the amounts which will be required in 1992, based on crop requirements (from *Pushparajah's* paper to the Colloquium)

	Use in 1982	*Estimate of use in 1992*
	Thousands of tonnes of K_2O	
Bangladesh	28	76
India	622	1130
Sri Lanka	45	75
Burma	11	60
Indonesia	133	400
Malaysia	194	320
Philippines	58	90
Thailand	38	80
Total	1129	2231

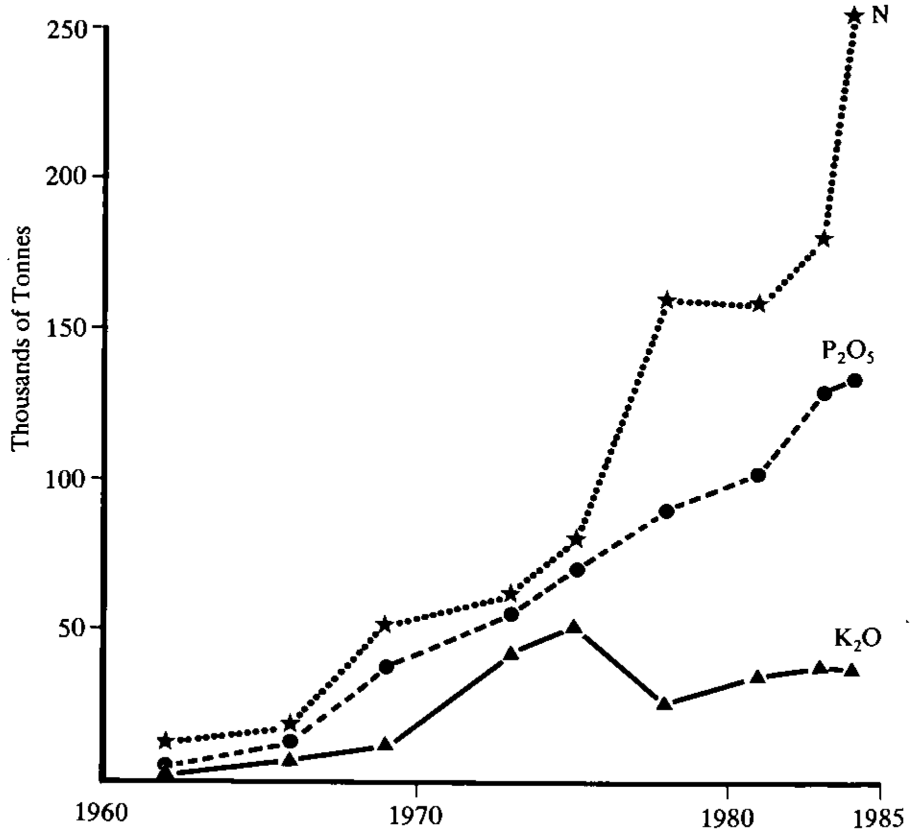

Fig. 2 Changes in the amounts of fertilizers used in Thailand 1962-1984 (data from Fertilizer Yearbooks published by F.A.O.)

7.2. Estimates of the future use of fertilizers in the tropics

7.2.1. Future use in Southeast Asia

Pushparajah presented to the Bangkok Colloquium estimates of the amounts of K-fertilizer which will be needed later in this Century. His first calculations were based on growth rates for the fertilizers used in Southeast Asia in recent years. They showed that past changes in fertilizer use are an unsatisfactory basis for assessing future needs since such estimates take no account of any current lack of nutrient balance in the region, or of the special needs of the soils and the farming systems for potassium to support other inputs; the assumption is that change in farming systems and practices will continue as in the past. *Pushparajah* emphasised that crop requirements and cropping patterns must be taken into account. He had calculated the nutrient cycles for paddy cropping in the following south-eastern Asia countries: Bangladesh, India, Sri Lanka, Burma, Indonesia, Malaysia, Philippines and Thailand. All the countries had deficits (calculated from amounts removed in paddy crops minus amounts of fertilizers applied) which ranged from 16 kg/ha (of $N + P_2O_5 + K_2O$) in Malaysia to 98 kg/ha in Burma per year; the deficit in Thailand was 65 kg/ha of $N + P_2O_5 + K_2O$ per year. The amount of potash removed by paddy in Thailand in the 1981/82 crop year was estimated to be 42 kg/ha of K_2O, the fertilizer used supplied 2 kg/ha of K_2O so there was a large annual deficit of 40 kg/ha of K_2O (which has to be supplied by soil and irrigation water, a situation which may not continue indefinitely as soil reserves become depleted). By assuming that the fertilizer nutrient ratios used on paddy were the same as the average use on the whole cropland the requirements for potash in the 8 countries in 1992 were estimated, these are stated in Table 5. The total amount of potash needed in 1992 for the whole of the 8 countries will be about 2.2 million tonnes of K_2O. So *Pushparajah* concluded that the consumption of potash in the Asian tropics is expected to range from 2.2 to 3.2 million tonnes of K_2O; the actual amounts used will depend largely on weather, crop production, and prices of crops and fertilizers.

7.2.2. Use in Thailand

Pushparajah stated that 58% of all the fertilizer used in Thailand in 1982/83 was applied to rice, fruits received 15% of the total and 12% was applied to vegetables. His estimates of the future use of potash by the year 1992 are:

Forecast based on	Tonnes of K_2O
1972-1982 changes	35 000
1977-1982 changes	60 000
Nutrient balance studies	80 000
Actual use in 1982-1983	38 000

The estimate of use in 1992 based on nutrient balance studies envisages a doubling of the K-fertilizer now used in Thailand. But even this increased use of K in 1992 would provide only about one-tenth of the total amount which is now recommended for the 10 crops discussed earlier (Table 3) and 8.5% of the K which these crops take up. The difference between this estimate of the K needed in the future and the total amount which would be recommended for only part of the crops grown in Thailand indicates that there is a serious need to assess the amounts of K which will be essential to maintain agricultural productivity and therefore national prosperity in Thailand. Similar considerations apply to other countries of the humid tropics.

7.2.3. Use in Latin America

Pushparajah quoted data published from Latin America which showed a large deficit of K_2O, calculated on the basis of crops removed from the land or exported minus the fertilizer-K applied. The amount of potash applied in the region needs to be increased to meet this deficit. *Pushparajah* concluded that by 1992 about 5 million tonnes of K_2O will be needed each year in Latin America (the total used in 1980 was only 2 130 000 tonnes of K_2O).

8. The way forward

It is clear that the crops grown in the humid tropics need large quantities of potassium to produce the good yields required to feed the local population and to support established export trades, and the potential for even larger exports of some commodities that can only be grown in the tropics. A logical and scientific basis for increasing the use of potassium will rest initially on plant nutrient balances for particular farming systems which are then adapted to whole countries and regions. The efficient use of these supplies of fertilizers that are shown to be justified, often imported at considerable cost to the nation, will depend on scientific research on the following topics and its application by advice to the farmers.

8.1. Soil characteristics

The first need is for an adequate classification of soils, supported by databases on the soils, both based on surveys. This information will be needed to plan for more intensive cropping systems, the crops being chosen to suit the soils. It is also needed for the transfer of new technologies, the correlation of the results of field experiments with soil type facilitates the transfer of recommendations derived from the experiments to other areas. Factors that affect the reserves of nutrients in the soils, and those that govern the efficiency of nutrients added as fertilizers, need to be related to soil type. The use of the *Fertility Capability Classification* developed by *Sanchez, Couto* and *Buol [1982]* has considerable promise for the achievement of these objectives.
Information on the minerals present in soils which may contain reserves of K and release them to crops will be required and this should be related to the soil surveys. When interpreting the results of nutrient balance studies it is necessary to forecast the extent to which reserves in soil can make up a deficit of K where the crops are removing more K than is replaced by fertilizers, crop wastes and organic manures.
Laboratory methods of assessing both the immediately available, and the fixed but potentially available reserves, of potassium in soils need more research. Reserves in subsoils need to be assessed. Agreement is needed on the values of available K in soils at which responses by particular crops to K-fertilizers are to be expected.

8.2. Research on plants

The crops from experiments will be analysed to measure uptakes of K and other nutrients; these data are required for calculating balances between inputs and outputs. Tissue analyses will aid in determining the needs for K-fertilizers. Further investigations on the value of these data are required and criteria to interpret the analytical measurements should be established. Crop analyses help in understanding the mechanisms of interactions between nutrients. Other work required on crops grown in field experiments is in plant physiology. Work on the effects of nutrients on yield formation is essential to an understanding of how fertilizers raise yields and is important in selecting the amounts of fertilizers to be applied to secure correct balance in the plant. A high concentration of K is needed for maximum photosynthesis and in cereals it benefits spikelet formation, grain foundation, and vigorous pollen. A high K/N ratio in the plant also benefits nitrogen metabolism and increases the amino-acids in the grain.

8.3. Field experiments

The previous Sections indicate that there is a need to establish long-term multidisciplinary field experiments on sites that are typical of the major soil types in each country. These experiments will provide the basic information needed to guide extension work planned to improve the productivity, efficiency and profitability of agricultural systems. They will provide information on the following topics: 1) Basic data for the calculation of nutrient cycles. 2) Information on responses to fertilizers and the interactions between nutrients and between nutrients and other inputs to the system (such as irrigation or pesticides). 3) They will form a basis for associated work on analyses of soils and crops, on nutrient reserves and the movement of nutrient ions in soil. This information is needed to derive correct recommendations on amounts of fertilizers to be applied and on times of application. At present there are too few of such experiments made in the humid tropics, but they should have the highest priority as they are essential for efficient management of fertilizers.

The experiments done within the *F.A.O. Fertilizer Programme* on farmers' land in five countries of southeast Asia are important in providing basic information and locating areas that are deficient in potassium. The *International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER)* was described to the Bangkok Colloquium. These coordinated schemes are important for developing collaborative work between agronomists and soil scientists at both national and international levels which results in technologies to secure efficient use of fertilizers. A chain of experiments to measure nutrient responses and interactions on a long-term basis, and to relate the effects measured to soil type and to climate, would be valuable in providing the information we need to use potassium efficiently to maintain production at required levels. The network would also provide a basis for soil classification methodology and to compare analytical methods to select those suitable for general application. Experimental work should include tests of times of application of K-fertilizers and on the maximisation of yields; in identifying all the constraints which limit the growth of crops it is essential to test the full range of inputs so that maximum yields are harvested from some plots in the experiments.

9. Pathways to progress

In the paper which *Ho* gave to the Colloquium in Bangkok he listed the important constraints which limit the use of potash in the countries that he had reported on (and which are listed above in Section 5). These constraints were:

1) Lack of credit
2) Inadequate adoption of other inputs
3) Lack of knowledge and information
4) Uncertainty of crop/fertilizer price ratio
5) Inadequate irrigation
6) Difficulties with the availability of potash in remote areas.

I consider that Governments should be fully aware of these constraints to the use of potash and therefore to the realisation of their targets for agricultural production to feed their own people and for the industrial processing and exports that lead to national prosperity. Governments should do all that they can to remove these constraints which arise from economic and physical reasons; they should also give full support to the work needed in research on the soil/crop system and the application of the results to practical farming. The scientific objective should be to manage plant nutrient balances in the farming systems of a country so that required productivity is achieved by increasing nutritional levels and preventing all deterioration in the fertility of the country's soils.

Finally it is appropriate to quote from the paper which *van Keulen* presented to the Bangkok Colloquium. He stated that continuous emphasis was required on «the fact that agricultural science can provide solutions, if the economic incentives are strong enough».

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Co-ordinator's Report on the 1st Session

H. Laudelout, Catholic University of Louvain, Soil Science Department, Louvain-la-Neuve/Belgium*, member of the Scientific Board of the International Potash Institute

It is a well-established custom in IPI Symposia that the co-ordinators should summarise the proceedings of the sessions over which they have presided.

Because the first session consisted of conclusions of the three colloquia which have led into this symposium, it would serve no useful purpose if I were again to cover the same ground. Nevertheless it may be useful if I emphasise that the conclusions of the three meetings have much in common though they refer to quite different ecological conditions.

One common conclusion was that the old-established concept of nutrient balance is still an excellent approach whether it be at the level of the field, the individual holding or the whole of a territory. Obviously, the analytical techniques used and their evaluation vary widely. Certainly, the straightforward calculation of the balance by subtraction of crop removals from the quantities of nutrients applied can be refined and improved. In fact, the true balance of an element is provided by the algebraic sum of movements between the various forms in which that element occurs: parent material, soil solution, secondary minerals, biomass etc. The techniques for measurement of the quantities and fluxes involved need to be considerably refined.

While I would not wish to anticipate the general conclusions which will be drawn from this meeting, it seems that research should be directed towards this goal and this is the reason why the next IPI colloquium will be devoted to this aspect.

* Prof. *H. Laudelout*, Université Catholique de Louvain, Département des Sciences du Sol, Place Croix du Sud 2, B-1348 Louvain-la-Neuve/Belgium

13th Congress of the International Potash Institute
August 1988 in Reims/France

2nd Session

Important factors in potassium balance sheets

Co-ordinator: *Prof. Dr. K. Mengel,* Institute of Plant Nutrition, University of Giessen/ Federal Republic of Germany; member of the Scientific Board of the International Potash Institute

Important Factors in Potassium Balance Sheets

J. Quémener, Research Centre, S.C.P.A., Aspach-le-Bas/France.*

Summary

In this paper we discuss the most important factors which determine the potassium balance of individual fields: soil characteristics, weather (climate), crops and cultural practices. Among the first, clay content and mineralogy (mainly 2:1 layer phyllosilicates, value and site of their negative charge, orientation of OH^- groups in the octahedral layers, substitution of F^- for OH^- in these layers ...), pH and its effects upon CEC, porosity and thickness of successive soil horizons, topography ...

Soil properties are affected by climate through temperatures (which modifies distribution of K between different categories), total annual rainfall and seasonal distribution (losses by leaching, run-off or erosion; alteration of K distribution between internal and external sites of the minerals and of K availability to crops by drying and alternate wetting and drying of the soil).

The potassium balance can be much affected by crop species through their K requirements and their growth characteristics (soil cover at times of peak rainfall can limit leaching; rooting depth: the subsoil may by explored or not; specific root properties may affect the accessibility of non exchangeable reserve K).

Incorporation to soil of crop residues, uneven application of fertilizers (or of K return to pastures in cattle urine) can give some trouble with K balance measurements. According as to whether past fertilizers practices has been deficient or excessive, some soil properties (buffer capacity, fixation capacity, capacity to release non exchangeable K) important for the future balance can be changed in one sense or the other.

In the temperate zone, in intensive agriculture with generous fertilizer usage, the crucial point appears to be the reversibility of fixation, that is the extent to wich fixed K can eventually be released, or more exactly how far crops (other than Italian ray grass) can utilise fixed potassium.

Introduction

Nutrient balance-sheets are important both in formulating advice and in assessing the effects of past fertilizer treatment. What is important to the farmer in the final analysis is the farm balance which is the difference between visible inputs (fertilizer purchased) together with invisible inputs (animal feeds) and outputs (nutrient content of produce sold off the farm). However, it is important to realise that this total balance is made up from individual field balances and that there may be transfer of nutrient from one part of the farm to another *([55]* and Figure 1).

* *J. Quémener,* Directeur, Centre de Recherches SCPA, Aspach-le-Bas, F-68 700 Cernay/ France

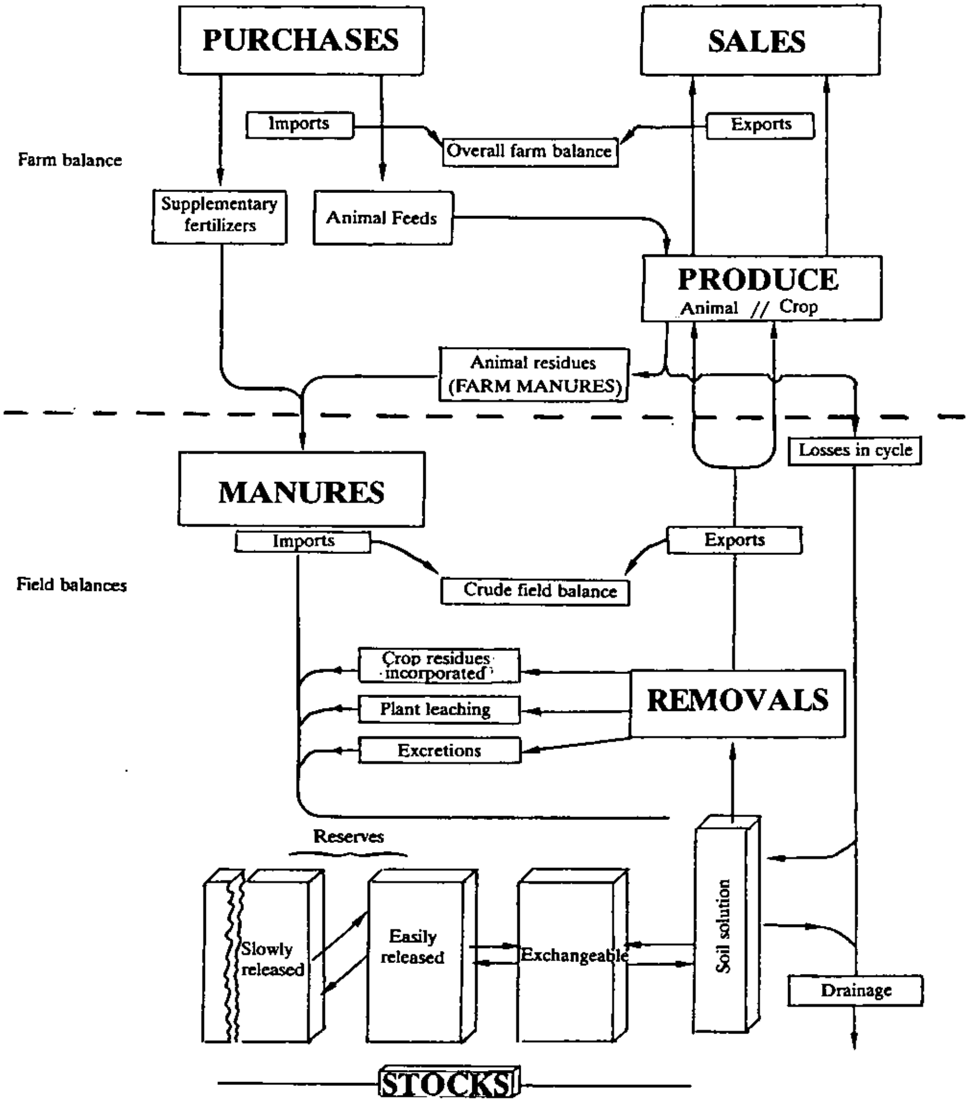

Figure 1 Nutrient (potassium) cycle after *J. Garaudeaux [55]*

It is our aim in this paper to discuss the various physico-chemical and biological factors which determine the potassium balance of individual fields. We shall not deal with economic aspects of the problem which have great importance in deciding fertilizer policy and hence affect the balance. For this reason the level of production, though it is the background of much that follows, receives very little attention.

Whether our concern is with the maintenance or improvement of fertility or, more rarely, with the exploitation of a superabundance of fertility, it is most important to have a thorough understanding of the underlying problems. The most important factor may in some cases be soil type, in others climate or the sequence of crops and cultural practices. Though the approach adopted here may be somewhat simplistic, we deal with the matter under these headings. These factors do not act in isolation and their interdependence will be emphasised.

In practice it would appear that the simplest approach to the control of fertility would be by the use of soil analysis. The last part of the paper deals, except a few special points, with the problems encountered in its use in following the balance rather than with its use for diagnosis. Methods of soil analysis used in various parts of the world are many and various; we are concerned here with the method most widely used in France, exchangeable K, which serves as a reference in the definition of major processes determining the availability of potassium (fixation, liberation) and has some aspects in common with other widely used methods.

Part 1: The Soil

1. Particle size distribution and mineralogy

1.1 Clay

Soil mineralogy and, in particular clay mineralogy, is most important in governing the behaviour of potassium in the soil. It has been shown that some features of potassium dynamics and balance in soil can be related to clay content. This is the case for example for fixation capacity (FC): studies by *SCPA* have resulted in regression equations relating FC expressed as % of added K to % clay; some examples of fixation capacity, expressed as % of added potassium, by *van der Marel's* technique *[92, 134]* follow:

- Soils on the Lias of the Lorraine Plateau
  % FC = % clay — 0.07 exchangeable K (ppm) +29.3 $\quad$ r = 0.85
- Soils of the Luxembourg province of Belgium
  % FC = 0.7.% clay — 0.097 exch. K (ppm) +28.9 $\quad$ r = 0.80
- Grassland soils in the Lille region
  % FC = 2.7.% clay — 0.044 exch. K (ppm) $\quad$ r = 0.92
- Clay loams of west Champagne
  % FC = 0.076.% clay — 0.031 exch. K (ppm) +33.4 $\quad$ r = 0.81

The primary factor governing the value of FC is always clay content. It has been shown *[146]* that for soils at minimum exchangeable K content, delivery of K to the plant is proportional to time, the proportionality coefficient depending on clay content, or on the minimum exchangeable K content. The latter and clay content are related: for the Corn Belt soils *[146]* the relation was:

K minimum (ppm) = 1.14% clay -2 $\qquad r = 0.95$

while for some sixty soils from *SCPA* experimental sites all over France we found:

K minimum (ppm) = 3.28% clay + 0.02 $\qquad r = 0.725$

The difference between this and the American result and our lower value of r can be attributed mainly to mineralogical differences.

Cation exchange capacity (CEC) largely depends upon clay content and clay properties and, in turn, buffering capacity (BC) is largely dependant upon CEC. Various relationships between CEC and its K saturation and BC have been proposed *[2,3]*:

$$BC = a - b \cdot \frac{Kex}{CEC}$$

$$\text{or } BC = c \cdot \frac{(Kex)^{-d}}{CEC}$$

Here again it is likely that the different equations express differences in mineralogical composition between soils of the same particle size distribution or same CEC.

Three important aspects of the K balance are ascribed to clay content: storage (or immobilisation) of part of the applied potassium, release of initially non-exchangeable K, variation in solution K concentration with exchangeable K content. These are all important in connection with the movement of K towards the root or through the profile.

1.2 Importance of different particle size categories

The definition of clay as particles < 2 µm covers a range of particle size. It has been shown that, from the point of view of the release of non-exchangeable K the very fine particles (< 0.3 µm) and their K content are of over-riding importance *[9]*. This avenue of research has been little explored perhaps because of the laborious nature of the work involved, perhaps also because the little work done has not confirmed the early result.

In contrast, the significance of the larger particle size fractions for K-dynamics has received more attention. First, it has been shown *[124, 135]* that some micas in large particle sizes can release more K than when their size is close to that of clays. This is interpreted as being due to greater distortion of the lamellae leading to breakages which favour the release. The study of release in separated particle size fractions while not leading to conclusions identical to the above, leads one to think that the silt fraction, or even the fine sand may not be of negligible importance in K release *[31, 99]*.

Thus, in soil studies in the Massif Central of France (Plateau de Millevaches) potassium dynamics seemed to be related more to silt content than to clay. However, these are acid mountain soils particularly rich in organic matter *[8]*.

Finally it has been shown that in the chalk soils of Champagne the porosity of the larger particles (> 2 mm) which is usually not identified in soil analysis has some significance as a trap or reservoir for potassium */16/*.

1.3 Mineralogy and potassium fixation

The attention of research workers has for long been focussed on the 2:1 layer phyllosilicates. An excellent recent review */61/* of the fixation of cations by clays has listed the factors concerned in the following order:

a) hydration energy of cation: if low, water is lost from between the layers which close: K^+, NH_4^+, Rb^+, Cs^+ are fixed, Na^+, Ca^{2+}, Mg^{2+} are not.

b) relation between the size of cation (dry) and interlammelar spacing of the tetrahedral layers: the closer these dimensions the more easily collapse occurs.

c) total layer charge: the higher it is, the stronger the adsorption.

d) location of the negative charges: the charges on the tetrahedral layers being nearer the adsorbed cations attract them more strongly.

e) the wedge structure of the edges of the bundles of aluminosilicate layers can fix cations by spatial matching.

f) faults in the structure, fissures or other changes in the lattice.

g) orientation of hydroxyl groups on the octahedral layers: if perpendicular to the basal plane of trioctahedral minerals, the positive charge of their protons strongly repels potassium and other cations; the dioctahedral micas with an angle of only 16° to the basal plane have a much lesser repelling effect.

h) replacement of OH^- by F^- in the trioctahedral minerals suppresses the above effect.

The complexity of this list reflects the diversity in the attribution of importance to one or another mineral species in fixation which is apparent in the literature: glauconite */34/*; degraded, expanding and expanded illites */2, 75, 82, 92/*; smectites; montmorillonite */47/*; often beidellite */14, 15/*; sometimes nontronite */43, 78/*; vermiculite */14, 106, 119, 122, 123, 132/* and even amorphous minerals */18/*.

One might think that this diversity is partly due to development in the techniques used; the quoted references cover 50 years. From time to time one finds expression of the view that actual soil minerals do not behave in exactly the same way as the reference minerals with the same names */125, 130/*. It may be noted that in French studies */117/* most cases of strong fixation (soil not dried after applying potassium) are attributable to smectites. Nevertheless we find among these soils presenting severe problems in regard to fertilizer advice dominantly illitic soils */82/*. While in the former group, K content in the clay fraction is low overall, scarcely attaining 1.5%, in the latter it is between 3 and 4%. K fixation by these clays of relatively high K content (at least as high as in other soils without the same strong fixing power), is probably located in very impoverished edges of certain crystals */2, 75, 92/* where the selectivity for K^+ ions is very high, as has been demonstrated in studies of alterations in micas, specifically biotites */80, 148/*.

The conclusions differ according as to whether one is dealing with fixation in samples after drying which is in agreement with the longterm enrichment of soils and its measurement by soil analysis or fixation without drying after application of potassium. The first can be attributed to smectites, the second to vermiculites */47/*. This result has not been unequivocally confirmed in some French soil studies *[117, 130]*.

It is true that there can be important differences in behaviour between minerals bearing the same name. In the case of the smectites the role of criteria c and d in the above list *[61]* is particularly emphasised *[127]*: fixation capacity from 1 to 2.7 according to total layer charge, rate of fixation increasing mainly with the tetrahedral charge.

1.4 Mineralogy and the release of non exchangeable potassium

Extraction by sodium tetraphenylborate (NaTPB) and exhaustive cropping in pots with barley both show *[155]* that the lamellar minerals can be placed in the following order for capacity to release K: vermiculite > illite > biotite > phlogopite > muscovite. The relation between results by the two methods varies somewhat from one mineral to another but overall the correlation is +0.955. The classing of the 3 micas in this experiment corresponds with other studies in which changes were induced *[128, 129]*.

Some of the differences appear to be due to composition: Substitution of —OH by —F changes the behaviour of trioctahedral micas and brings it close to that of the dioctahedral micas *[128]*. Oxidation of divalent ions (ferrous iron) in the octahedral layer slows down experimental alteration of some biotites *[128]* and increase in the proportion of oxidised iron decreases the uptake of K by *Trifolium subterraneum* in pot culture *[58]*. The classification thus obtained is in agreement with that by NaTPB.

The criteria listed in the paragraph on fixation seem to apply also as regards liberation albeit with a different order and one addition suggested in a recent publication *[19]* according to which traces of rubidium in the mineral have an effect, liberation diminishing with rising Rb content.

The work discussed above illustrates the value of NaTPB in investigating K availability in soils. What is known of the mode of action of this reagent on the micas *[121, 128]* is paralleled by what some *[91, 97]* think about the possibility of the liberation of K to plants by the lamellar minerals (especially biotite) without any noticeable modification of the alumino-silicate skeleton.

The situation is quite different in the feldspars which can hardly release internal potassium without destruction of the skeleton *[107, 130]*. The latter is confined to particular conditions of podsolisation in the temperate climate. Here, plants seem to have little aptitude to utilise mineral K. In the humid tropical climate, feldspar potassium can be a very important reserve *[107, 126, 156]*.

In the temperate climate much importance is attached to the presence of illites *[25, 51, 133]* and sometimes glauconite *[1, 9, 56]*. Several cases have been mentioned where strong liberation of K has been associated with the presence of zeolite *[142, 147]*.

Most of what has been cited so far in this section relates to K as a constituent of the minerals (native K, primary reserve). But in cultivated soils a stock of «fixed» K is built up little by little, and its importance depends mainly on the presence of «fixing» minerals as mentioned above. This fixation is sometimes thought to reduce fertilizer efficiency (this more so in soil where wet fixation exceeds 50%) *[82]* but it can equally be thought of as a favourable factor *[93]*. «Storage» by fixation in effect can reduce leaching and the «fixed» K can eventually be freed *[156]*. Soils with an initially low capacity to liberate K can thus be transformed into good liberators *[9]*. The example in

Figure 2 illustrates such a change in soil on the *Aspach-le-Bas Experiment Station.* While the original uncultivated soil had a low capacity to release K, the orchard soil, generously fertilised for 20 years showed fertility much higher than the difference in exchangeable K content of the two soils would indicate. On the other hand on certain very high fixing soils the stock built up by generous fertilizer applications can call for lowering of the norms for the interpretation of soil analysis *[115]*.

Figure 2 suggests that the native K reserves of this soil and the reserve built up by K application have differing acessibility. The difference is not always so great but in a general way, it is usual to distinguish two categories of «accessible» non-exchangeable K, differing in rate of release *[71]*. It would be advantageous if these two categories could be distinguished by methods other than pot culture but it is uncertain whether techniques using more aggressive reagents *[2, 65]* can give results in agreement with those in pot culture.

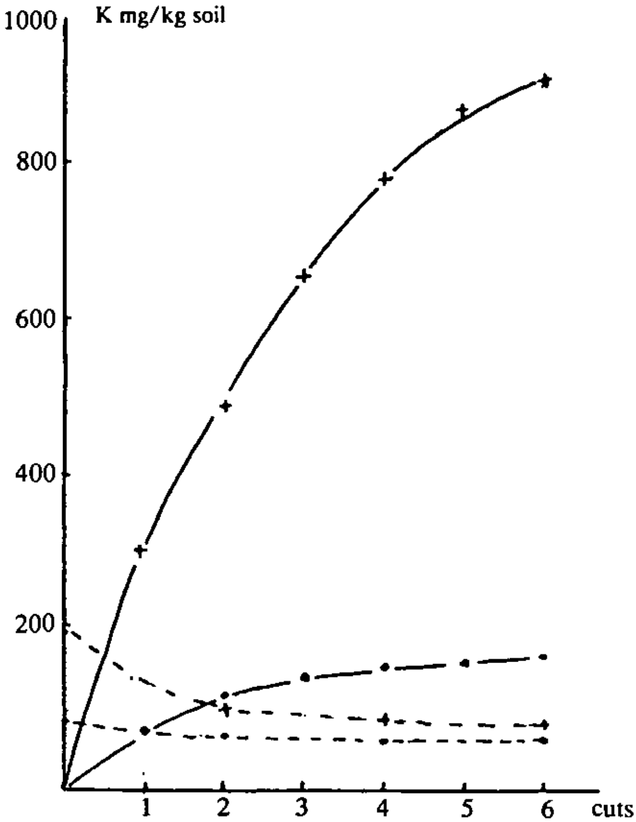

Figure 2 Uptake of potassium by Italian ryegrass from 2 Aspach soils

· fallow	Broken line:	Exchangeable K
+ orchard	Continuous line:	K-uptake

1.5 Mineralogy and buffer capacity

The concept of buffering capacity is in effect a translation into relatively simple terms of the potassium selectivity of soils. By selectivity is understood preferential adsorption of one cation in comparison with another. This has mainly been studied in the context of K-Ca exchange. The preference for K, attributed especially to its low hydration, diminishes as the charge density (charge per unit surface) increases.

Quantity/intensity isotherms, used for the measurement of buffer capacity, have been used to distinguish sites of differing selectivity for potassium in soils *[21]*. It has been recognised for over 20 years that there are 3 kinds of sites on lamellar clay mineral crystals differing in K selectivity related to their situation on the crystal; in order of increasing selectivity they are: plane surfaces, layer edges, wedge sites due to bending of the layers near the edges. But thermodynamic re-examination of the problem has shown *[61]* that some minerals have more than 3 types of site, others fewer; differences in charge density are involved besides the localisation of the sites. The situation of tetrahedral – octahedral charge also has an influence *[10, 103]*.

Research has shown *[10, 61]* that the K selectivity of clay minerals decreases in the order: micas – vermiculite – illite – montmorillonite. The existence of different types of site has not been unequivocally demonstrated for the last *[10]*.

This kind of work is difficult with minerals as sometimes the picture is distorted by the presence of impurities. For instance, kaolinite showing abnormally high K selectivity was found to be polluted by traces of vermiculite and it is rare for montmorillonite to be free from traces of mica *[61]*.

Extension of the results to soils is a tricky matter in so far as the fineness of the particles plays part (increase in the relative number of edge sites) *[10]* and because K selectivity varies with the degree of K saturation (diminishing as the latter increases). In certain soils with dominant mica the Q/I curves rapidly become horizontal showing that K adsorption ceases above a certain saturation *[100]*.

1.6 Conclusion

Knowledge of particle size distribution and clay mineralogy is essential for the understanding of K dynamics but the processes involved are so complex that, on the one hand, the acquisition of data is very costly and on the other, their inclusion in simulation models of practical interest is difficult. The difficulty is all the greater since many soils contain a mixture of modification products from the original material. In some cases, re-equilibration or exchange between these cannot be excluded *[102]*. However, our knowledge has progressed considerably and will progress further with improvements in technique (electron microscopy, X ray diffraction, measurement of layer charge).

In practice, at least in France, the idea is accepted among workers in this field that these matters are all brought together in the concept of CEC. Nevertheless, part of CEC is ascribable to organic matter and this has led some workers to measure a mineral CEC by different ways and to propose a method *[4]* which minimises if not entirely eliminates the organic CEC. More and more we have come to realise that the electric charges of which the CEC is a global expression have a very variable distribution, very significant for potassium. Practical progress with the use of CEC is still not altogether satisfactory.

2. Organic matter

A recent review *[108]* comments that if this subject «has received some attention» the information obtained is «to say the least meagre» and that there is a great deal of divergence between the various results obtained. Particularly in the field of K – Ca exchange some have found no effect from application of organic matter (farmyard manure) while others have found a decrease in K selectivity or even the reverse at least at low levels of K saturation, that is in conditions where the selectivity for K is the highest. The latter is interpreted as indicating increase in the proportion of interlayer sites with high selectivity, the former result as the reverse. The latter case may be due to envelopment of the mineral particles, the former to the application of organic matter or after it evolution in the soil of H^+ and NH_4^+ ions which interfere in K exchange. This must be reconciled with the effects of different types of organic matter: their effect (diminution of K fixation) is related to their susceptibility to change in the soil (green manure > farmyard manure > straw compost) or to their acidity (moss peat).

Alongside work on the application of organic matter there have been comparisons of plots with differing humic balance sheets or comparison of samples of the same soil before and after destruction of the organic matter. In the first case results may be affected by inter-plot differences in mineral composition; in the latter mineral characteristics may be altered by the destructive treatment *[107]*. The last remark casts some doubts on the relevance of most studies of soil mineralogy!

In *SCPA* work relating K dynamics to various soil characteristics, differences in organic matter have seldom had much if any effect.

Strongly fixing soils, often formed under hydromorphic conditions are usually very high in organic matter. This may only be an indication of soil forming processes superimposed on mineralogical development. However in some of these soils it is sometimes difficult to free clay samples from organic residues which leads one to hypothesise about the formation of clay-organic matter «intergrades» *[43]*. Finally we would suggest that whatever the technique used – application or destruction – investigators have not gone very far into description of the organic matter: farmyard manure is not a very uniform material. We should strive for greater precision but the necessary work seems to us to be as demanding as mineralogical studies.

3. pH and lime status

3.1 Effect on buffer capacity

A decrease in pH can reduce the buffering capacity *[2]* of some soils but this is not the general rule. Such changes will not occur unless the change in pH significantly alters exchangeable Ca content, as one would expect from the cation exchange equation, the buffer capacity being generally measured in the frame of K/Ca exchange. Some work *[89, 101, 151]* has been done on varying the pH of soils which shows that exchange capacity increases more or less strongly with pH. The results show that buffer capacity increases with pH following increase of CEC due to the appearance of variable charges. These new charges seem to have a preference for K^+ or selectivity for Ca^{2+} differing from the initial charges of acid soils, the sense of the change differing from one soil to another. Certain results (diminution of K preference) seem explainable by increase in charge density; the location of the new charges (in particular variable charges on the organic matter may lead to formation of complexes with Ca but not with K) probably have an effect, though some long-term experiments are affected by fixation phenomena.

3.2 Effects on fixation and liberation

Fixation is favoured by high pH (2). Very strongly fixing soils are almost all calcareous. Work on naturally acid soils *[151]* seems to show that there is no change in fixation up to about pH 6. Above that there appear to be minor changes. However, in an experiment on soil columns with two acid soils from southwest France it was shown that after generous liming, the K in drainage water was greatly diminished but this appears to be more related to an increase in fixation (*cf* the case of the sandy soil) than to retention in the exchangeable form *[68]*.

There are relatively few results on the effect of pH on liberation of non-exchangeable K to plants and they are difficult to interpret because extreme acidity affects crop physiology and hence capacity for K uptake from non-exchangeable sources *[38]*.

4. Other characteristics

The above characteristics (particle size, mineralogy, organic matter level, pH or lime status) are somehow localised and must be considered with other factors such as the thickness of successive soil horizons or depth of the cultivated layer and the immediately underlying subsoil, their apparent density and by the extent of the soil which may be reached by applied potassium and the volume explored by the roots. The last is related to structure and water circulation; this in relation to porosity and topography affects the movement of potassium to depth (leaching) and at the surface (run-off). Information on these points is uneven; we have more information on certain aspects of the fate of K addition (migration and fixation in the profile) than on others (run-off) and in a general way on this than on the location of crop removals or on the weighting to be accorded to point values in relation to the volume of soil exploited *[23]*.

Theoretical study *[149]* has pointed to the fact that the distribution of K in a profile due to water percolation is related not only to the amount of water but to porosity weighted for the thickness of each of the horizons concerned and their cation exchange capacities. This can be allowed for by expressing values per unit soil volume rather than per unit weight. A similar model could be used with regard to fixation capacity.

All the factors controlling water movement in the soil should be taken into account. In the same climate, drainage varies with the nature of the soil *[96]* (drainage/rainfall varying from 3 to 14%) and for the same soil (in this case Limagne black soil) with lysimeter depth (the percentages being 7,14 and 23 for depths of 145, 85 and 50 cm).

In practice, many things affect percolation, in addition to those mentioned above: succession of horizons, discontinuities of porosity, surface conditions (compaction, cultivations) *[30]* which can cause run-off or lateral movement, gradient, fissures *[37]* and pockets of cryoturbation *[17]* etc.

The succession of horizons having very different properties can cause problems, especially when the horizons are thin. For instance there may be very rapid movement through the upper horizons and virtual disappearance of K by fixation in the subsoil *[56]*.

All these are in a general way brought together in lysimeter studies *[17, 33, 37, 40, 42, 44, 59, 60, 74, 94]* which are summarised in Table 1. It is difficult in these to identify the effects of the soil itself. In the first place many refer to disturbed soils. This apart, there are few lysimeter installations which allow the comparison of different soils side by side in the same climate. Concerning this last aspect the results from Limburgerhof and Clermont-Ferrand are rare and very interesting exceptions. Depth of lysimeter varies greatly from one site to another.

Part 2: Weather

Soil properties concerned in the potassium balance are affected by climate through:
- temperature which modifies equilibria and distribution of K between different categories,
- precipitation, or rather the combination of this and evapotranspiration which controls soil moisture, and if excessive leads to leaching or when too low alters the distribution of K between internal and external sites of the minerals.

1. Effect of temperature

It has been shown *[61, 143]* that K selectivity decreases as temperature rises. The result, at the same total K content is that soil solution K concentration increases, with temperature thus increasing accessibility to plants. Plants may show more variation in K content between years than between rates of K fertilizer application (a very clear result of experiments at Aspach) *[90]*. This can affect estimates of the K balance: it is customary for this purpose to use average values for crop K content in calculating K removals, assuming that inter-year differences will be self compensating. This will be the case only over an extended period during which the same crop is grown frequently. If not there will be errors at least with some crops.

Another consequence of high temperature raising solution concentration is the risk of greater migration of K to depth.

2. Effects of precipitation

Temperature variations are not the sole cause of changes in crop K content. Leaching of nutrients from parts of the plant may be considerable (cereal straw in the period before harvest). This washing out of nutrients has been much studied in tropical forest where it is a main factor in nutrient circulation, contributing more than twice as much as litter and reaching 60 to 170 kg/ha/yr K depending on local conditions *[24]*. However, the most important effects of rainfall and its distribution, most frequently studied are those on nutrient (particularly K) mobility in the soil and also the effects of alternate drying and wetting of the soil on the liberation and fixation of non-exchangeable K.

2.1 Rainfall and leaching

In the tropics losses of K when drainage exceeds 500 mm can be very considerable when high rates of fertilizer are applied. When the soil has only small reserves of K, the K content of drainage water is low (Table 1). There may also be considerable losses in the temperate martime climate on irrigated sandy soils (Saucats) and even on sandy loams or loams (Quimper, Limburgerhof) with very different drainage conditions. This is because seasonal distribution is often more important than total annual rainfall. For instance at Clermont-Ferrand drainage in lysimeters may be non existent in some years (1965, 1968 and 1973) though total rainfall is average. The explanation is that the soil was covered by crops (winter crops) taking up water throughout the year. It matters greatly whether or not the ground is covered by crop at times of peak rainfall. The same explanation applies to Quimper with the highest rainfall and the lowest evapotranspiration in winter (soil sometimes bare and low temperature). Differences between tropical sites can be similarly explained.

2.2 Surface losses and erosion

Here there are fewer data than for leaching; many lysimeter installations, especially the older ones, are not equipped for measurements. Surface run-off can attain proportions almost comparable with leaching losses. For example at Azaguié on the Ivory Coast surface run-off can reach 100 mm or so when average drainage is over 800 mm. Inter-year variations of 36-114 mm on the same site are large *[59]*. In other cases surface run-off is very low – less than 1% of the rainfall *[13]*. With mountain climate and topography *[37]* much higer levels are reached.

Generally speaking losses of K dissolved in surface run-off are much lower than leaching losses. But there may be movement of solid soil matter in hilly regions and then losses can amount to some 100 kg K_2O/ha/yr *[37]* with losses of some tens of tons of surface soil.

Where rains are less frequent but violent, the losses may be in the inverse order of importance: erosion > run-off > drainage *[110]*.

Table 1: Losses of potassium by leaching in various situations

Place	Period	Soil	Rain + irrig. mm/yr	Soil depth (m)	Drainage mm/yr	Crop	K fert. kg/K_2O/ha/yr	Losses kg K_2O/ha/yr
Cayenne	76-83	ferralitic on magmatite	3170	1.40	815	rotation	235	14
Azaguie	66-68	ferralitic on schist	2020	1.75	828	banana	565	296
Dchang	73	ferralitic	1433	0.85	531	maize	80	15
Gagnoa	76	ferralitic on granite	1432	0.80	475	maize	0	11
Ampangabe	80	on granite	1314	1.00	420	maize	60	14
Bouake	81	on granite	1166	0.80	522	maize-cotton	160	3
Bambey	54-66	ferrugineous sandy	660	1.80	137	rotation	15	12
Adirondack	66-68	coarse sand	102.7	0.61	183	forest	0	0.66
			102.7	0.61	280	forest	445 in 1 appn.	46.6
			74.3	0.61	136	forest	445 in 1 appn.	59.4
			74.3	0.61	276	forest	0	2.4
Limburgerhof	35-46	loamy sand	656	1.00	252	various	—	57
		loam	656	1.00	178	various		22
Sezione di Modena		sandy loam		1.00	460	maize	0	5.4
		sandy loam		1.00	412	maize	200	6.3
		sandy loam		1.00	527	cultivated fallow	0	5.2
Vicarello		clay-loam	700	drainage	148	grass		9.2
		clay-loam	700	drainage	199	wheat (min. cult.)		9.61
		clay-loam	700	drainage	169	wheat (conventional)		15.7
Chalons	74-80	chalk		2.00	197	rotation 1	198	25.2
					119	rotation 2	154	8.7
					180	vineyard	21	25
Quimper	54-65	organic sandy loam on granite	1089	0.90	490	rotation	140+CaO	31.3
					502	rotation	0+CaO	20.7
					522	rotation	0	23.3
					567	bare	CaO	54.1
					560	bare	0	51.6
Saucats	72	sandy podzol	1226	1.25	840	maize	200	62
					700	fescue	250	26
Versailles		brown earth (loam)	595	0.60	146	rotation	0	4
Clermont-Ferrand	61-76	granitic	585	1.45	32	rotation	200	8
		basalt	585	1.45	9	rotation	200	3
	55-58	calcareous	566	0.85	162	bare		45
		clay black soil	566	0.85	58	rotation		25

3. The effects of drying and alternate wetting and drying of the soil

These have been the subject of much research over the past forty years (among others): *6, 11, 12, 20, 27, 29, 32, 35, 47, 48, 53, 57, 62, 64, 69, 72, 85, 86, 95, 105, 114, 120, 136, 137, 144, 145, 152, 157* to which must be added some references cited above in connection with fixation). From these very diverse data based on various techniques and on many different soils some general tendencies emerge:

1. In the great majority of cases, drying of soil samples changes their exchangeable K content: increase or decrease in samples of soil not having received K fertilizer shortly before sampling; systematic decrease (fixation) when they have. The direction of change is dependent on K content. It has been proposed that for every soil there is a K level at which drying has no effect *[95]* and attempts have been made to relate this to CEC but with most variable results *[6, 47, 95]*.

2. The size of the effect varies with clay mineral composition (see above regarding fixation).

3. Re-moistening a sample after drying can have very different effects on exchangeable K: reversibility (at least partial) of the effect of drying *[86, 138]*; no effect *[6, 120]*; accentuation of the effect of drying particularly in some cases of fixation *[20, 120]*.

4. The last result was frequently the case after repeated wetting and drying though most of the work refers to one drying. Work at Versailles *[57]* was concerned with the effect of alternate wetting and drying on K fixation by montmorillonites (especially that from Wyoming). Progressive fixation of K can change the original disorganised structure of these minerals to the organised structure typical of micas. The number of drying-wetting cycles needed to obtain maximum K fixation on bi-ionic (K-Ca) montmorillonites decreases as the proportion of Ca increases. This fixation is accompanied by demixing of the two ions in material initially homogeneous in K/Ca ratio leading to the formation of K montmorillonite. Drying temperature has no effect above 40 °C, the minimum needed to drive out all water from the interlamellar space.

5. (4) above poses two questions: what does «dry» (particularly «air-dry») actually mean or what is the moisture content of a «dry» soil; what are the processes taking place in the course of drying? Moisture content below which changes in exchangeable K content occur are variously stated by different authors: less than 50% of field capacity *[6]*; 5% water *[86]*; between 5 and 15% *[138]*; below 10-12 % but with a stronger effect below 5-6% *[137]*.

Figure 3 shows for several soils from SCPA experimental sites the effect of drying on samples which have or have not received an application of potassium before drying *[29]*. We found the three types of curve described elsewhere *[137, 138]*: continuous diminution in exchangeable K most important in a) slight increase in b), change in both directions in d), due perhaps to difference in mineral composition.

Rate of drying also has an effect *[29]*. The amount fixed is smaller when drying is rapid as if collapse of the mineral increases the proportion of sites accessible to K exchange unless the fixation is counterbalanced by cleavage perpendicular to the layers

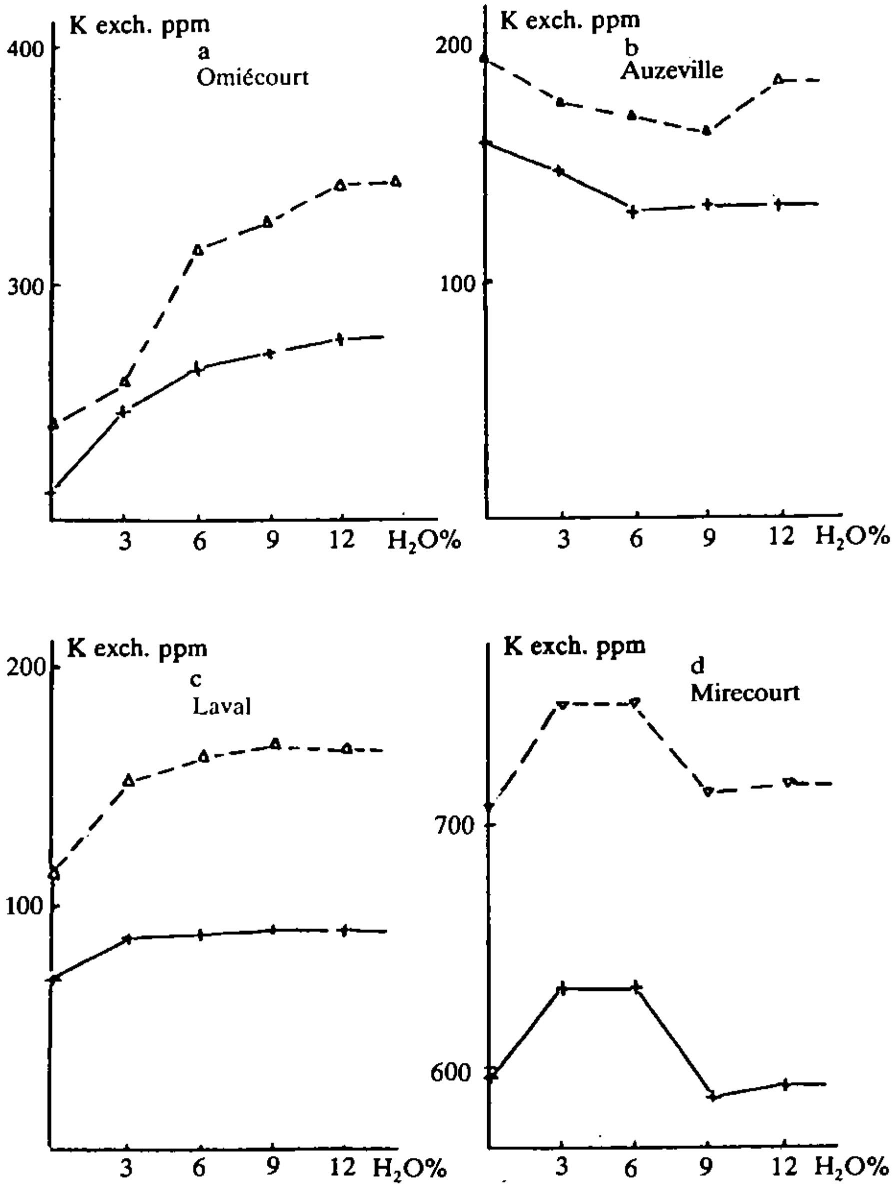

Figure 3 Change in exchangeable K content during drying
+ Original soil
Δ Original soil to + 0.1‰ K_2O — — — with K
∇ Original soil to + 0.2‰ K_2O ——— without K

due to greater tensions. Figure 3 shows that change can set in at 12% moisture content but generally and more strongly below 6% and even more so below 3%.

Some *[11]* have mentioned the importance of atmospheric humidity during drying. It is true that this varies greatly with the season and from one laboratory to another so that «air dry» samples can vary in actual moisture content. Stored samples lose in particular a large part of their water during storage. All these differences have effects on the measurement of exchangeable K especially when soils receive regular K dressings and this may explain why such measurements do not accurately reflect the K balance.

While there is no doubt that the moisture content of samples stored in the laboratory can reach very low values (< 3%), what is the situation in the field? It has been shown that the surface centimetre of soil is subject to considerable changes in moisture content through the season, with parallel fluctuations in exchangeable K content *[86]*. Due to the parallelism it is supposed that the changes induced by desiccation are reversible but this is not always the case. If the change is irreversible it would be expected that the effects of seasonal variation would be cumulative over several years finally affecting a large part of the soil to plough depth. Prolonged and detailed work on experimental plots would be needed to verify this.

It is not difficult to find in the temperate climate soils in which the plough layer falls some years below the moisture levels mentioned above: in the 1976 drought, soil samples taken by *SCPA* showed moisture contents at sampling time below 3%.

6. There is little information on the effects of desiccation or repeated wetting and drying on categories of K other than exchangeable but we mention some results with NaTPB extraction. Table 2 shows the effect of drying on 0.1 N NaTPB (7 days contact) extractable K in some Limagne soils *[78]*. We see that on these soils, the effect is at least as great, if non greater in both absolute and relative (in relation to the value in moist soil) terms than the effect on exchangeable K, as is the case for soils A1 and A2, which are typical of this well known fertile black soil. Thus it seems that all the interlamellar K is «shifted» by drying to sites more accessible to these reagents at least in this smectite soil.

Table 2 Effect of drying on exchangeable potassium and K extracted by sodium tetraphenylborate in some black soils from Limagne (78)

	Soil 1		Soil 2		Soil 3
	A (1)	B (1)	A	B	B
Exchangeable K					
– moist soil	693	213	578	125	76
– soil after drying	765	395	612	234	155
– re-wetted dry soil	623	249	460	164	114
K Na TPB 0.1 N (ppm):					
– moist soil	1075	302	723	150	80
– soil after drying	1456	701	855	273	194

(1) A: good maize growth
B: bad maize growth

We find the same in Figure 4 dealing with the effect of alternate wetting and drying on K extracted by a more aggressive reagent (0.1 N NaTPB + 1.9 N NaCl, *i.e.* 2N in Na) *[114]*. Though in this case we do not start from moist samples (samples already air-dry) the effect of alternate wetting and drying is large for this soil which had been subjected to prolonged exhaustion in pot culture. The effect is much less for enriched samples but again in the same direction with increase in accessibility with successive dryings at least for the range of contents which we examined. It is not yet possible to state whether the phenomenon reverses with larger additions of K as can be the case with exchangeable K (increase of fixation).

In some soils (with dominant illite chlorite clay) alternate wetting and drying produced no change in the extraction curves by Na TPB + NaCl *[118]*.

7. The consequences of the effects of drying of the soil on plant nutrition have been widely studied:

- the potassium liberated is at least partially (due to the possible reversibility on rewetting) utilised by crops *[11, 12, 71, 85, 136, 145, 157]*.
- fixed potassium especially when added shortly before drying may become less assimilable *[27, 48, 53, 145]*.

To conclude, straightforward consideration of the effects of drying or alternate drying and wetting on exchangeable potassium and on uptake by plants is sufficient to shows that exchangeable K, which is the conventional method of analysis in use is not a good indicator of the relative K availability of different soils.

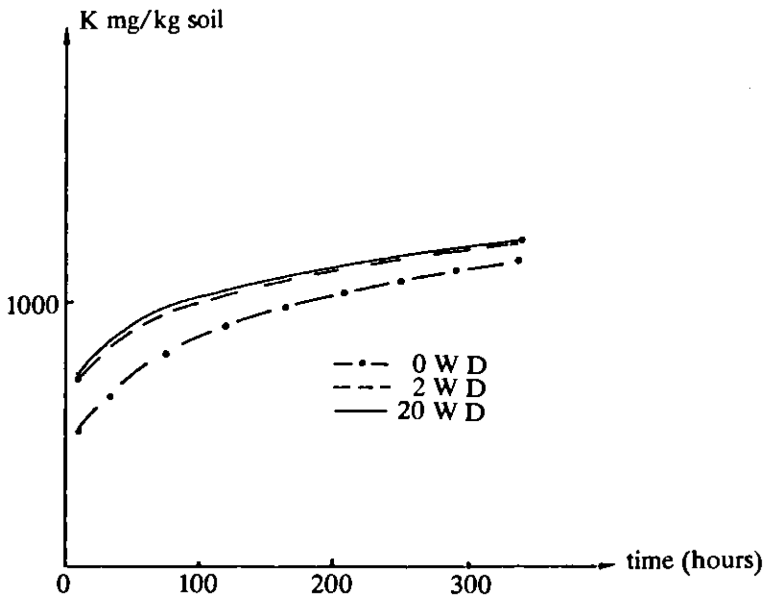

Figure 4 Effect of alternate wetting and drying (WD) on K extracted by NaTPB + NaCl (Soil with smectite — Petite Beauce)

Part 3: Crop and Cropping History

The potassium balance can be much affected by crop species through their K requirements and their growth characteristics (soil cover, rooting pattern); past and present cultural practices including fertilizer practice; rate and method of application of fertilizer; their interactions with soil and climate.

1. Past history

According as to whether past fertilizer practice has been deficient or excessive, some soil properties important for the future balance can be changed in one sense or the other. In other words, the future balance is not independent of history.

1.1 Effect on buffer capacity

Effects of deficient or excessive K application to a soil on the Q/I relationship have been much studied *[2, 3, 5, 22, 52, 61, 98, 140]*. In a general way the effects of enrichment or impoverishment are shown in change of the origin of the AR and Δ K axes but without change in the shape of the curve at least when differential fertilizer treatment has not been very long-lasting (20-30 years). Over longer periods results are sometimes contradictory but generally change in shape of Q/I curves is slight and in practice, at least as a first approximation, one can say that for a given soil the Q/I curve reflects the change in buffer capacity of a soil due to difference in K balance.

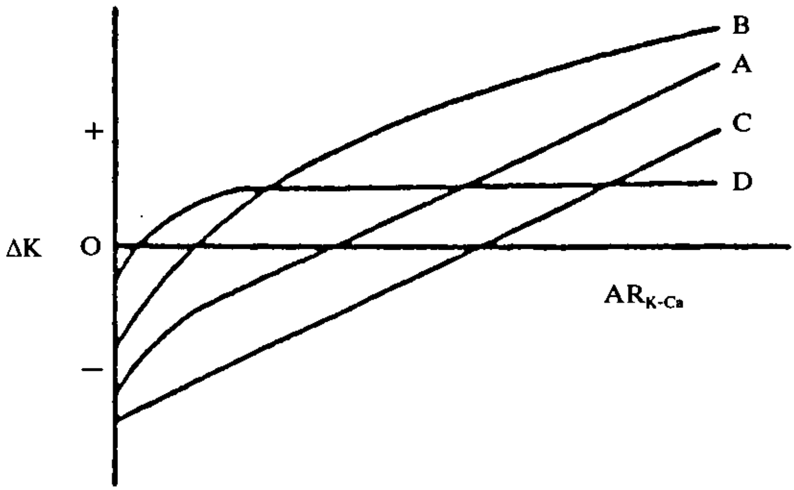

Figure 5 Typical Q/I relations for soil potassium, where Q/I is the change in exchangeable K^+, ΔK, versus the activity ratio, $AR_{K\text{-}Ca}$.

A, normal clay loam soil; B, heavy clay soil; C, peaty organic soil; D, soil with little or no fixed charge. *Goulding [1983] after Beckett [1972]*

Behaviour varies with the type of Q/I curve as shown in Figure 5. Soils A and C (and even soil D above a relatively low K content) do not change or only slightly in buffer capacity at least within the usual range of fertilizer applications. Type B (which applies to the soil for which equations are given in Part 1 and which we have found to be the most frequently occuring) shows buffering capacity decreasing as it is enriched in K. Above a certain K level the numerator of the K/CEC ratio becomes dominant, BC being the inverse of the K/CEC ratio. Though clay soils normally have a higher BC than sands, clay soils very rich in exchangeable K can have buffer capacities rather low in relation to CEC; in France we have found this mainly in shallow skeletal soils with a high proportion of coarse particles. Their low content of fine earth means they are easily enriched and this, along with their low buffering capacity, allows them to be rich in K and to give good yields without manure though they respond to fertilizers *[84]*.

1.2 Effects on fixation capacity

Over 30 years ago it was found that potassium fertilizer reduced wet fixation more than dry fixation *[134]*. This is often still true but with some slight change. Figure 6, relating dry or wet fixation and exchangeable K, shows the effect of differential fertilisation over 20 years on the INRA-SCPA experiment at Omiécourt. The effect of former balances on dry fixation is somewhat greater than on wet fixation but it should be noted that it required a high rate of application (K_3) to reduce fixation significantly. The manner in which fixation capacity varies with clay content is affected by clay content and the type of clay minerals. The regression equations given at the beginning of this paper give some idea of the variation in relation to change in exchangeable K content for several types of soil. The relationship is improved by adjusting exchangeable K content for clay content or CEC: on a hundred soils on plateau loam in Normandy-Picardy, we found that fixation capacity reduced by 5 points (5% of fixation) for an increase of 1% in K saturation (1% of CEC).

The relative constancy of dry fixation capacity is justification for expression of fixation as a percentage of K applied, implicit in the *van der Marel* method. This approach assumes that fixation is proportional to applications: this is acceptable for practical purposes so long as soil texture is not too light, that is for clays and some loams. It does not hold for sandy soils in which the percentage fixation decreases much more rapidly with rate of application *[117]*.

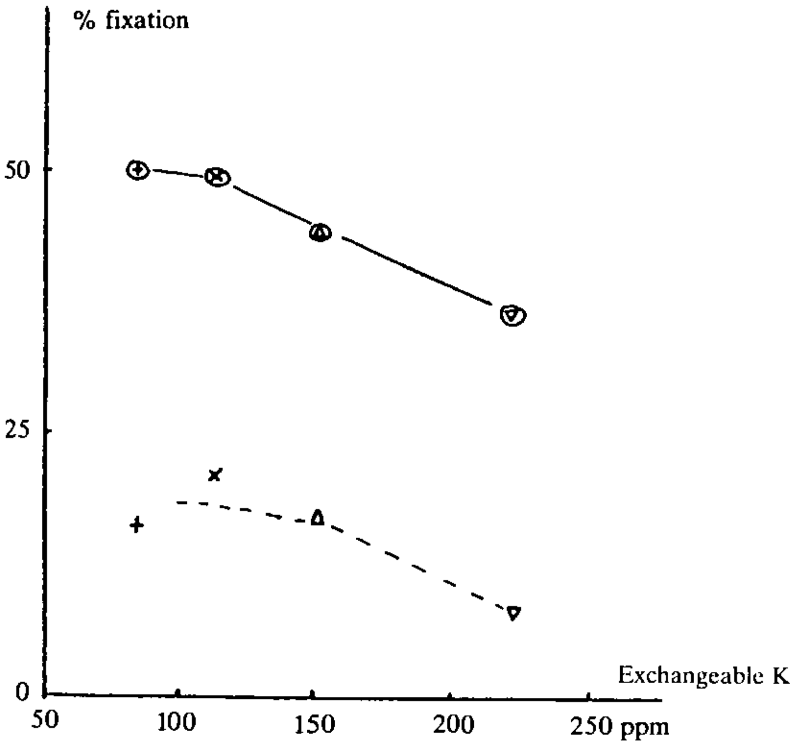

Figure 6 Relation between exchangeable K and fixing capacity (after 20 years differential fertilizer treatment) Omiécourt INRA-SCPA experiment (Somme)

- van der Marel method
- encircled points — after drying
- others — no drying.

1.3 Effects on release

In the first part we put forward the idea that fixation of potassium can transform a soil with little capacity to release K into one with a large capacity. Figure 2 illustrates this. It remains to estimate how far the K balance resulting from past history relates to the capacity of the soil to liberate K.

Some very complete work on this point has been published by Rothamsted *[70, 71]*. Exhaustive cropping with ryegrass in pots of samples from different experimental plots, and considering only «easily available potassium» (exchangeable + non-exchangeable) has shown that the value of this potassium is well related to previous field treatment. This K is also well correlated with exchangeable K measured before cropping in pots. The slight differences are thought due to the fact that generous applications and intensive cropping do not always allow for complete equilibration between exchangeable and non-exchangeable K.

The release of non-exchangeable K in pot culture is equally well correlated with exchangeable K measured before cropping; no doubt because the soils have the same origin. Differences in K uptake by ryegrass from one to another sample were about 3 times the differences in exchangeable K (twice as much from non-exchangeable as from exchangeable K). This ratio would vary with the origin of the soil.

The percentage recovery in pot culture of K residues accumulated in the field over 100 years (1848-1951) agreed with that obtained with ryegrass grown in the field over 9 years and was about 70%. We think that this percentage is related on the one hand to the soil and on the other to the plant used (ryegrass). Taking account of the characteristics of the latter it is probably the maximum (for this type of soil).

In summary, because the ryegrass recovers 70% of the residual potassium, and 3 times as much as exchangeable K, the latter only «identifies» o.33 × 0.70 = 23% of the residual K; some 75-80% of the K applied has apparently «disappeared» and this is quite usual in field experiments.

The recovery of residual K varies with past cultural history. Recovery from large applications followed by several years fallow are lower (only 40-50%) than from repeated applications to cultivated land. The age of the residues is also probably of importance. At Aspach we have found 73% recovery from 2-3 year old residues against 55% for 8 year old, but this applies to uncultivated soils.

2. Applications: method and rate

Most results quoted in the literature relate to fertilizer applications corresponding to normal farming practice. Applications greatly exceeding these rates may occur when agricultural or agro-industry wastes are spread. Conclusions vary with the type of soil; suitable types conserve most of the potassium applied *[36, 49, 87, 104, 111]*. Apart of these somewhat special cases there may be doubt about the rates actually applied as the material may be applied unevenly. In such cases we use the term «density» of application for lack of a better term.

On rubber in Malaysia, because the practice is to apply fertilizer in a ring round the tree, quite small in diameter when the tree is young, the actual rate of application per unit surface area may be 150 times as high as indicated by average rate/hectare. With annual rainfall of 2500 mm/yr and heavy showers, losses of K can easily amount to 50% of application *[112]*. In such case one may have resort to divided dressings or to the use of coated fertilizers.

Without considering such extreme cases, usual practical farming offers examples of localised heavy applications at rates far exceeding normal fertilizer rates: the return of K to pastures *[39]* in cattle urine can reach as much as 2t/ha K_2O in one urination. The study of individual urine patches shows that the fate of urine potassium depends on weather, soil type and date of application. On the light soils of western France *[54, 109]* the loss in some cases may be almost total. On deep loamy soils with high fixation capacity as at Aspach the herbage can recover 50% of this over several years, the remainder only being recoverable very slowly *[81]*. This applies to spring application. Recovery from autumn applications when crop growth is slowing in winter are less. These results on individual patches are confirmed by comparison of parallel experiments on temporary and on permanent pastures [73]; under normal grazing there is additional non-uniformity in the pattern of distribution of the urine patches which is far from uniform, patches tending to be concentrated in certain areas near drinking troughs, under shade etc. Grazed grass is the most complex situation one meets in evaluating the K balance.

Fertilizer, except at the stage of establishment when it is worked into the seedbed, is applied to the surface of grassland. For arable crops, surface application is the rule with the techniques of minimum cultivation now used. This reduces the volume of soil directly affected by the fertilizer. This is not a very serious matter as long as this technique is not permanently used on a field. Should this be the case serious problems would arise in evaluating the K balance and in the interpretation of soil analysis.

3. The plant

3.1 Removals and residues

Obviously, the crop has a great effect on the K balance since different crops differ greatly as regards K uptake. Considering the effects of climate we have said that there is great variation in content between years at least for some plant parts and the use of average values can be a source of error getting larger if we are considering short periods.

That part of the harvested crop removed from the field does not necessarily contain the major part of the K taken up. The efficiency of fertilizer in relation to crop and cultural system was recently discussed in an IPI Colloquium *[46]*. The lower the efficiency the lower is the proportion of applied nutrient leaving the farm. This definition of efficiency appears to us to consider fertilizer as a raw material rather than as a production factor (well supplied soils). The same applies to the individual field: the soil (plus fertilizer) should supply to crops more than the amount of K actually removed in harvested crop. We have seen an example in the case of grass above: the fate of the K which is not removed in crop (of the order of 90%) is a complicated matter.

To a lesser extent (because they are more uniformly distributed) the fate of K in crop residues like cereal straw is somewhat problematic. Year to year variations in exchangeable K content on some experimental plots (Figure 7) have been attributed to recent incorporation or residues (cereal straw, beet tops, or even more, rape straw) *[79, 83]*. It is likely that climatic factors interfere: Incorporation of crop residues had such an effect on exchangeable K, probably because of sampling times, that there may not have been sufficient time to establish equilibrium between the different K pools. The availability of K in crop residues is virtually equivalent to that of fertilizer K, with sometimes a delayed effect to the conditions of breakdown of these residues in the soil *[13, 41, 45, 63, 67, 154]*. In the extreme case, where the soil remains very dry after incorporation of residues, K availability from them in the short term may be nil.

Soil sampling is normally avoided in the weeks following fertilizer application; we are much less particular when the K is applied as a crop residues: however, rape straw contributes as much K as a very generous fertilizer dressing.

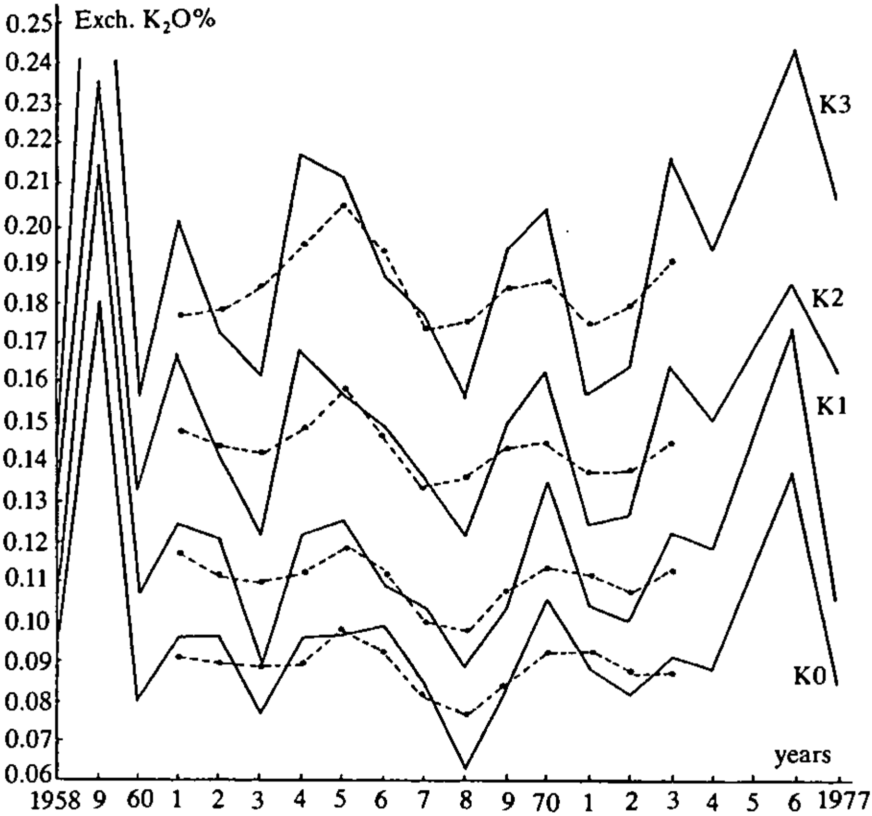

Figure 7 Changes in exchangeable K content at Omiécourt (Somme) (Moving 3 years averages broken line)

3.2 Roots

Rooting pattern interacting with soil factors can affect the K balance and even more so analytical values:

- rooting density may lead to uneven uptake,
- rooting depth – the subsoil may or may not be explored,
- specific root properties may affect the accessibility of non-exchangeable reserve K.

Taking account of the fact that the relation between crop removals and change in exchangeable K content is far from linear (because of the stabilisation of exchangeable K around a minimal value in continuous cropping) */146/*, there may be differences in the balance indicated by analysis and the gross K balance (applications less removals). It has been found that in otherwise identical pot experiments done in pots differing in size, the relation between the gross balance and the balance shown by analyisis may not be the same. One might consider that in very small pots exploration of the soil is almost uniform and that the same does not apply in large pots were the effects of walls on rooting pattern may be very important *[26]*. In the field, however, it might be thought that cultivations render the soil more homogeneous but there are still discrepancies between results in small pots and field observations (66).

Exploration of the subsoil is receiving more attention but we have few data where this is taken into account in formulating fertilizer advice or in calculating the balance (particularly the transfer of nutrients from depth to the surface). It must be acknowledged that the work needed is difficult. A technique using labelled Rb, in the ploughed layer has recently been proposed *[77]*.

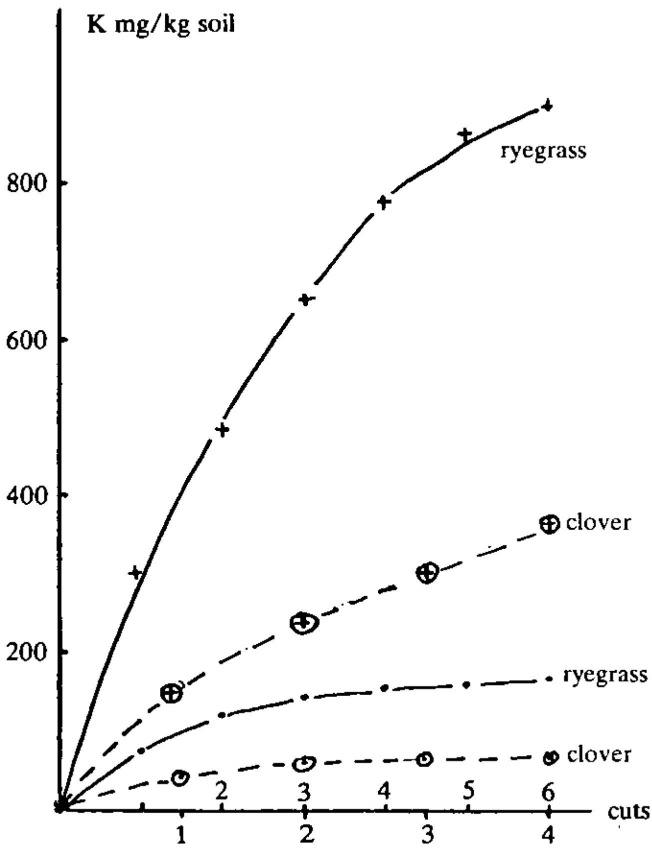

Figure 8 Comparison of uptake of K by Italian ryegrass and red clover for the same cropping period on the two soils of Figure 2 (Aspach fallow •; Aspach orchard +; Broken lines and encircled: clover)

It is well known that crops vary in their ability to exploit soil potassium and especially non-exchangeable potassium. The contrast between grasses and legumes is a classic case. It has been shown that these two families have not the same capacity to obtain K from biotite (wheat and lucerne *[91]*). Figure 8 illustrates this difference (Italian ryegrass and red clover) for the two soils of Figure 2. But such comparisons are difficult to interpret. On the one hand recent observations on the importance of root extension for K uptake *[28, 139]* involve measurement of roots; on the other, pot culture can impose restrictions on root growth in certain species and this type of work is no substitue for field investigation of the effects of potassium fertilization.

3.3 Soil cover

Crop cover, either by virtue of K uptake or by transpiration which reduces water percolation can limit leaching. This has already been mentioned in the section on climate. Several examples in Table 1 touching the effect of continuous cover are significant in this connection (Quimper *[40]*, Saucats *[42]*).

Part 4: Practical Aspects – Problems in Soil Analysis

Generally speaking it can be said that leaching, surface run-off and erosion are not major sources of potassium losses except in certain cases where are coinciding abundant and badly distributed rainfall on soils with little capacity to retain K (coarse textured soils), insufficient or discontinuous plant cover, and unfavourable topography (hilly regions). In the temperate zone such conditions rarely coincide and losses by these means remain slight.

However, at the present time, agricultural advisors and the more advanced farmers are expressing some disquiet over possible losses of potassium and mistrust K balance. These people confine themselves to a very simple accounting procedure setting «income» against «expenditure» as in a bank. That this reveals an enormous gap is to us not at all surprising. It is easy to arrive at a precise figure for «income» taking some precautions (supervision of spreading, analysis of farm manures), which are, it must be said, not always taken. Inputs thus measured are not always the same as intentions, but they can be reliably measured.

Accurate assessment of crop removals calls for separate weighing of harvests from each field which is not always possible with the machines in use or with contractors. The more or less accurate yield estimate is multiplied by a mean figure for nutrient content derived from experimental results. Such approximation can lead to serious error in the short term.

However, even on experiments where inputs and removals are precisely measured we mostly find the same gap *[83]*. The failing is in soil analysis and is due mainly to the phenomena of liberation and fixation combined with exchangeable K measured by exchange to ammonium or something similar.

The comparison between under-fertilised and non-fertilised plots by this technique reveals little and underestimates the size of negative balances because of the occurrence of liberation. In the extreme case after a time without any fertilizer it shows nothing at all because of the existence for a given soil of a «minimal» value for exchangeable K *[146]* which is really a minimum threshold or an asymptotic value only changing very slowly. This value can be easily obtained by exhaustive cropping in pots (Figure 9) but appears more slowly or less frequently under field conditions because of the effects of alternate wetting and drying, of restitutions, even if very small, of crop residues and of crop species because some crops cease to take up K well before the soil arrives at this very low values. However we do know of cases where this «minimum» value for exchangeable K is compatible with obtaining quite high yields: this is the case with certain clay-loams of the Beauce region, where the threshold value is around 150 ppm at which appreciable cereal yields are possible (8 t/ha maize). The practical question is: how long does this state of affairs apply?

Certain methods (using the reagent NaTPB + NaCl) do allow us to follow depletions at this minimal value of exchangeable K (for some soils originating from continuous pot culture) *[116]*. Tests with applications in the field have so far revealed nothing, perhaps because of the effects of alternate wetting and drying *[118]*.

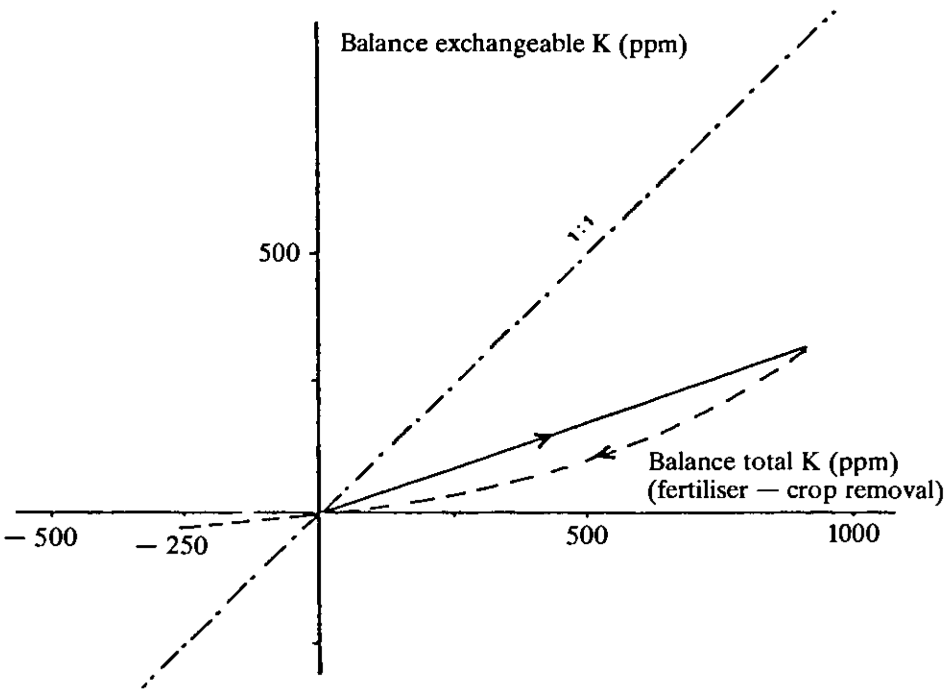

Figure 9 Relation of balance to exchangeable K in pot culture *(Quémener [113])*

This is of little interest to practical farmers who are concerned at least in intensive agriculture not to let their soils decline in fertility and therefore apply at least the equivalent of crop removals. Of more interest are problems related to soil enrichment because people fear that because of fixation they may not recover their investment in generous fertilizer usage.

Various methods have been tried or proposed with might give a better estimate of fertilizer balance. While some may appear to give better indications than exchangeable K, it is an illusion to suppose that they could give an accurate picture of the balance; only total K could do this but its agricultural significance is doubtful and, except in particular circumstances its relative precision is not sufficient. At the present stage of development it is probably best to try to improve the interpretation of exchangeable K.

This can be done first of all by improving sampling: rules are often proposed according to which it is advisable to repeat sampling periodically *[7]*; in order to follow the balance this involves sampling on a reduced area of the field, not allowing us to measure thoroughly its heterogeneity but allowing greater precision in following the course of development. Sampling time could have some influence *[153]* and the crop preceding sampling should always be the same *[104]*. Weather between incorporating residues and sampling which has effects already pointed out, though they are not yet fully understood, should be noted in the hope of improving the interpretation of results.

It is clear that the mass of soil concerned in the cycle is very important. This is fairly easy to comprehend for the plough layer but the significance of the subsoil is not so easy to investigate for reasons already mentioned. We need more and more precise experimental results on this point. Finally and above all we need to take account of fixation and liberation.

A first approximation can be made from laboratory results for fixation capacity actually measured or whose value can be estimated from regression equations developed from determinations on a sufficient number of samples to permit their calculation from values for current soil analyisis, clay content and CEC etc. *[115]*.

It is curious that it is with strongly fixing soils that such measurements appear to give the best agreement with practice *[115]*. In other cases, one has the feeling that fixation measured in the field in experiments *[83]* is higher than laboratory values at least those obtained by various methods *(van der Marel* in our case).

There may be several reasons for this: effect of repeated wetting and drying, duration of the development... But it may be remarked in Figure 9 that the balance indicated by analysis for the same total K balance differs between the curve of enrichment represented by the continuous line, and the curve of depletion following enrichment (discontinuous line). The intervals between the two curves are less marked near the point of departure of the depletion curve (enriched soil which corresponds to the precedent case – strongly fixing soil from which uptakes are small in relation to necessary enrichments) and near the origin of the axes where there was a kind of maintenance which reflects the view that exchangeable K will be maintained with maintenance dressings. (In fact, in this type of experiment, there is on certain soils some difference when the balance between application and removal is zero.) Between the two extremes the depletion curve departs more or less from the enrichment curve in a manner differing from one soil to another: it would be important to relate these differences to soil characteristics. All this supposes the plant is growing on enriched soil to take up preferentially exchangeable K.

For sure, the rates of K used in these experiments did not correspond with those used in practice. It is difficult to know how great is the total mass of soil concerned in the potassium balance. It is also difficult to know how much soil is affected by a particle of fertilizer: it would be expected to vary with the size of the fertilizer particle (more important with the use of granular fertilizer) and the way in which K diffuses in the soil and soil moisture content; but one would think that it would be rather restricted at least for a time.

Heterogeneity resulting from the application of fertilizer, at least soon after application, justifies the opinion of those who would like to add to the categories «exchangeable» and «non-exchangeable» a «fertilizer» category. To the latter an utilisation coefficient could be attributed. There are few measurements of this in the case of potassium, the reason being the lack of a suitable labelled isotope at a reasonable price. K enriched in ^{40}K, the only product with a sufficient half life to use, is too costly to allow many measurements to be made. One of them *[50]* has only given very low values (5.4 to 11.3% according to the plant) for this utilisation coefficient perhaps because the soil concerned was high in K. This should, however, be useful in devising simulation models which might explain the differences in Figure 9 and apparently very high rates of fixation (compared with laboratory measurements) found for certain soils in the field.

Conclusion

Soil texture and mineralogical composition, weather via the soil water regime, cultural practice and past fertilizer history all to a greater or lesser extent modify soil properties, with effects on the main processes which determine the potassium balance: delivery (liberation) – retention (fixation) and mobility in the profile.

Touching the last point, movement to depth has been thoroughly investigated. To a certain extent, the interaction of climate and plant is the dominant factor and in some cases appears to be more important than the nature of the soil. Movement from depth upward does not seem to have attracted as much attention and has been little investigated on account of difficulty in investigating the root system and uptake from the different horizons. Transfer from depth to the surface soil layer is of particular importance when the crop is a gross potassium feeder but does not contain large amounts of K in the portion removed from the field at harvest when most of the potassium taken up is returned to the soil by way of crop residues within a short period.

The fate of potassium in residues can raise problems in soil analysis in relation to climatic conditions prevailing between their incorporation and soil sampling as affected by soil type and more particularly fixation capacity.

Vast quantities of theoretical data on fixation have been accumulated. There are methods of measurement by which its relative extent can be estimated though the effects of weather (alternation of wetting and drying in the field) are difficult to foresee, the more so in the short term. The crucial point appears to be the reversibility of fixation, that is the extent to which fixed K can eventually be released. Various techniques can be used. The most difficult but interesting aspect to measure is the release available for a crop. It seems desirable to counteract the impression given to the farmer by the use of exchangeable K in soil analysis that losses due to fixation are apparently very serious, which discourages him from investing in fertilizers. Almost total reversibility is shown in pot culture of grasses and by using reagents which imitate the behaviour of such crops. We need to know how far crops other than Italian ryegrass can utilise fixed potassium.

Finally, the method of applying fertilizer or of returning crop residues (placement, surface application with minimum cultivation) pose problems in evaluating the actual balance and in the interpretation of soil analysis. Uneven return of residues and their «density» (in kg K_2O per unit surface) is a serious problem under grazing, the most difficult with the potash book-keeper is concerned.

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Assessment of K Losses in Tropical Cropping Systems of Francophone Africa and Madagascar

C. Pieri and R. Oliver, Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières, Département du CIRAD, Montpellier/France*

Summary

K losses from cultivated land in Francophone Africa and Madagascar are closely related to the nature of the soils and their management. In traditional systems, K losses are usually moderate (less than 20 kg/ha/yr K_2O) if erosion is not severe. In more intensive annual cropping systems and under commercial perennial crops, leaching losses may amount to 50% of K applied as fertilizer.

The degree of leaching is related to soil physical and chemical characteristics, namely sandy texture, low organic matter content (< 2%), low pH and, consequently, low effective cation exchange capacity (frequently < 1.5 me/100 g).

On the farm, management of crop residues may enhance or reduce K losses. Control of K losses from cultivated soils is directly related to:

1) Effective control of soil erosion and run-off,
2) Maintenance of soil pH and organic matter content,
3) Efficient use of K and other fertilizers.

1. Introduction

According to *FAO* estimates, Africa's demand for potash which was about 300 000 tones K_2O for 1983/4 will exceed 400 000 tonnes by the end of the eighties, and will further increase regularly over the following decades. At the same time there is some fall-off in demand for phosphate and an increase in nitrogen demand which reflects the world situation. Neither Africa nor Madagascar have indigenous sources of potash. The low *per capita* income which obtains over most of the continent, especially in West, Central and East Africa, not only imposes a need to increase agricultural productivity by peasant farmers through easier access to fertilizer but also demands that fertilizer use should be as efficient as possible in order to optimise the cost benefit ratio.

* *C. Pieri,* Chef Div. d'Agronomie, et *R. Oliver,* Ing. de Recherche, Institut de Recherches Agronomiques Tropicales, CIRAD, B.P. 5035, F-34032 Montpellier-Cédex/France

This preoccupation with short term economic profitability must not allows us to forget the recent interest expressed by research workers and those responsible for development in the use of potassic fertilizer as a means of reducing over a long period year to year variations in yield under conditions of low or deficient water supply to crops. These are conditions which have unhappily become so familiar since the early seventies.

In order to optimise the use of potassium and to organise the use of potash fertilizer on sound lines to ensure economic returns in the short and long term, it seemed important to identify, and ascertain the relative importance of the various ways in which K is wasted in tropical systems and to better identify the causes of processes which lead to disequilibrium in the K balance of cultivated soils and their implications.

2. Source and extent of potassium losses in the tropics

Soils usually cultivated with rain-grown crops in Francophone Africa and Madagascar mostly belong to the group of ferrugineous tropical soils or to the ferralitic soils. These soils are characterised by freedom from irreversible fixation of K *(Boyer [1982]);* Incubation experiments on soils having received applications of KCl have confirmed this for the soils of many of the experiments mentioned here (Table 1).

It is true that in the geographical region with which we are concerned losses of fertilizer potassium are limited to those caused by movement or surface water and by soil management at farm level.

Table 1. Exchangeable K (cobaltihexammonium chloride) and proportion of 200 kg/ha K_2O applied remaining exchangeable (R. Oliver, private communication)

	Ferrugineous tropical			Ferrallitic		
Soil	Bambey	Kita	Sikasso	Ampangabé	Divo	Boumango
Exch. me/100 g	0.081	0.274	0.436	0.079	0.141	0.531
% applied K remaining exchangeable	94.2	76.8	93.2	99.1	95.1	95.0

2.1 Erosion, surface run-off and K depletion of soils

The potential for erosion, because of torrential rains is from 3 to 60 times higher than it is in the temperate zone *(Charreau* and *Fauck [1976]).* There is little erosion under the natural vegetation but it can be multiplied 1000-fold when the land is cropped *(Roose [1980])* and on steep slopes soil losses may reach more than 200 t/ha/year *(Lal [1984]).* However, on the gentle slopes of the basement complex (less than 2%)

soil losses vary from 0 to 70 t/ha/yr, equivalent on account of their low K content to but a few tens of kilos of potassium (total K_2O) per hectare per year (Table 2).

However, this greatly underestimates the actual losses of K due to erosion because erosion losses are mainly of the finer soil particles which are richer in minerals. Thus, based on the estimates of *Charreau* and *Seguy [1969]* for the area of Sefa in Casamance (S. Senegal) it emerges that the eroded soil contains on the average five times the proportion of fine particles as does the natural surface soil and this puts actual annual losses of potash between 10 and 47.5 kg/ha when account is taken of the K content of the various particle size fractions (Table 3).

Finally it should not be overlooked that a significant amount of K can be dissolved in surface run-off (Table 4) as laboratory analysis shows that 30-70% of the exchangeable K is water-soluble (see Appendix I).

Table 2. Losses of soil by erosion and decline in exchangeable and total K

Site	Slope %	Rainfall (mm)	Soil loss t/ha/yr	Potassium loss kg/ha/yr		Ref.
				Exch.	Total	
Séfa (Senegal)						
1955 – 1962	1.25	1235	4.75	0.25	2.15	(37)
cereal/groundnut rotation	2.0	1235	11.81	0.62	7.36	(37)
Manankazo (Madagascar)						
grass	–	1670	–	–	–	(33)
over-grazed grass	–	1670	13.6	0.37	2.65	(33)
Nanisana (Madagascar)						
1958 – 1963	3.8	1700	3.8–11.4	0.15–0.45	0.75–2.3	(11)
Adiopodoumé (Ivory Coast)						
Pineapple (residues burnt)	4	3350	1.2	0.057	0.5	(39)
Pineapple (residues burnt)	20	3350	69.0	3.7	32.3	(39)
Pineapples (residues as mulch)	4	3350	0.1	traces	traces	(39)
Pineapples (residues as mulch)	20	3350	1.0	0.06	0.5	(39)
Saria (Burkina Faso)						
Natural regrowth	0.7	830	0.5	0.02	1.6	(36)
Sorghum	0.7	830	4.0	0.19	12.6	(36)
Bare soil	0.7	830	10.0	0.47	31.2	(36)

Table 3. Total K in particle size fractions at SEFA (Senegal) (Oliver, private communication)

Fraction	Clay	Fine silt	Coarse silt	Fine sand	Coarse/sand
Total K meq/100 g (extractant $HF-HClO_4$)	4.69	4.23	3.07	0.87	0.06

Table 4. Estimates of K lost in surface run-off

Agronomic conditions	Slope %	Rainfall (mm)	Applied K_2O Kg/ha/yr	Run-off (mm)	Loss K_2O Kg/ha/yr	Ref
Dense secondary forest Adiopodoumé (I.C.)	?	2100	0	1.05	0.5	(38)
Maize with fertilizer Adiopodoumé (I.C.)	–	2100	36	52	10.5	(38)
Forest – Azaguié (I.C.)	–	1800	0	35	0.5	(38)
Bananas – Azaguié (I.C.)	14	1650	480	35	20.5	(14)
Bananas – Azaguié (I.C.)	14	2040	770	114	25.1	(14)
Saria (Burkina Faso)						
– Natural fallow	0.7	825	30–60	45	0.6	(36)
– sorghum	0.7	825	30–60	165	8.7	(36)
– natural fallow	1.4	825	30–60	25	0.8	(36)
– sorghum	1.4	825	30–60	124	4.7	(36)

These «fluid» losses are greatly increased if high rates of potash or organic residues are applied as in the banana plantations of the lower Ivory Coast *(Godefroy et al. [1975])*, where peak values for K in surface water reach 100 mg/l (Figure 1).

While K losses through erosion are only moderate (up to 20 kg/ha/ when cropping is non-intensive, they are greatly increased under intensive conditions with massive applications of fertilizer and organic manures (industrial crops) under West African conditions with high potential erosion. In peasant farming with low inputs, the usually advised fertilizer rates (150 kg/ha of 10:20:10 or 10:20:20 for cotton and cereals) are sufficient only to replace K removed by erosion and far short if erosion is not well controlled.

2.2 Drainage and leaching of potassium

Arrangements to measure drainage of water to depth and leaching of nutrients beyond the reach of roots were set up in Africa more than 30 years ago. These were usually simple lysimeters drained by gravity and are still in use in Senegal (south, central) at Burkina Faso, in the Ivory Coast (northern, central and southern), in Chad and Cameroon. For several years now, new methods for studying the movement of water in the soil have been used which give a better picture of spatial variability in soil properties and behaviour *(Vachaud et al. [1982])*. A large amount of data relating to leaching losses in West Africa and Madagascar is now available.

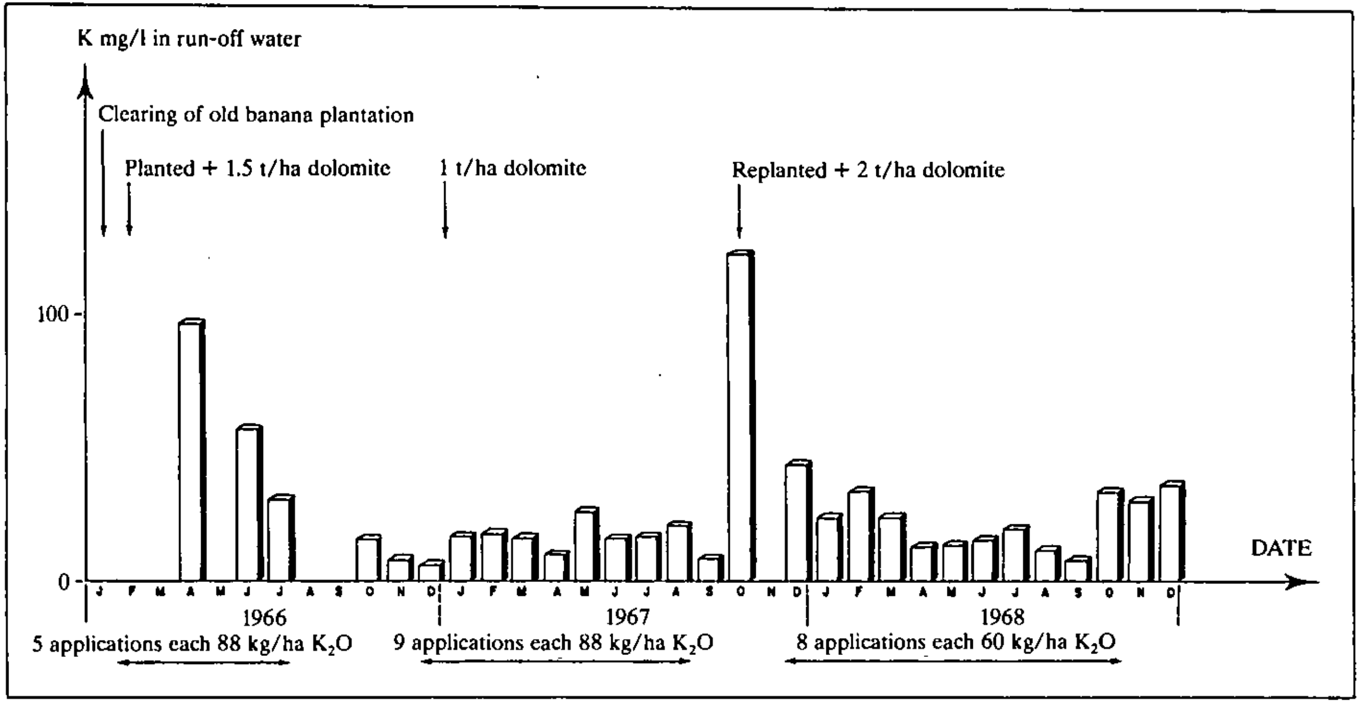


Fig. 1 Changes in potassium content of run-off water in banana plantation on the Ivory Coast (after *Godefroy et al. [1970]*)

2.2.1 The natural environment

In the grassy savannah comprising *Pennisetum, Andropogon, Imperata* and *Hyparrhenia,* with annual rainfall between 500 and 900 mm, there is no drainage beyond the level reached by the dense and deep roots of these grasses (2-4 m).

In the more elevated humid savannah, *Arrivets [1986]* found annual losses of less than 10 kg/ha K_2O (8.5 kg/ha/yr) under natural grass regrowth of the hills around Antananarivo. Despite high rainfall (1600 mm) and through-drainage (960 mm), the unsaturated ferralitic soils of this region are so low in nutrients, especially K (< 0.1 me/100 g in surface soil and 0.05 me/100 g below 20 cm) that nutrient losses by leaching remain very small.

The K cycle under forest has been investigated by several *ORSTOM* workers and *Boyer [1982]* has summarised the main facts. In the evergreen forest of the lower Ivory Coast there is virtual equilibrium between leaching losses from the surface horizons (313 kg/ha/yr K_2O according to *Roose* cited by *Boyer)* and annual additions by leaching of foliage and shedding of senescent vegetation (100-300 kg/ha/yr K_2O according to Mrs. *Bernhard – Reversat [1973]).*

Thus in most natural ecosystems, *i.e.* forest or Sahelian savannah, of West Africa and Madagascar potassium (and also phosphorus), in contrast with calcium and nitrogen, is only moved below 40 cm to a very minor extent *(Lamotte* and *Bourlière [1978]).*

2.2.2 Non-intensive annual cropping systems

Cropping systems using little in the way of inputs and where only a small proportion of the produce is sold are still dominant. According to *FAO [1979]* African farmers use only one hundredth of the fertilizer used in Europe (1.5 kg/ha *vs.* 114.7 kg/ha $N+P_2O_5+K_2O$) and a tenth of that used in Latin America. It is against this background of low or moderate fertilizer dressings, as advised by agricultural development agencies, that investigation of losses by leaching has been done in Francophone tropical Africa (Table 5).

On average, these losses are often less than 10% of fertilizer potassium applied (40-60 kg/ha K_2O) but can reach 30% on permeable sandy soils in the Sudano-sahelian zone through the joint effects of uneven distribution of rainfall and poor rooting of crops *(Pieri [1983]).*

2.2.3 Intensive cropping

Higher rates of potash are applied in plantation agriculture or in some other conditions studied by the *Research Services* (Table 6). Usually, leaching losses of K are still moderate but, where massive rates of KCl are applied to continuous maize as on unsaturated ferrallitic soils on the high Madagascar plateaux, losses may amount to 40%.

The most extreme case is seen in the banana plantations of lower Ivory Coast. The high rates of application necessary for this K-hungry crop and their placement around the stools increase leaching of potassium. Besides K^+ is not very efficiently taken up by the very superficial root system which is often further restricted by the depradations of nematodes which are difficult to control.

Table 5. Estimates of leaching losses in some non-intensive annual cropping systems in francophone Africa and Madagascar

System	K_2O applied kg/ha/yr	Drainage mm	Losses of K_2O kg/ha/yr	% of applied	Ref
Maize – Apangabé (Mad.)	60	740	8.6	14.3	(3)
Millet/groundnut Bambey (Sen.)					
– Millet	60	10	0.3	0.5	(35)
– Groundnut	60	101	5.2	8.6	(35)
Millet/groundnut Bambey (Sen.)	25–75	–	3.0	12–4	(32)
Bouaké (I.C.) 80 + 81					
– Maize	35	220	1–2.5	3–7	(7)
– Cotton	45	230	2.0	4	(7)

Table 6. Estimates of leaching losses under crops receiving large potassium dressings

System	K_2O applied kg/ha/yr	Drainage mm	Losses of K_2O kg/ha/yr	% of applied	Ref
Rotation maize-soya 76–83 Cayenne (Guyana)	234	679	14	6	(19)
Bananas–Azaguié (S. Ivory Coast):					
69–73	330–860	500–900	280–660	–	(15)
mean	662	–	453	68	–
Pineapples 75–79 Benoua (I.C.)					
– residues incorporated	820 (fertilizer)	–	28	1.9	(42)
– residues burnt	+	–	20	1.4	(42)
– residues mulched	623 (residues)	–	16	1.1	(42)
Maize (1972)	300	780	125	42	(33)
Maize (mean 1975–1977) Ampangabé (Mad.)	100	740	17.8	17.8	(33)

Severe leaching losses of fertilizer have also been reported in Zaire under oilpalm. *Laudelout [1950]* showed that two thirds of potassium applied in a year had moved to depth beyond 60 cm on a yellow ferrallitic soil at Yangambi. *IRHO* (in press) also found that the soil solution under oilpalms (Dabou, Ivory Coast) sampled at 60 cm depth by ceramic cups contained 0.8 to 1.0 g/l K, 5 months following placement of potash fertilizer (at a rate, within the radius of application, equivalent to 3 t/ha K_2O).

These results show that the risk of leaching losses under humid tropical conditions are very high when genereous rates of fertilizer are applied on freely draining soils of low exchange capacity. Even splitting the application of potash (in practice, 7 splits over the cropping cycle of bananas on the Ivory Coast) is not sufficient to keep leaching losses at an acceptable level. The only alternative would be to improve the power of retention of the soil, but, in economic terms, it remains to be shown whether such investments (improvement of CEC by applying organic materials) could be justified in either the short or the long term.

2.3 The management of farming residues and the re-cycling of potassium on the farm

Under practical conditions on African farms, the mode of disposal of crop residues has significant consequences for the potassium balance of the soil. More than 70% of the K is in the vegetative parts, even up to 90% in abundantly tillering crops such as african millet *(Pennisetum)* (Table 7).

It is known that mobilisation of nutrients varies greatly from year to year *(Déat et al. [1976])* and with fertilization. While on this point, it should be emphasised that the «economically profitable» fertilizers recommended in some agricultural projects could prejudice the K status of soils in the long term because, though these fertilizers correct the main deficiencies of tropical soils in phosphorus and nitrogen, one eventual result is the inducement of potassium deficiency *(Pieri [1983])*.

A similar situation can come about through basing potash fertilization on apparent potassium balance (restitution of K removed in crop produce) for crops with dominant vegetative production like forages *(Velly et al. [1972])* and *Pennisetum* millet *(Pieri [1972])*. In such cases, the application of K fertilizer may result in luxury uptake with which is correlated accelerated exhaustion of soil K reserves (Figure 2). However, this is not a serious problem in Africa where, in subsistence agriculture, the amounts of fertilizer used are derisory.

Table 7. Nutrients removed at harvest in total crop and proportion contained in crop residues in some tropical annual crops

Crop	Yield t/ha dry matter		Total nutrient uptake at harvest						
	Vegetative (P.V.)	Marketed (P.M.)	kg/ha N	P_2O_5	K_2O	% in P.V. N	P_2O_5	KO	Ref
Millet	5.2	1.5	45	15	85	40	33	90	(40)
Groundnut	0.95	1.5	69	8	23	17	16	53	(34)
Sorghum	7.7	4.6	92	53	138	35	30	83	(34)
Maize	4.9	3.5	108	26	101	84.6	38	75	(34)
Cotton	(4.1)	2.1	82	37	107	55	53	82	(34)
Soya	3.0	2.2	140	27	140	14	19	70	(24)
	fresh wt.								
Pineapple	–	70–90	255	55	720	75	64	76	(18)
Banana	–	50	280	80	1360	64	63	74	(18)

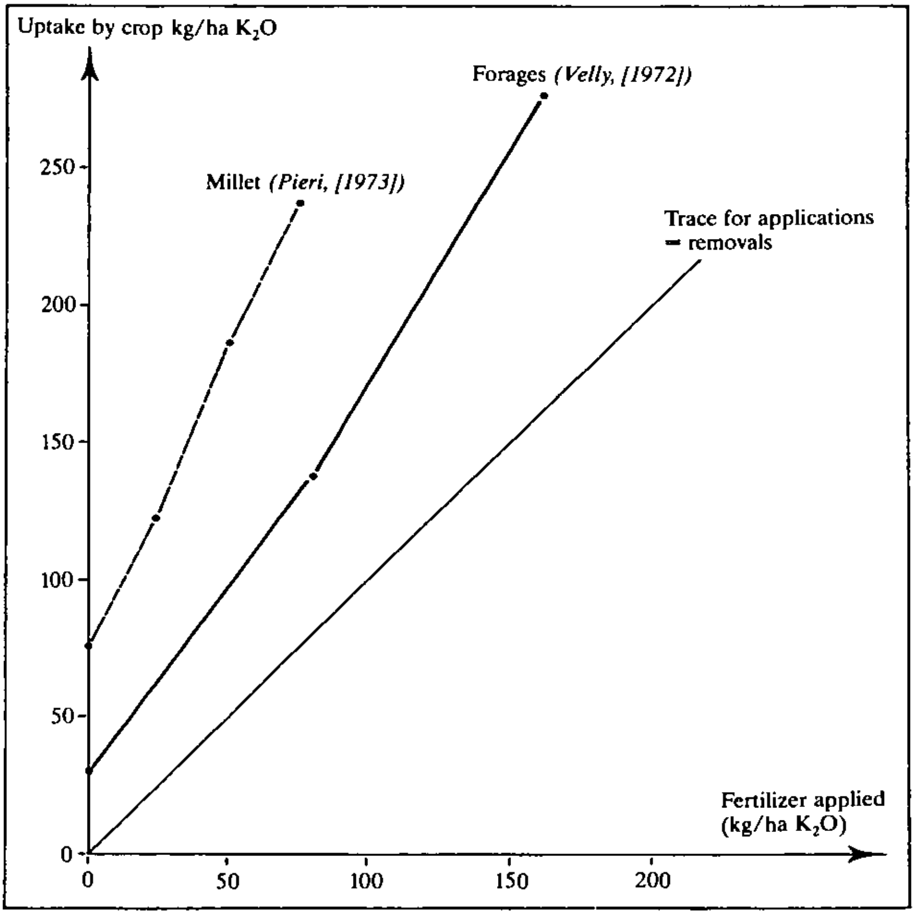


Fig. 2 Potassium uptake in relation to fertilizer K applied: luxury consumption by *Pennisetum* millet and tropical forages.

Traditional use of crop residues for family needs and for feeding livestock leads to systematic exhaustion of the soil on the village periphery to the benefit of land near the houses where food crops for the household are grown *(Allard et al. [1983]). Lericollais [1972]* showed that in northern central Senegal the ratio between land manured by transfer of fertility and land deprived of crop residues as a result was 1 to 4 (140 ha manured out of a total cultivated area of 535 ha). Such a system was formerly justified in a region where there were abundant reserves of land, but such a situation no longer applies. The rapid increase in population in Africa (2.7% p.a. the highest in the world) even though there is some migration to the towns, is resulting in progressive saturation of the rural space *(Zachariah* and *Condé [1981])* and this makes such a system of tansferring fertility inappropriate.

Competition for use of the biomass produced is the more severe in arid and semi-arid regions of the world and particularly so in Africa. In these places, the energy crisis is just as severe as the food crisis but it carries a greater risk for the environment. According to *CTFT*, the annual need for firewood at Burkina Faso has risen to 4.8 million m^3. Availability from natural forest growth is 3.5 million m^3, and the balance is made up by burning crop residues; the national picture reflects that at the village level *(Allard et al. [ibid])*.

Thus it is that in this climatic region, biomass available for the maintenance of fertility, not just of potassium but also organic matter, is negligible and the situation is becoming worse day by day due to the trade in crop residues (groundnut haulm) for urban small livestock enterprises.

The humid tropics happily enjoy more favourable conditions because the production of biomass, not limited by a water deficit, renders available sufficient organic residues to maintain soil fertility provided traditional clear-and-burn systems are rationalised *(cf. IITA* work – *Okigbo [1984])*.

2.4 Conclusion on the loss of K from cropping systems in francophone Africa

The discussion of K losses under diverse conditions in Africa leads to one conlusion. Losses of K from the soil are not significant under the natural vegetation, such as forest or savannah grassland, but they become so when the land is brought under cultivation. The main reason for this is change in the water cycle in surface soil and the changes in root exploration which result.

In the semi-arid savannah it can be estimated that with less intensive systems involving annual crops, losses amount to 10-20 kg/ha K_2O/year removed by erosion, less than 10 kg/ha moved to depth in drainage and from 10 to 100 kg/ha consequent on failure to return crop residues to the field.

In the humid tropics and using traditional systems, the potential for loss through water movement is higher though one finds that the amount of K removed from low fertility unsaturated ferrallitic soils can be less than 10 kg/ha/yr. But, when fertilizer use is more intensive, the losses increase sharply and can reach 60% of the rate applied (in the case of bananas on unsaturated ferrallitic soils).

The situation is particularly serious in the dry zone because of the inherently low fertility of the soils under present conditions for environmental control. However, because annual biomass production is not limited by water availability in the wetter areas, it is easier to devote some of the dry matter production to maintenance of potassium and organic matter status of farm soils.

The dominant factor in loss of potassium from the systems is the method of disposing of crop residues. However, it is no less important to identify soil characteristics and properties which, under given climatic and cropping conditions, may affect the extent of these losses.

3. Edaphic factors affecting losses of potassium from soils

K losses involved in the movement of surface water are related to the volumes of water running off the surface and drainage to lower depths.

3.1 Movement of surface water

Much work has been done in this area on the effects of water, soil and cropping. The subject has recently been reviewed by *Pédro* and *Kilian [1986]*. The illustration in the Appendix 1, shows the relative importance of water movement within the soil surface and plant cover as related to biological and climatic factors in West Africa. The figure clearly illustrates the importance of lateral movement (run-off and erosion) in arid and semi-arid regions as affected not only by the nature of plant cover but also by soil structural organisation. On this latter aspect, the leached ferrugineous tropical soils have specific characteristics and behaviour unique to these areas according to the authors already cited who consider that they are difficult to fit into classification systems, *e.g.* ultisols, acrisols, red-yellow podzolic soils etc.

These soils, with an impoverished, very sandy, A2 horizon, overlying a compacted iron-rich clayey layer, often containing iron concretions, have limited through-permeability making the surface dynamics predominant and this might appear surprising on soils of superficially coarse texture.

3.2 The K content of surface water

The content depends on the one hand upon the soluble K content of the soil and its powers of retention, and on the other on applications of fertilizers and manures and the capacity of the crops to take up K.

3.2.1 K content of superficial water

The major influence of fertilization on run-off water was illustrated in Figure 1. Several workers have also mentioned the connection between exchangeable K content of surface layers of cultivated soils and soluble K, a relationship which is much affected by rainfall pattern and hence the water relations of the soil *(Godefroy [1975]; Dognin et al. [1980])*.

The type of crop also plays a significant part in year to year variation in exchangeable and soluble K contents of the soil as we have shown *(Pieri [1982])* in the case of a 5 year rotation of millet (high K uptake, exch. K = 0.06 me/100 g) and groundnut (lower K requirement, exch. K = 0.11 me/100 g).

3.2.2 K content of percolating water and equilibrium ratio

The K contents of water below the rooting zone of crops is relatively constant throughout the cropping cycle. This is the conclusion reached by several writers *(Arrivets [1986]; Godon [1985]; Pieri [1982])* using lysimeter data under annual crops:

	Mean content me/l		
	K	Ca	Mg
French Guiana (cereal rotation)	0.02	0.38	0.21
Madagascar – Ampangabe (maize)	0.02	0.05	0.04
Senegal – Bambey (millet – groundnut)	0.08	1-2.5	0.5-1.6
	(0.05	0.11)	

The variability is more marked in Senegalese dune soils (clay <4% to 2 m, CEC<1 me/100 g), but still limited so far as K is concerned.

Using *Beckett's* procedure, equilibrium activity ratio AR^K_O and potential buffer capacity PBC^K have been determined for some twenty soils (Appendix II) and some of the Q/I curves are shown in Figure 4.

From these first results it appears that:

a) Equilibrium activity ratio (AR^K_O) of these soils is variable but sometimes very high – 108×10^{-3} (mole/l) $^{1/2}$ for the ferrallitic soil at Dabou in Lower Ivory Coast which receives 250-300 kg/ha KCl each year; it is therefore not correct that tropical soils always have lower equilibrium activity ratios than temperate soils *(Graham* and *Fox [1971])* though it may be true in general (mean AR^K_O being 15.8×10^{-3} (mole/l)$^{1/2}$ with the exception of the Dabou soil. As *Mutscher [1985]* suggested, the presence of some clays (vermiculite) seems to affect the Q/I relationships of these soils, as verified for the «terres de barre», degraded or not, of Togo (Davie, Agbomedji, *cf.* Appendix.

b) AR^K_O is much decreased under continuous cropping despite regular application of K fertilizer *(e.g.* Dabou) without detectable effect on buffer capacity (Figure 3).

It should be noted that, with the exception of Dabou values for AR^K_O are closely correlated with exchangeable K (r = +0.82) and soluble K (r = +0.87). On the other hand, the shape of the Q/I curves clearly illustrates variability in K retention by these soils (Figure 4) and that this is sometimes very limited as in the case of the ferrallitic

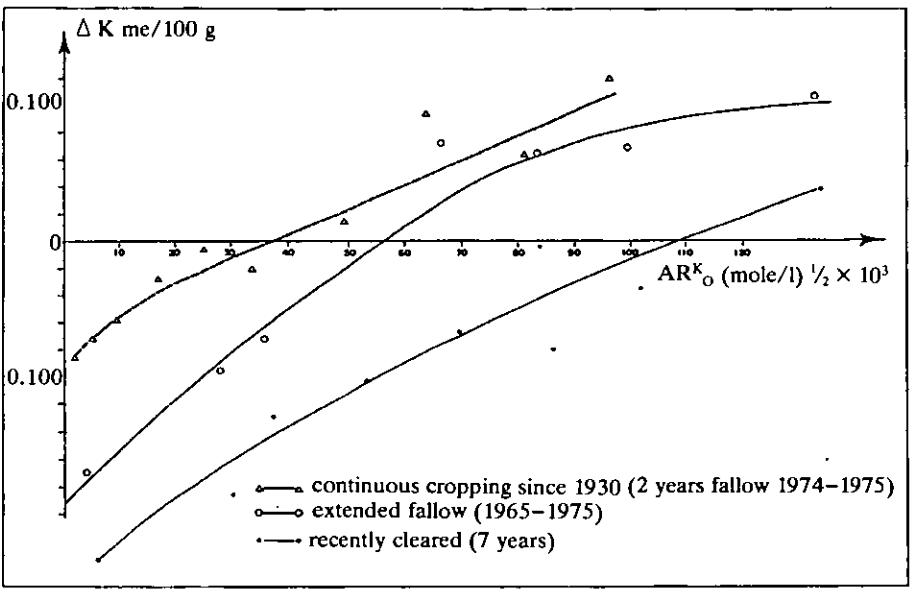


Fig. 3 Dabou: Effects of cropping history on AR^K_O (Ivory Coast, in publication)

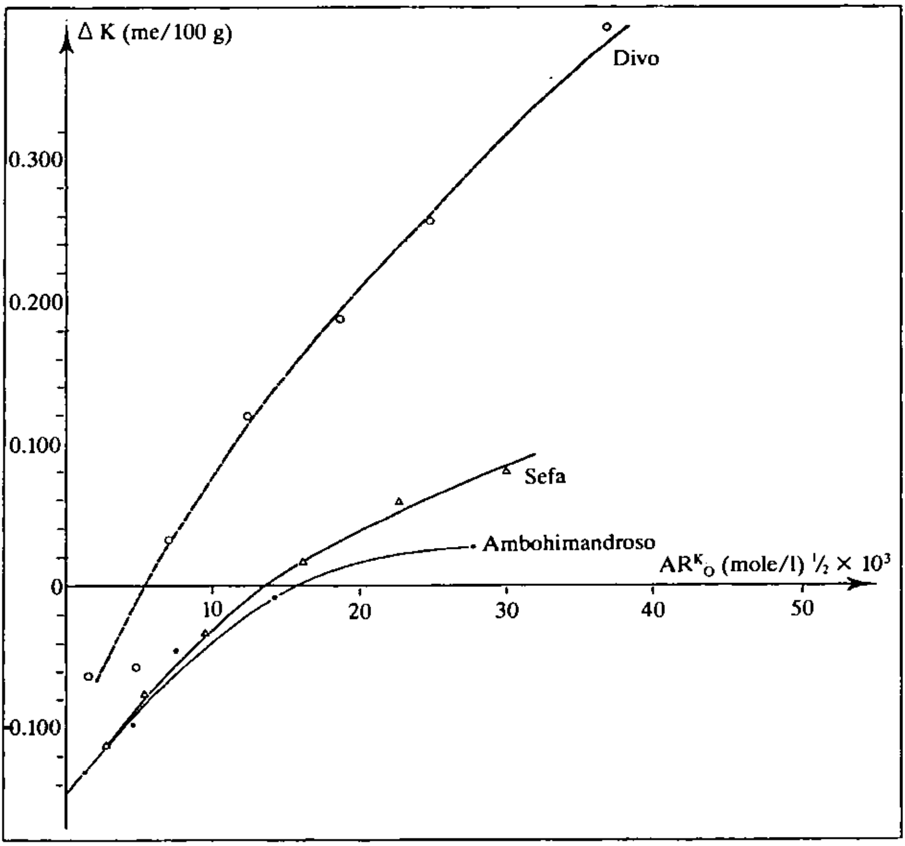


Fig. 4 Variation in Q/I relationship in some tropical soils.

Ambohimandroso – ferrallitic soil on basalt – Madagascar
Sefa — leached ferrugineous tropical soil – Senegal
Divo — ferrallitic soil on granite — calcareous alkaline – Togo

soil at Ambohimandroso (Madagascar). This confirms *Ouvry's [1985]* conclusions from thermodynamic studies of K/Ca, K/Mg and K/Al equilibria in ferrallitic soils (Lamé on the Ivory Coast, Aek-Loba in Indonesia) that maximum K saturation cannot exceed 40% of the effective CEC in soils dominated by kaolinitic minerals and rich in sesquioxides.

3.3 Conclusion

Taking account of both the dynamics of surface water and variations in its K content shows that:

- In the semi-arid zone, losses of potassium result from both surface run-off and erosion in a manner imposed by the structural organisation of tropical ferrugineous soils with impaired permeability in the deeper layers.
- In the more humid areas, despite increased downward movement of water, losses of K in drainage are not very great and less than those of Ca and Mg which are mobile. However, when K fertilization is generous the risks of K loss are very high. The capability of the soils to retain cations is in general low in unsaturated ferrallitic soils characteristics of the area. Negatively charged sites which would adsorb cations are by no means plentiful and the problem is how to improve the effective CEC of these soils in order to obtain higher efficiency of K fertilizers.

4. General conclusions and practical implications

Consideration of the losses of potassium to which the tropical agricultural systems of francophone Africa and Madagascar are subject, highlights the importance of the proper management of crop residues as a means of preserving the K balance. The losses involved in the circulation of surface water (run-off and drainage) appear to have only a limited impact on the balance. This, at any rate, is the case in traditional African farming systems which can be maintained without ill effects provided sufficient land is available to permit sufficiently long fallow periods.

In the arid and semi-arid savannah zone where serious pest incidence does not prohibit the keeping of livestock, there are traditional systems for maintaining land productivity based on the «transfer of fertility» in which crop residues are concentrated on a small area in the form of manure or where there may be additional wastes available from outside the farm.

In the humid tropics the virtual absence of livestock makes such transfers impossible. However, to the extent that agricultural systems approximate the natural forest conditions («alley cropping» system with residues left *in situ)*, or in shifting cultivation with low population density and with 20-40 years rest under natural regrowth, one can at least hope that the K status of the soil will not become seriously diminished.

However, in both dry and humid areas, the traditional systems are becoming less applicable due to demographic pressure and change in economic requirements (decline in influence of the extended family and the struggle for cash income) and to factors related to degradation of the environment.

In the savannah, where one may encounter high rural population density (over 100 inhabitants per km^2 in the groundnut basin of Senegal and in many sub-urban areas) the high energy demand can no longer be satisfied by local wood production without resulting deforestation. The need to cover the demand for fuel and animal feeds means that it is not possible to devise a strategy for the conservation of soil potassium based solely on the recycling of farm residues.

In the forest zone, with settled farming, it is essential to maintain inputs of potassium as has been amply demonstrated on plantations.

There is a need to resort to the use of potassium fertilizers in intensive systems in order to maintain fertility over the coming years. In such systems it should, thanks to the development of transport and mechanisation, be possible to ensure the restoration of transportable crop residues to the farms as has been demonstrated in the cotton-growing areas of francophone Africa.

Where such conditions apply, unlike the traditional farming systems, K losses through movement of surface water can become the major source of potassium loss in intensive systems.

The control of erosion and run-off calls for general environmental protection and this has implications at the farm level (cultivation method) at the village level (land-tenure) and also at higher levels (watersheds), regions, whole countries (integrated campaigns for land and forest conservation).

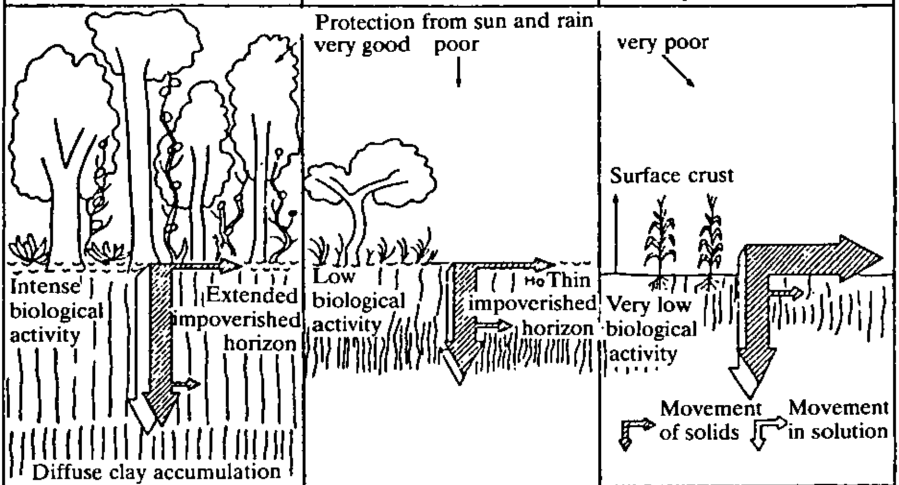
So far as present-day practical farming is concerned two matters should be accorded priority:

- Improvement of crop establishment (root penetration to depth and rooting density) which is major factor in the ability of crops to exploit the soil's potential.
- A potassium fertilizer policy which takes better account of the risk of losses by leaching, especially on well drained tropical soils, making use of split applications when economic conditions allow (labour cost) and by improving K retention by the soil.

  From this point of view, experience shows shows that, apart from the control of erosion, a sound K fertilizer policy also requires control of soil acidification to reduce aluminium toxicity and improve rooting. This should be done before embarking on the use of K fertilizer as has been shown by *Angé [1984]* with reference to cotton in Senegal.

It has also been shown that, particularly in the case of unsaturated ferrallitic soils, mineral amendments (lime or phosphates) can tangibly reduce loss of cations through leaching because of the significant increase in CEC which they being bring about in soils dominated by colloids of variable charge. *(Haile et al. [1985])*.

Appendix I Representation of movement of water unter three tropical ecosystems. By kind permission of *E. Roose [1980]*



	Dense sub-equatorial forest	Shrubby tropical savannah	Cultivated areas Clay accumulation
1)	Deep/vertical	Superficial	Very intense lateral
2)	Diffuse	Localised	Localised
3)	Homogeneous	Differentiated (texture)	Differentiated (structure)

1) Soil dynamics

2) Clay illuviation

3) Soil morphology

Appendix II K parameters in some tropical soils

No.	Source of sample	Minerals	% clay	% silt	Potassium			
					Soluble me/100 g	Exch. me/100 g	$AR^{K}o$*	$PBC^{K}o$**
1	Bambey 0–20 cm	m – K ++ +++	4.1	2.3	0.035	0.070	6.4	11.4
2	Sefa 0–20 cm	K	17.3	5.1	0.063	0.130	23.8	7.6
3	Kita 0–20 cm	I – K ++ ++	10.2	4.8	0.098	0.270	29.2	5.1
4	Koporo 0–20 cm	I – K ++ +++	4.5	2.7	0.060	0.110	20.7	2.6
5	Bebedjia 0–20 without K fertil.	I – K ++ +++	8.7	3.1	0.143	0.310	32.0	3.6
6	Bebedjia 0–20 with K fertil.	I – K ++ +++	8.8	3.0	0.232	0.420	67.2	2.1
7	Ampangabe 0–20	K +++	12.9	16.5	0.047	0.090	14.5	4.5
8	Ambohimandroso 0–20 cm	in – I – K + + ++	25.1	34.8	0.053	0.160	15.6	5.0
9	Divo 0–20 cm	K +++	23.9	4.6	0.049	0.120	5.4	18.4
10	Dabou F2 0–20 cm	I – K + +++	13.8	2.2	0.053	0.113	36.5	2.0
11	Dabou G6 0–20 cm	I – K + +++	13.8	2.2	0.119	0.258	108.0	0.84
12	Dabou D4 0–20 cm	I – K + +++	13.8	2.2	0.109	0.198	56.5	3.2
13	Baniaka 0–20 cm	I – K + +++	45.7	5.7	0.050	0.156	26.0	5.6
14	Boumango 0–20 cm	I – K + +++	42.9	9.9	0.221	0.560	27.5	14.0
15	Davié 0–10 cm	K – V +++ ++	9.3	2.7	0.023	0.051	3.7	9.2
16	Davié 10–20 cm	K – V +++ +	10.3	3.0	0.009	0.028	1.2	9,6
17	Davié 20–25 cm	K – V +++ +	17.0	3.7	0.006	0.025	1.1	18.8
18	Agbo 0–10 cm	K +++	5.3	1.9	0.020	0.040	9.2	2.6
19	Agbo 10–20 cm	K +++	7.1	1.9	0.008	0.022	2.8	4.2
20	Agbo 20–50 cm	K +++	19.8	1.5	0.006	0.023	2.0	7.6
21	Sikasso 0–20 cm	m – I – K + + ++	10.7	8.7	0.149	0.460	47.5	7.8

* $10^{-3}(\text{Mole/l})^{1/2}$ ** $\text{me/100g/(mole/l)}^{1/2}$

K = kaolinite I = illite V = vermiculite in = interstratified m = montmorillonite

$^{+}$ = low $^{++}$ = moderate $^{+++}$ = dominant clay

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Potassium Release from Sandy Soils

D. L. Sparks, Department of Plant Science, University of Delaware, Newark/USA *

Summary

The kinetics of K release were investigated on three soils from the Middle Atlantic Coastal Region of the USA. Previous experiments had shown that corn (*Zea mays* L.) grown on these soils did not respond to K applications. The soils contained high levels of total K – most of which was in the mineral phase and contained in the sand fraction. Large amounts of K-feldspars were prevalent in the sand fractions. The kinetics of K release were studied on the whole soils and sand fractions using a H-saturated resin and 0.01 *M* oxalic acid. Substantial K release occurred over a 30 d period and more K was released with H-saturated resin than with oxalic acid. The K release which occurred from the sand fractions is directly attributable to the highly weathered nature of the K-feldspars as observed through SEM analyses. The mechanism of K release from the soil feldspars appears to be a surface-controlled reaction.

Introduction

The release of potassium (K) from interlayers is a dynamic process which has profound effects on both the chemistry and fertility of soils. Dynamic reactions exist between each of the four phases of soil K *(Sparks [33], Sparks and Huang [34])*.

The kinetics of exchangeable K release from soils have been studied by several researchers *(Jardine and Sparks [13], Sivasubramaniam and Talibudeen [29], Sparks and Jardine [35], Sparks et al. [37])*. These investigations have clearly shown the importance that clay mineralogy plays in the overall release rates.

Numerous studies have appeared in the scientific literature on the release of K from the interlayers of micas *(Feigenbaum et al. [8], Malquori et al. [16], Quirk and Chute [22], Scott and Reed [28])* and from the nonexchangeable phase of soils *(Havlin and Westfall [9], Havlin et al. [10], Martin and Sparks [17], Sadusky et al. [26], Talibudeen and Weir [38]). Mengel [18]* has extensively reviewed the literature on plant uptake of interlayer K which indicates that many plants feed from interlayer K, particularly monocots.

Potassium release from specimen and soil feldspars has been studied by *Berner and Holdren [3], Huang et al. [12], Sadusky et al. [26]*, and *Song and Huang [30]*. However, the weathering of feldspars and particularly the kinetics of K release from them is not well understood *(Berner [2], Wollast [39])* and needs further study.

In the past, researchers have thought that only small amounts of K from feldspars and micas were released over a growing season to plants *(Rasmussen [23])*. However,

* Dr. *D. L. Sparks*, College of Agricultural Sciences, Dept. of Plant Science, 147 Townsend Hall, Newark, DE 19717-1303/USA

recently a number of reports have appeared in the scientific literature showing a remarkable lack of response by crops such as corn *(Zea mays* L.) to K applications on sandy soils *(Liebhardt et al. [15], Rehm and Sorensen [25], Sparks et al. [36]), Woodruff and Parks [41]).* The lack of crop response is somewhat anomalous since these sandy soils have low levels of K in solution and exchangeable phases. However, they often contain copious quantities of feldspars and micas. It has been hypothesized by several researchers *(Rehm and Sorensen [25], Sparks et al. [36])* that the lack of crop response may be attributable to K release from nonexchangeable soil K. Unfortunately, few reports have appeared on the release of K from sandy soils and the role that the sand fractions play in the overall K balance of soils. Accordingly, the objectives of this communication are to investigate the kinetics of nonexchangeable K release from sandy soils which have shown a lack of crop response to applied K and to elucidate the mechanisms of this release. The studies reported in this communication are based on research of *Sadusky et al. [26]* and *Sparks et al. [36].*

Materials and methods

The soils employed in this study were sampled from field experiments conducted by *Sparks et al. [36].* The latter experiments were begun in 1982 on a Kennansville loamy sand (Arenic Hapludults), a Rumford loamy sand (Typic Hapludults), and a Sassafras fine loamy sand (Typic Hapludults) in Delaware, USA. These are major soil types in Delaware and in the Middle Atlantic Coastal Plain Region of the USA. Some basic properties of the soils are reported in Table 1; the analyses were conducted using standard procedures reported previously *(Sparks and Jardine [35]).* These soils contain high amounts of sand and have low CEC and organic matter contents (Table 1). The mineral suite of their <2 μm clay fraction, as determined by X-ray diffraction and differential scanning calorimetry analyses, is dominated by kaolinite and chloritized vermiculite.

Table 1. Basic chemical and physical properties of soils studied.

Horizon	Depth	pH	CEC	Organic matter	Particle size analyses Sand	Silt	Clay
	cm		cmol kg^{-1}	----------------	%	----------------	
			Kennansville loamy sand				
Ap	0– 23	6.8	3.6	1.30	83.9	14.7	1.4
E	23– 58	7.0	2.0	0.17	77.9	19.5	2.6
Bt2	85–118	7.0	4.0	0.04	77.3	12.1	10.6
C	≥140	7.1	2.0	–	89.5	8.2	2.3
			Rumford loamy sand				
Ap	0– 25	5.3	1.7	1.00	80.6	16.0	3.4
BC	89–109	6.4	2.2	0.10	66.0	24.9	9.1
			Sassafras fine loamy sand				
Ap	0– 20	6.0	2.4	2.0	65.5	25.3	9.2
Cl	84– 99	5.2	2.3	<0.1	76.6	7.6	15.8

Potassium chemistry of soils

The K status of each soil profile was determined. Potassium was extracted with both 0.5 *M* $CaCl_2$ and boiling 1 *M* HNO_3 *(Pratt [21])* to determine exchangeable and nonexchangeable phases, respectively. Total K in the soils and sand fractions was determined by HF digestion *(Bernas [1], Buckley and Cranston [4])*. Potassium in each of the extracts was measured using atomic absorption spectrophotometry. Mineral K levels in the soils were estimated by subtracting the sum of $CaCl_2$ and HNO_3-extractable K from total K. The amount of K feldspars in the sand fractions of selected soil horizons was determined by petrographic analyses.

Kinetics of nonexchangeable K release

The kinetics of nonexchangeable K release from the three soils and from the coarse (0.50–1.00 mm), medium (0.25–0.50 mm), and fine (0.10–0.25 mm) sand fractions of the Kennansville loamy sand were investigated using a H-saturated resin and oxalic acid at 298 K *(Sadusky et al. [26])*. Before initiating the kinetics studies, the soil and sand samples were Ca-saturated with 0.5 *M* $CaCl_2$ to remove any native exchangeable K. The samples were then washed with deionized water until a negative test for Cl^- was obtained with $AgNO_3$.

Duplicate 2 g samples of Ca-saturated soil or sand were added to 80 mL polypropylene centrifuge tubes with 4 g of moist Bio-Rad AG 50 WX H-saturated resin and 50 mL of 0.001 *M* HCl. The resin had a CEC of 54.1 mol (H^+) kg^{-1}. Homoionic H-resin was prepared by leaching the resin with 1.0 *M* HCl solution and washing out the salt with deionized water. The samples were equilibrated at 298 K ± 1 for 10 min to 30 d on a reciprocating shaker. Thirty days was a time when an apparent equilibrium in nonexchangeable K release was obtained from the soils and sand fractions. To minimize weathering and abrading of the adsorbents, the shaker was turned off every other hour during the equilibration period. After equilibration, the soil or sand fractions were separated from the resin by sieving and the resin was leached with 80 mL of 1 *M* NH_4 Cl to remove the nonexchangeable K. The leachate was then brought to a 100 mL volume and analyzed for K as before.

The rate of nonexchangeable K release from the soil and sand samples was also determined using an organic acid, oxalic acid. The samples were equilibrated for the same time period as used in the H-resin studies. After equilibration, the samples were centrifuged at 2000 rpm for 10 min and a 10 mL aliquot was taken and analyzed for K as before *(Sadusky et al. [26])*.

Feldspar grains were handpicked from the fine sand fractions of the soils and analyzed before and after the 30 d equilibration with H-saturated resin using *scanning electron microscopy* (SEM). The soil feldspar grains were washed only with deionized water prior to examination by SEM *(Sadusky et al. [26])*. These analyses were performed to assist in elucidating the mechanisms of K release from the soils and to assess the importance of the K-feldspars in releasing K which could be available for plant uptake.

Results and discussion

Although yield data for the Kennansville and Sassafras soils are not shown, there was a general lack of corn yield response to applied K over a 4 year period (Table 2) for all three soils. For the Rumford soil, only in 1983 did there appear to be a significant yield response to applied K – but only for the split treatments *(Sparks et al. [36])*. The yields for the 4 year period were quite high on all three soils.

This lack of crop response seems singular since the soils are sandy (Table 1), they were irrigated which would enhance leaching, and high plant populations were present. Under these conditions, one might expect a yield response to applied K. However, these results are consistent with the findings of other researchers who have studied sandy soils *(Liebhardt et al. [15], Rehm and Sorensen [25], Sparks et al. [36], Woodruff and Parks [41])*. *Liebhardt et al. [15]* failed to observe a yield response to K application over a nine year period on sandy soils. The question then becomes why does this anomalous behavior occur?

Table 2. Effect of potassium applications on corn yield on Rumford loamy sand.

Potassium rate	1982	1983	1984	1985
$kg\ ha^{-1}$		$kg\ ha^{-1}$		
0	13109	8906	9722	9220
94	13359	9408	10098	10224
94S*	13987	11478**	10223	–
282	13422	8530	9973	9283
282S*	13798	13297*	10474	–

* Potassium applications were split into three equal increments and were applied at planting, at the ~61 cm growth stage, and at the early silking stage.

** Yields are significantly different from the 0 kg K ha^{-1} treatment at the 0.05 level of probability.

Potassium chemistry of soils

All three of the soils contained high amounts of total K (Table 3). However, the levels of $CaCl_2$ and HNO_3 extractable K were low and comprised a very small percentage of the total K. The bulk of the total K in these soils was in the mineral form (Table 3). For example, in the Rumford Ap and BC horizons, mineral K comprised 96 and 98%, respectively, of the total K contents. The rather low amounts of exchangeable K as measured by $CaCl_2$ would perhaps suggest that a crop would respond to applied K. However, as has already been noted, no significant crop responses were received (Table 2).

One revealing aspect to the data in Table 3 is the large amount of total K present in the sand fractions of these soils. Taking into account the percentage of sand in each horizon (Table 1), the data in Column 6 of Table 3 represent the amount of total K in the sand fractions based on a whole soil basis. In the Kennansville loamy sand, for example, 87 and 74% of the total soil K in the Ap and Bt2 horizons, respectively, is contained in the sand fractions. This was also true in the Rumford soil which is very sandy (Table 1). In the Sassafras soil, which contains more clay, 65 and 79% of total soil K in the Ap and Cl horizons, respectively, was found in the sand fractions.

Most of the total K in the sand fractions can be directly attributable to the high amounts of K-feldspars present (Table 3). There appears to be a strong correlation between K-feldspars and total K in the sand fractions (Table 3). The K chemistry data vividly point out the tremendous reservoir of K in the sand fractions of these soils.

Table 3. Potassium chemistry of soils and sand fractions.

		Soil K Chemistry				Sand K Chemistry	
Horizon	Depth	$CaCl_2$ Ext.	HNO_3 Ext.	Mineral K*	Total K	Total K**	Feldspar K***
	cm	--------------	cmol kg^{-1}	--------------			Vol %
			Kennansville loamy sand				
Ap	0– 23	0.25	0.42	35.02	35.69	30.88	9.5
Bt2	85–118	0.25	0.49	45.30	46.04	33.86	12.0
			Rumford loamy sand				
Ap	0– 25	0.33	0.49	21.67	22.51	18.62	6.7
BC	89–109	0.21	0.54	23.39	23.96	16.76	8.2
			Sassafras fine loamy sand				
Ap	0– 20	0.35	0.56	43.54	44.45	28.95	16.0
Cl	84– 99	0.13	0.36	45.99	46.48	36.69	24.0

*Mineral K = [(total K) − ($CaCl_2$ Ext. K + HNO_3 Ext. K)].
**These data represent the amount of total K in the sand based on a whole soil basis.
***Determined through petrographic analyses of the whole sand fraction.

Kinetics of nonexchangeable K release

Over a 30 d period, large quantities of K were released from the soils (Table 4, Figure 1). Initially, K release increased rapidly and then began to level off as an equilibrium was approached. More K was released in the subsoil horizons than in the Ap horizons of each soil which is directly attributable to the higher clay contents in the former which are high in chloritized vermiculite.

The level of solution K markedly affects the release of nonexchangeable K from soils *(Martin and Sparks [17])*. The K concentration in the solution phase must be kept very low, or K release will be inhibited *(Fanning and Keramidas [7], Feigenbaum et al. [8])*. The concentration of soluble K in the soil-resin suspension of this study ranged from 1.00 to 1.50 × 10^{-3} mmol L^{-1}. *Rausell-Colom et al. [24]*, using a leaching technique, found that concentrations of solution K up to 1.00 mmol L^{-1} did not retard K release from trioctahedral mica whereas concentrations above 0.10 mmol L^{-1} inhibited K release from muscovites. Thus, with the H-resin there should have been no inhibition of nonexchangeable K release from interlayers in this study.

Table 4. Potassium release from soils using a H-resin and oxalic acid.

Horizon	Depth	H-Resin	Oxalic Acid
	cm	mg kg^{-1}	
		Kennansville loamy sand	
Ap	0– 23	77.5	0.77
Bt2	89–118	98.0	1.16
		Rumford loamy sand	
Ap	0– 25	67.0	0.55
BC	89–109	90.0	0.77
		Sassafras fine loamy sand	
Ap	0– 20	91.5	0.22
Cl	84– 99	96.0	0.66

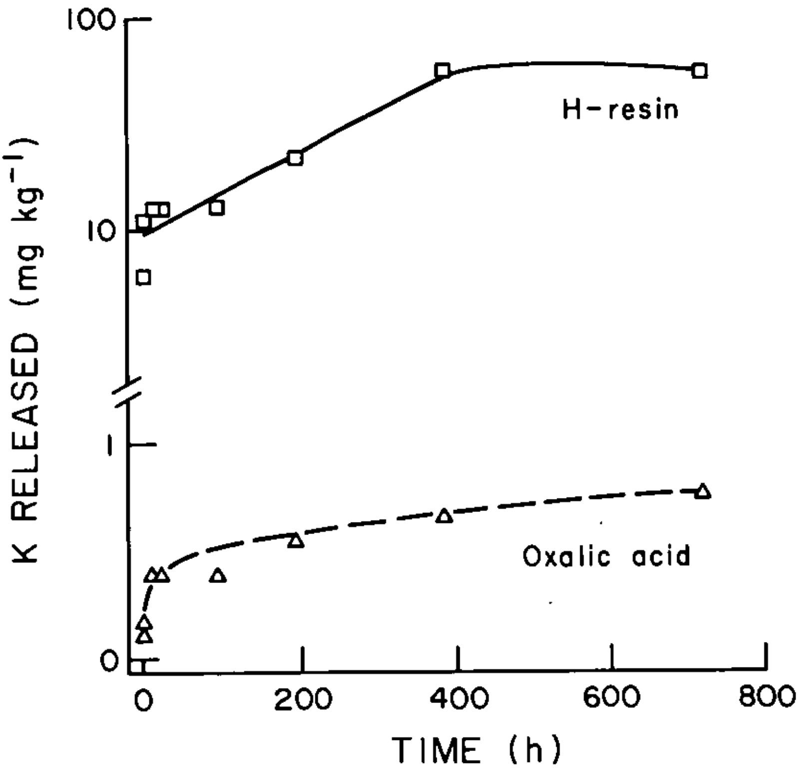

Figure 1. Kinetics of nonexchangeable K release from the Ap horizon of a Kennansville loamy sand using H-resin and oxalic acid.

However, this may not have been true with oxalic acid. Much smaller quantities of K were released from the soils using oxalic acid than with H-resin (Table 4). With the H-resin a sink was provided for the released K – thus further release could occur. However, no such sink was present with the oxalic acid. Additionally, the pH of the oxalic acid was considerably higher than with the H-resin which could have caused less release.

Significant quantities of K were released from the coarse, medium, and fine sand fractions of the Kennansville soil to H-resin (Table 5, Figure 2) with the fine fraction releasing the most. This is important because the fine fraction comprises the bulk of the sand in these soils. If one averages the quantity of K release from the three sand fractions, multiplies by the percentage of sand in each soil horizon, and then divides this quantity by the total K released from the whole soil, some interesting data are obtained. One finds, for example, that in the Kennansville Ap and B2t horizons, 68 and 63%, respectively, of the total K released is coming from the sand fractions. These data again point to the immense importance of the sand fraction of these soils in the overall K balance.

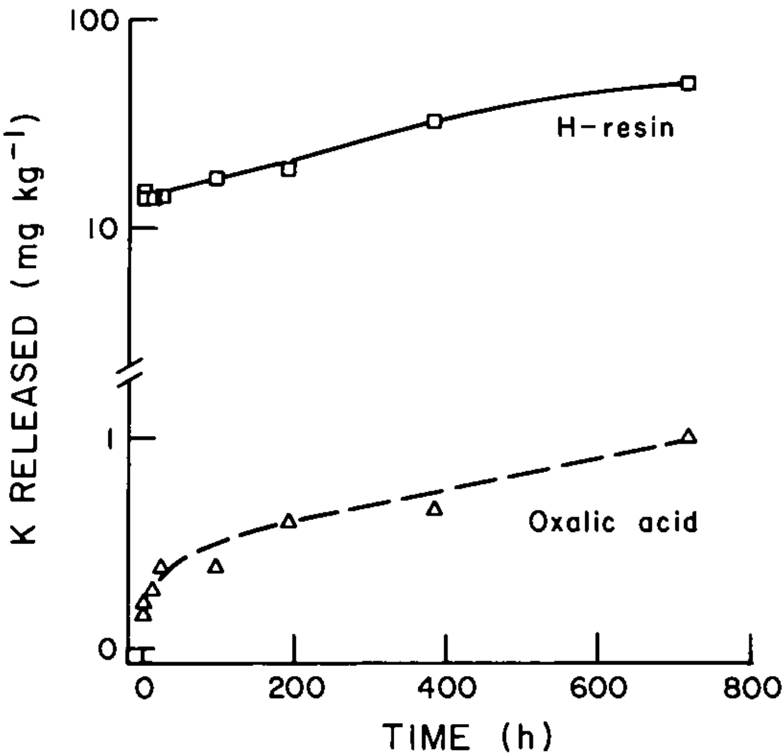

Figure 2. Kinetics of nonexchangeable K release from the fine sand fraction (0.10–0.25 mm) of the Ap horizon of a Kennansville loamy sand using H-resin and oxalic acid.

Table 5. Potassium release from sand fractions of a Kennansville soil using H-resin and oxalic acid.

Soil Horizon	Depth	K Released from Sand Fractions*					
	cm	mg kg^{-1}					
		H-Resin	*Oxalic Acid*	*H-Resin*	*Oxalic Acid*	*H-Resin*	*Oxalic Acid*
		coarse (0.50–1.00 mm)		med. (0.25–0.50 mm)		fine (0.10–0.25 mm)	
Ap	0– 23	53.5	0.50	65.0	0.72	71.5	1.05
E	23– 58	53.5	0.55	58.0	0.72	87.5	0.99
Bt2	85–118	76.0	1.06	69.5	1.05	99.5	1.10
C	≥140	87.5	1.27	88.5	1.27	99.5	1.76

*These values represent amounts of K released at 30 d.

Mechanisms of K release from feldspars

Although not shown, a number of simple kinetic models were applied to the K release data including the first-order and parabolic diffusion equations *(Sparks [31, 32])*. It was found that a simple first-order equation as given below best described the release of K:

$$\ln (K_o - K_t) = 1nK_o - k_2t$$

where K_o = nonexchangeable K released at 30 d, K_t = nonexchangeable K released at time t, k_2 = nonexchangeable K release rate coefficient, and t = time. Sparks and his coworkers *(Carski and Sparks [6], Jardine and Sparks [13], Ogwada and Sparks [19],* and *Sparks and Jardine [35])* had earlier found that K release from interlayers was best described using first-order kinetics particularly for periods of 40 d or less.

To determine the significance of K release from the sand fractions and to explain the mechanism for this release, SEM analyses were conducted on feldspar particles from the fine sand fractions of the soils before and after weathering with the H-saturated resin. Scanning electron micrographs for the fine sand fraction from the Ap horizon of the Kennansville soil are shown in Figures 3–4.

In Figure 3 is a SEM of a feldspar grain before treatment with H-resin. The fuzzy areas in the center and upper right of the photograph are secondary precipitates of hydroxyl-Al and Al-silicate material. This occurs on the surface of the grain which acts as a site for nucleation. *Petrovic [20]* suggests that this material has a very low density and ion diffusion rates through it are within an order of magnitude of diffusion rates in water. The light patches within this probable amorphous mass may be crystals of kaolinite forming.

The remainder of the surface of the grain (Figure 3) is a K-feldspar. The surface features are very similar to those described by *Berner [2]* and *Holdren and Berner [11]*. First, one sees small submicron to micron linear or curvilinear cracks forming on the flat surfaces, best exhibited in the right center of the micrograph. One can also see a widening of the cracks and the formation of oval shaped etch pits. These are often obscured by larger prismatic etch pits (upper right hand corner of SEM). This is the

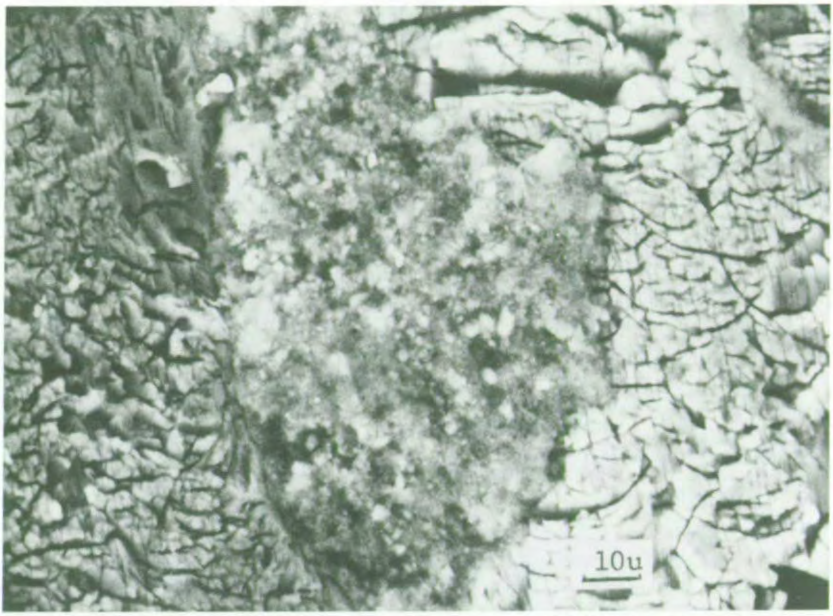

Figure 3. Scanning electron micrograph of a Kennansville soil feldspar before treatment with H-resin.

Figure 4. Scanning electron micrograph of a Kennansville soil feldspar after 30 d treatment with H-resin.

most important stage of weathering as chemical weathering may lead to enhanced mechanical weathering by the abrasion and subsequent removal or "plucking" of loose pieces of the surface. The etch pits may align along structural and crystallographic axes forming saw-tooth patterns (lower right hand corner of SEM). Finally, the coalescence of the prismatic etch pits produces an angular, highly irregular surface. The SEM photographs clearly show the highly weathered nature of the feldspars in these soils which could be sources for K release to plants.

A SEM of the feldspar particles after the 30 d treatment with H-resin is shown in Figure 4. This micrograph shows the same weathering patterns and etch pits as found and described above. One will note the general absence of the "fuzzy" precipitate which was found in the untreated feldspar grain (Figure 3). This is likely a result of the agitation of the grains which would inhibit nucleation of the precipitate on the feldspar grains. However, one can see (Figure 4) that the extent and depth of weathering as exhibited by the etch pits is much more drastic after weathering with H-resin than before (Figure 3).

One question that arises from these data is what is the mechanism by which K is released from the feldspars of these soils? Two theories have been advanced to explain the dynamics of feldspar weathering. Results from recent studies on specimen feldspar weathering *(Holdren and Berner [11], Lagache [14], Petrovic [20])* suggest that during dissolution the rate limiting step is a surface-controlled reaction resulting in a constant rate of dissolution. On the other hand, other workers *(Busenberg and Clemency [5], Wollast [39])* suggest that weathering of feldspars proceeds incongruently with the consequent formation of a residual protective layer of altered composition on the surface of the mineral. As a result so called parabolic kinetics is found where the rate of dissolution decreases with time due to the growth in thickness of such surface layers *(Schott and Berner [27], Wollast and Chou [40])*.

The data collected in this study would suggest that the surface-controlled kinetics theory is operable for soil feldspar weathering. The presence of etch pits on the weathered feldspar grains would suggest a surface-controlled reaction *Berner [2], Sadusky et al. [26])*. The etch pits indicate selective attack of the feldspar surface by soil acids (Figure 3) which is enhanced on laboratory weathering (Figure 4). An additional piece of evidence that would suggest a surface-controlled rate of K release from the interlayers of these soils is the linear rate of K release from the sand fractions with H-resin (Figure 2). If parabolic kinetics were occurring, non-linear plots would have been observed *(Sadusky et al. [26])*.

Conclusions

The sandy soils examined in this study exhibit a remarkable ability to release nonexchangeable K. Much of this release occurs from the sand fractions which are high in K-feldspars. The feldspars, as examined by SEM, are very weathered and exhibit pronounced etch pits. The mechanism of K release from the K-feldspars would appear to proceed via a surface-controlled release process. The lack of crop response that has been observed on these soils following K applications can be explained by the large amounts of K that are being released from the sand fractions which are highly weathered. These data vividly point out the importance of sands in supplying K to plants grown on Atlantic Coastal Plain soils.

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Root System and Potassium Exploitation

D. Steffens, Institute of Plant Nutrition, University of Giessen/Federal Republic of Germany*

Summary

Lolium perenne grown on a soil low in exchangeable K^+ in pot culture exploited non-exchangeable K^+ better than did *Trifolium pratense*. Root development and K^+ uptake was studied in field experiments to find an explanation of differences in non-exchangeable K^+ uptake by the two plants. *Lolium perenne* had greater root fresh weight, root density, root surface and root length per m^3 soil than *Trifolium pratense*. In both species, root parameters and K^+ uptake were well correlated. Uptake rates per unit root surface and root length were always higher in *Trifolium pratense*, the greatest difference between the two being in K^+ uptake rate per m root length (2 to 3 times higher). Because of its greater root length and root surface, L perenne can take up more K^+ under low availability conditions.

True K^+ availability in soils is not just a question of physico-chemical soil parameters such as K^+ concentration in soil solution, K^+ buffer capacity and soil moisture content but also depends substantially on biological factors such as root growth and root morphology.

1. Introduction

Soil testing attempts to measure available nutrients and hence to derive fertilizer recommendations. Recent fertilizer experiments, however, have shown that such crops as legumes, potatoes and sugar beet show yield responses to K^+ fertilization whereas grain crops seldom do so *[8, 16, 13, 14]*.

We were therefore interested in the question: why do monocotyledones in particular respond less to K^+ fertilization than do dicotyledones? This problems will be treated in the following relating to K^+ uptake experiments with grass and clover.

* *Dr. D. Steffens*, Institut für Pflanzenernährung, Justus Liebig-Universität Giessen, Südanlage 6, D-6300 Giessen/Federal Republic of Germany

2. Results

2.1 K uptake potential for red clover and grass.

In a pot experiment (permanent cropping system), the K^+ uptake potential of red clover *(Trifolium pratense)* and grass *(Lolium perenne)* was tested for a soil low in available K^+, in both a mono- and mixed culture system. The soil contained 112 mg kg^{-1} soil exchangeable K^+ and 22.3% clay. It was found that as soil K^+ was depleted the relative yield of red clover decreased to a greater degree than that of grass (Figure 1). In the mixed culture system where clover and grass competed for K^+, the yield decrease for red clover was greater than in the monoculture system. In the mixed system the percentage of clover in the total plant matter (clover + grass) was particularly low if no K^+ was applied. The improved K^+ uptake potential of grass as compared with red clover was also reflected by the K^+ content of the above-ground plant material, as grass showed a higher K^+ content in the mixed culture than in the monoculture. The opposite held true for red clover. *[19]*.

During a period of 3 years exchangeable soil K^+ under grass and red clover had decreased by approximately 30 mg K^+ kg^{-1} soil (Table 1). The K^+ uptake of the clover and grass, however, was much higher than the decrease in exchangeable K^+ which shows that most of the K^+ taken up by the crops originated from the non exchangeable soil K^+ fraction.

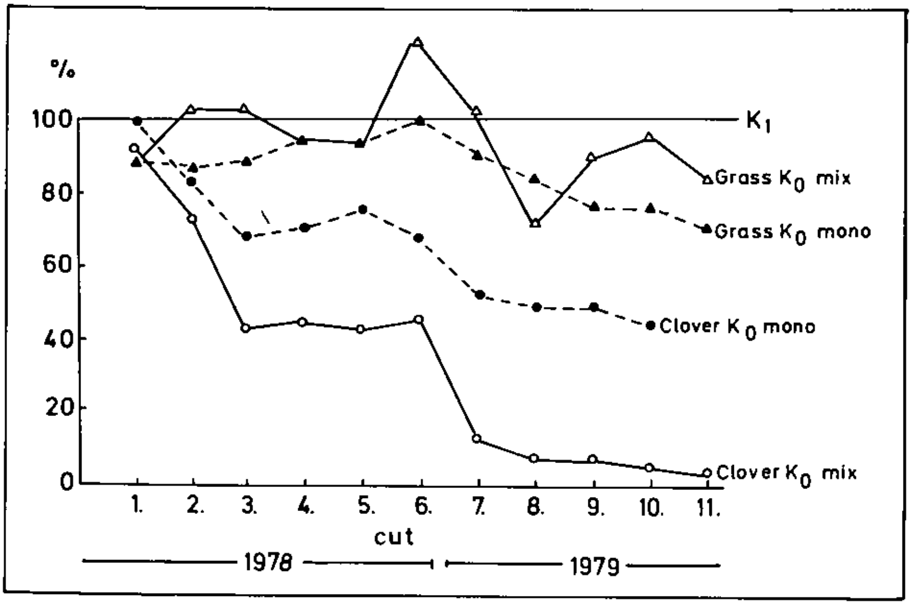

Fig. 1 Relative dry matter yield of clover and grass grown in monoculture or in mixed culture (K_1 treatment of the appropriate cut = 100%
K_0 = without K^+) *[18]*.

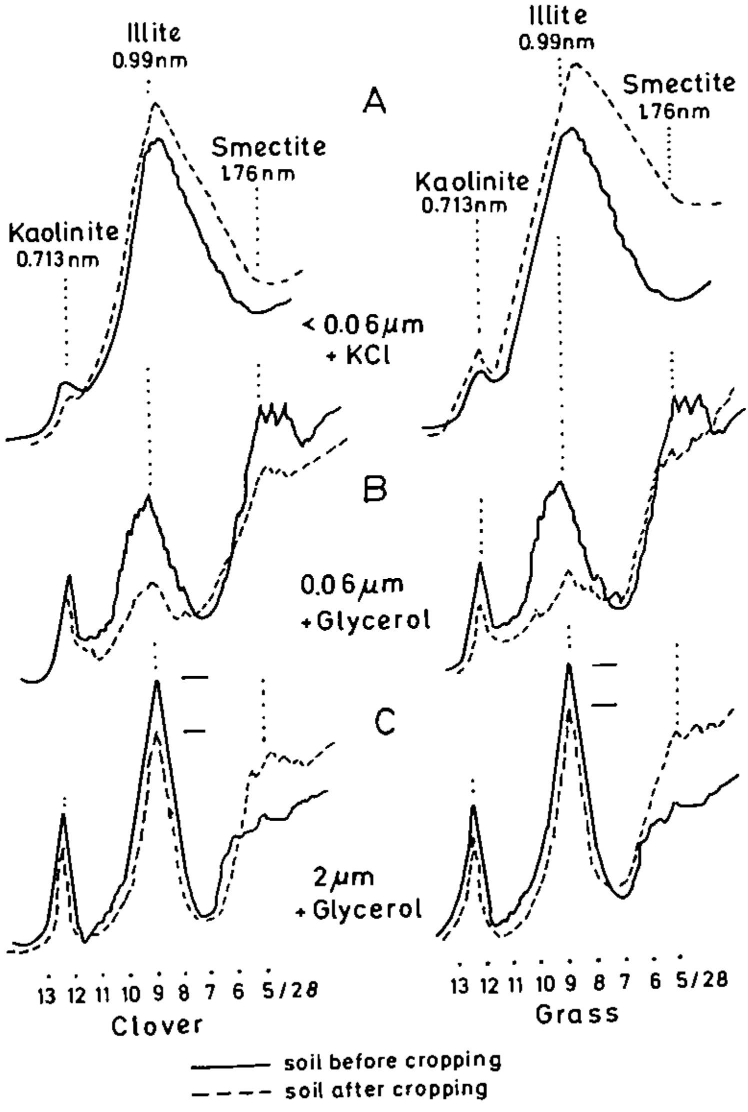

Fig. 2 Effect of soil K^+ exhaustion on X-ray diffraction diagrams obtained from soil cropped with clover and grass in pot experiments.
A: Soil samples contracted by KCl treatment.
B: < 0.06 µm particle size fraction treated with glycerol.
C: < 2 µm particle size fraction treated with glycerol *(19)*.

Potassium uptake from this fraction was 382 mg K^+ kg^{-1} for grass and 277 mg K^+ kg^{-1} soil for clover demonstrating that grass exploited the soil better for non exchangeable K^+ than clover. This finding was confirmed by the greater net K^+ fixation of the soil after the growth of grass (see Table 1). The greater K^+ uptake of grass from the non exchangeable fraction is also reflected by the change in clay minerals. Under grass illite was converted to vermiculite to a greater extent than under red clover as is evident from Figure 2. This diagram shows that cropping decreased the illite peak (Figure 2 B, 2 C) and that K^+ treatment of the clay samples increased the smectite signal (Figure 2 A) which means that the samples had lost K^+). This loss was greater under grass than under clover *[20]*. Moreover, red clover lowered the pH value of the test soil from 7.0 to 4.5. For grass the pH value remained constant *[10]*. This drastic proton release of red clover roots did not, however, promote the release of interlayer potassium. It seems more likely that the improved K^+ exploitation potential of grass as compared with red clover may be attributed to root morphology and root growth. To test this, root development and K^+ uptake of grass and red clover were studied under field conditions.

Table 1 Effect of exhaustive cropping of rye-grass and clover in pot experiments on K^+ uptake of the crop, exchangeable soil K^+ and dry K^+ fixation capacity. Soil Kleinlinden, cropping period 3 years *(Tributh et al. [1986])*.

	K uptake	Exchang. K	K^+ fixation	Net increase in K^+ fixation capacity
		mg K kg^{-1} soil		
Before cropping	—	112	328	—
After cropping				
clover	277	78	546	218
rye grass	382	80	679	351

2.2 Root development and root growth of grass and red clover under field conditions.

This experiment was performed in 1980 on a Alfisol-Udalf soil of which the characteristics are listed in Table 2. More precise data on the experiment and root measurement technique were published by *Mengel* and *Steffens [11]*. The fresh weight of the roots of grass and clover are shown in Table 3. The root fresh weight for both plants increased over the 3 month period. The largest proportions of roots of both species were found in the upper soil layer (0-25 cm), which generally also contains the most nutrients. Grass had a higher root fresh weight than red clover at each sampling date in the upper soil layer (0-25 cm). 105 days after seeding grass also produced a greater root fresh weight than red clover in the deeper soil layers (25-100 cm). This shows that legumes (except lucerne) do not necessarily root more intensively into the subsoil than do graminaceous plants, as *Müller et al. [12]* likewise discovered in their experiments with oats and horse beans. Grass also had a greater root density than red clover (Table 4). Root density was greatest in the top soil. From the various root par-

Table 2 Chemical and physical properties of the soil profile (Alfisol, Udalf)

Soil depth (cm)	pH (N KCl)	K DL method[a]	P (ppm)	Organic matter	$CaCO_3$ (%)	Clay (%)
0- 25	6.6	341.3	130.0	1.68	0.12	15.6
25- 50	5.9	150.0	32.5	0.90	0.10	21.9
50- 75	6.0	87.5	12.2	—	0.15	19.7
75-100	6.4	74.0	17.2	—	0.21	19.3

[a] Five grams soil extracted with 250 ml double lactate solution (0.02 *M* calcium lactate + 0.02 *M* HCl, pH = 3.7) for 2 h

Table 3 Root fresh weight of *Trifolium pratense* and *Lolium perenne* in relation to soil depth and days after seeding (g root x m^{-2} soil surface)

Soil depth (cm)		Days after seeding 55	69	76	90	97	104	111	118
0- 25	*T. pratense*	208	435	630	848	1109	902	1047	1219
	L. perenne	526*	1392*	1855***	2672	2384**	2576***	2640**	2608**
25- 50	*T. pratense*	—	49.6	87.2	186	267	178	440	191
	L. perenne	—	79.5	138	134	219	250	283	259
50- 75	*T. pratense*	—	—	12.8	34.2	32.0	47.9	62.1	88.8
	L. perenne	—	—	5.3	22.1	62.9	65.4	82.2	62.9
75-100	*T. pratense*	—	—	—	4.32	4.0	8.48	15.2	25.4
	L. perenne	—	—	—	—	—	20.5	34.6	54.2

Significant difference between *T. pratense* and *L. perenne* at *, < 5%; ***, < 1%; ***, < 0.1%

Table 4 Root density of *Trifolium pratense* and *Lolium perenne* in relation to soil depth and days after seeding (number of cut roots x m^2)

Soil depth (cm)		Days after seeding 55	69	76	90	97	104	111	118
0- 25	*T. pratense*	336	608	672	1396	2728	2168	3952	4296
	L. perenne	524	848	1068*	2780**	4264**	3400	6368	11464***
25- 50	*T. pratense*	8	96	140	420	608	708	1332	1208
	L. perenne	8	68	124	560	856	784	1300	1616
50- 75	*T. pratense*	—	8	24	112	124	140	352	408
	L. perenne	—	—	20	40	104	152	568	420
75-100	*T. pratense*	—	—	—	28	12	24	28	8
	L. perenne	—	—	—	—	4	20	204**	208*

Significant difference between *T. pratense* and *L. perenne* at *, < 5%; **, < 1%; ***, < 0.1%

ameters, the largest differences were found in the root lengths and root surfaces between both species. Grass attained root surfaces and lengths nearly three times greater than red clover (Tables 5 and 6). Root diameter for grass was 0.14 mm and for red clover was 0.28 mm. This finding is in good agreement with observations of *Evans [3]*. In addition root hairs of grass were nearly twice as long as the hairs of red clover roots. For this reason there is a larger soil volume available for the exploitation of K^+ available to a root segment of grass than to red clover. Root parameters and K^+ uptake of clover and grass were closely correlated (Table 7). Close correlations were found particularly for root length and root weight and to a lesser extent for the root surface and root density. By calculating the K^+ uptake rates per unit of root parameter it became evident that red clover, particularly per meter of root length and day, had absorbed three times as much K^+ as grass (Table 8). This increased rate of K^+ uptake of red clover as compared with grass is presumably the main cause for the better K^+ exploitation potential of grass. This statement is explained in the following with the help of the diagram shown in Figure 3. Generally the K^+ concentration of the soil solution versus K^+ uptake rate is reflected by a saturation curve. If the K^+ uptake rate of grass required for optimum growth is one third that of clover the K^+ concentration required for optimum K^+ supply can also be much lower for grass as compared with clover (Figure 3). Potassium release from the non exchangeable K^+ pool depends on the K^+ concentration of the soil solution. The lower the K^+ concentration the higher is the net release of K^+ *[9]*. Hence the lower K^+ concentration of the soil solution required by grass has a beneficial effect on the net release of K^+ from the non exchangeable pool. This is in agreement with the finding that clover produced a lower yield than grass at low levels of exchangeable K^+. These do not assure the higher K^+ uptake rates required by red clover *[19]*. This finding probably explains the observations made by many authors that grasses grow better at low levels of available K^+ than clover *[1, 5, 15]*.

Table 5 Total root length of *Trifolium pratense* and *Lolium perenne* in 1 m^3 soil volume in relation to days after seeding

Days after seeding	Root length (km x m^{-3} soil volume) *T. pratense*	*L. perenne*
55	1.81	10.46**
69	4.11	28.50**
76	6.30	38.69***
90	8.16	55.63***
97	11.39	51.68***
104	9.50	55.74***
111	11.36	57.81**
118	12.77	56.56***

Significant difference between *T. pratense* and *L. perenne* at **, < 1%; ***, < 0.1%

Table 6 Total root surface of *Trifolium pratense* and *Lolium perenne* in 1 m^3 soil volume in relation to days after seeding

Days after seeding	Root surface (m^2 x m^{-3} soil volume) *T. pratense*	*L. perenne*
55	4.16	14.56**
69	7.36	30.24**
76	12.48	40.64**
90	14.08	50.08***
97	19.68	43.20**
104	17.12	49.28***
111	22.72	51.68*
118	25.76	68.80**

Significant difference between *T. pratense* and *L. perenne* at *, < 5%; **, < 1%; ***, < 0.1%

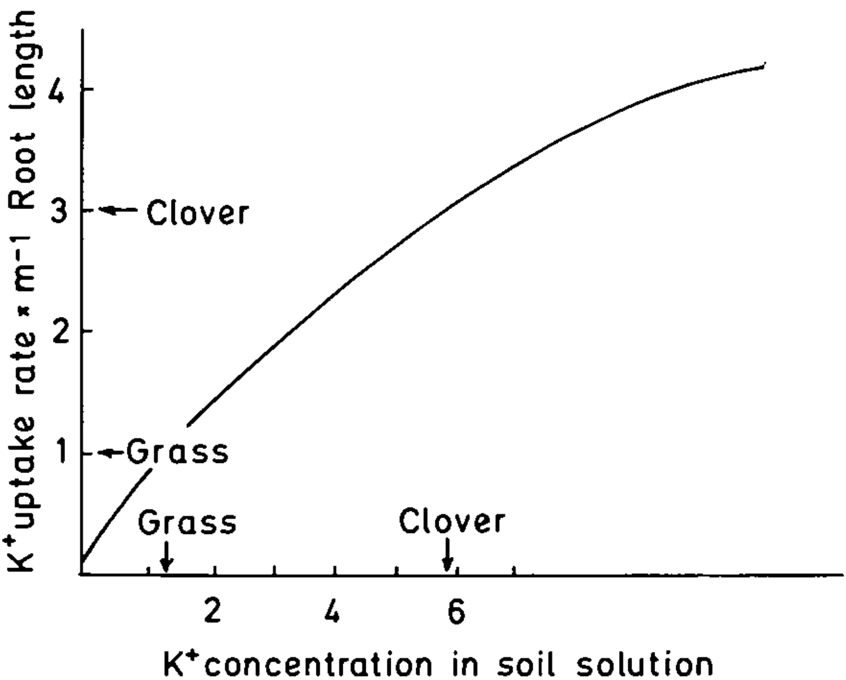

Fig. 3 Relationship between K^+ uptake rate per unit root length and K^+ concentration in the soil solution. Scales for both axes are relative.

Table 7 Correlation coefficients for K^+ uptake *versus* measured root parameters of *Trifolium pratense* and *Lolium perenne*. The data reflect the total K^+ uptake per unit soil surface and the root parameters per unit soil surface.

Root parameter	r
Root fresh weight	
T. pratense	0.92***
L. perenne	0.94***
Root density	
T. pratense	0.86***
L. perenne	0.82***
Cation exchange capacity	
T. pratense	0.79***
L. perenne	0.70***
Root surface	
T. pratense	0.85***
L. perenne	0.83***
Root length	
T. pratense	0.91***
L. perenne	0.93***

Table 8 Root K^+ uptake rate per day and unit root parameter of *Trifolium pratense* and *Lolium perenne*. Each figure is the mean value of eight single values obtained from eight harvests.

Root parameter	Unit	*T. pratense* K^+ uptake (mol $\times 10^{-5} \times d^{-1}$)	*L. perenne*
Fresh weight	g	0.36	0.26***
Root density	100 cut roots	4.31	5.00
Cation exchange capacity	me	13.90	16.13
Root surface	m^2	22.35	14.13**
Root length	m	42.79	13.67***

Significant difference between *T. pratense* and *L. perenne* at *0, < 1%; ***, < 0.01% level

2.3 The importance of roots in releasing interlayer potassium.

The results on the K^+ exploitation potential for red clover and grass, discussed in the preceding sections, were obtained on loess soils. Illite is usually the predominant clay mineral in these soils. Because other soils contain clay minerals differing from those in loess, the release of interlayer potassium may differ for various soil types. For this reason, the uptake of non exchangeable K^+ by rye grass was studied with four different soil types *[6]*. The results of this experiment were obtained using a technique developed by *Helal* and *Sauerbeck [4]*. In this technique the soil penetrated by roots is separated from the root-free soil by a steel net which cannot be penetrated by roots. Thus a zone in which roots grow and a zone without roots are obtained. The lower part of Figure 4 shows the level of exchangeable K^+ after grass growth *versus* the distance from the steel net (zone without roots). It is evident that the level of exchangeable K^+ decreased with a decrease in distance for the two brown soils whereas for the two other soils (Alfisol, Inceptisol) no major decrease in exchangeable K^+ was observed.

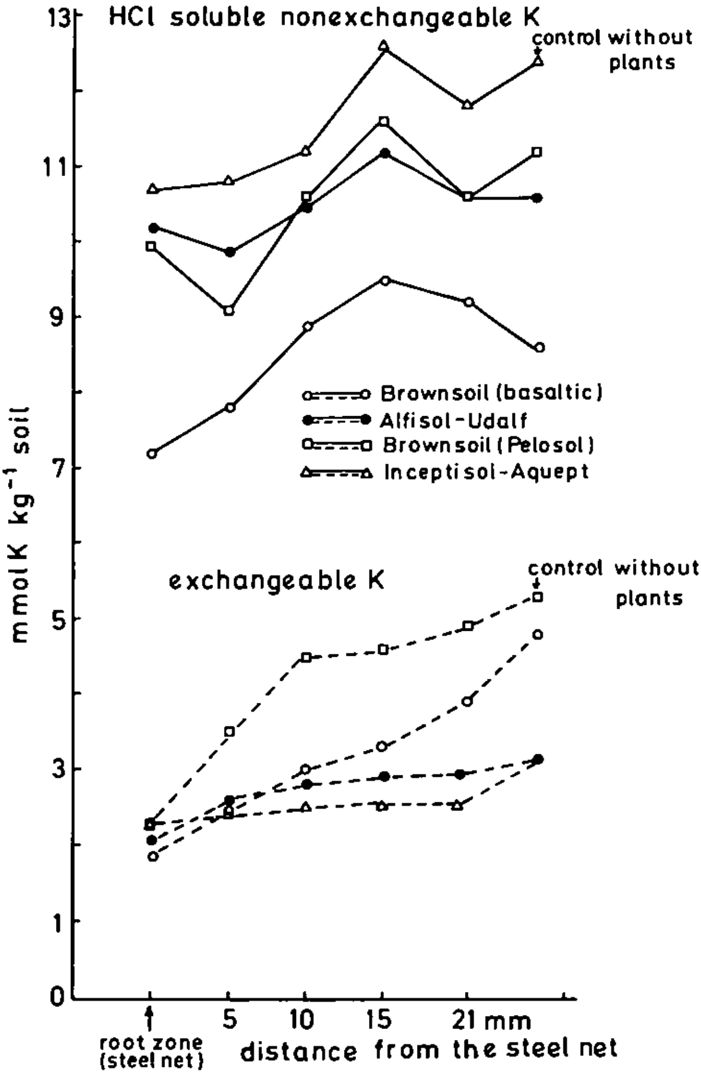

Fig. 4 Level of non exchangeable K^+ and exchangeable K^+ in relation to the distance from the rooting zone (steel net). The K^+ depletion resulted from K^+ uptake of *Lolium perenne* grown for 70 days. The non exchangeable K^+ fraction represents the difference between HCl soluble K^+ and the exchangeable K^+ *[6]*.

The pattern for the non-exchangeable K^+ is shown in the upper part of the Figure 4 and shows that non exchangeable K^+ was also released in the soil compartment without roots.

It is apparent that the depletion curve for non exchangeable potassium extended from the steel net (= root surface) up to 5 mm into the brown soil (Pelosol) and to 10 mm into the Inceptisol-Aquept soil (Figure 4). *Kuchenbuch* and *Jungk [7]* found a 2 mm depletion zone from the root surface for non exchangeable K^+. In the brown soil (basaltic) a decrease in non exchangeable K^+ was found only in the root compartment (Figure 4). Unlike all other soil, no significant decrease of non exchangeable K^+ could be found in the Alfisol-Udalf soil. This finding is most surprising since it is well known that soils derived from loess (Alfisol-Udalf) can release much available K^+. The finding is also in contrast to the K^+ uptake of the grass which also showed that a high proportion of K^+ taken up by the grass originated from the non exchangeable K^+ pool. The discrepancy is due to the technique of estimating the decrease in non exchangeable K^+ by the difference method. It is beyond the scope of this article to explain this technical shortcoming in detail. For the Inceptisol-Aquept soil and brown soil (basaltic) there was good agreement between the decrease in non exchangeable K (HCl soluble K) and the K uptake of grass. As already mentioned, grass has a better potential for exploiting soil K^+ than red clover.

This is especially true for interlayer K^+. According to *Claassen* and *Jungk [2]* root hairs are of crucial importance for soil K^+ exploitation. They found that rape was more K^+ efficient than maize, followed by onion. This ranking in K^+ efficiency was directly proportional to the length of the root hairs. Rape had the longest root hairs as compared with maize and onion. The length of the root hairs, moreover, determined the size of the K^+ depletion zone as well as the rate of K^+ uptake per unit root length. From this *Claassen* and *Jungk [2]* concluded that root hairs have a great significance for K^+ uptake capacity. In our own experiments grass had longer root hairs than red clover; therefore the soil can be more depleted in potassium per unit root length. We doubt, however, whether the length of root hairs is of outstanding importance, root length seems to be of equal relevance (Tables 5 and 8).

3. Concluding remarks

The experimental data discussed above have shown that K^+ uptake and exploitation of soil K^+ depend much on root morphology. Hence the actual availability of K^+ in soils is not only a question of physico-chemical soil parameters such as K^+ concentration of the soil solution, K^+ buffer capacity, and soil moisture but depends also substantially on biological factors such as root growth and root morphology. Since a single root can only exploit a small proportion of the total soil volume, root length and length of root hairs are considered as important root factors for the exploitation of soil K^+. Both factors determine to a great extent the soil volume being mined for nutrients by plants. The importance of root factors for K^+ uptake in comparison with physico-chemical soil parameters was also emphasized by *Silberbush* and *Barber [17]*.

Acknowledgement

Special thanks to Prof. Dr. *K. Mengel* and *J. Keller* for translation work.

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The Effect of Increased P and K Dressings on Yield and Quality of Starch Potatoes Grown on a Fixing Soil

A. Edelbauer, Institute of Plant Husbandry and Plant Breeding, Agricultural University, Vienna/Austria*

Summary

The effect of increased P and K dressings on the yield and quality of two varieties of potato grown in rotation on a fixing soil was studied in a field experiment. Under-supply of P and K greatly reduced yield of both tubers and starch and this was overcome by applying 400 kg/ha P_2O_5 and 900 kg/ha K_2O. In the first year, soil analysis 5 months after applying the fertilizers by both calcium ammonium lactate (CAL) and electro-ultrafiltration (EUF) showed no relation between soil P and K contents and fertilizer treatment. Two years later there were close correlations between nutrient application, soil nutrient content and yield parameters. Phosphate content of starch in the *cv* Hermes was increased by about 17% by applying phosphate. Molecular weight distribution in amyloses showed differences between *cvs* and fertilizer treatments.

1. The problem and description of the experiment

At the end of the seventies, severe difficulties were experienced in growing potatoes on ploughed out drained meadow land in Weitersfeld in Waldviertel, Lower Austria. In spite of annual applications of 150 kg/ha each N, P_2O_5 and K_2O the potato plants showed symptoms with blistered leaves with a bronze metallic sheen. Leaf tips were curled downwards and brown necrotic spots spread from the leaf margin into the intercostal spaces. Tuber yields were only about a half of expectation. The tubers showed more after-cooking blackening than usual.

Consultation with the *Federal Plant Protection Institute* suggested no biotic cause for the leaf symptoms and it was decided in 1982 to investigate the problem in a field experiment. Exploratory soil analysis indicated K deficiency and hinted at an under-supply of P.

The results for the 6 samples (each of 15 cores/3a) showed great variation within the experimental area for both major and minor elements (Table 1).

* Dr. *A. Edelbauer,* Institut für Pflanzenbau und Pflanzenzüchtung, Universität für Bodenkultur, Gregor Mendel-Strasse 33, A-1180 Wien/Austria

Table 1 Soil nutrient status before laying down the experiment. Range of values in 6 samples to 20 cm depth.

pH	CAL mg/100 g			Exchangeable cations me/100 g			EDTA mg/kg				B after Baron	K fixation mg/100 g
$CaCl_2$	K_2O	P_2O_5	Ca	K	Mg	Na	Fe	Mn	Cu	Zn		
5.9 - 6.9	3.0 - 6.0	2.1 - 4.2	18 - 45	0.11- 0.18	3.7 - 4.3	0.2 - 0.3	850- 3930	149- 6300	7 - 17	5 - 10	0.5 - 1.0	47 - 82

To assist in unravelling the K dynamics, further samples were taken from the same area for the 0-30, 30-60 and 60-90 cm horizons for mineralogical examination and the results are given in Table 2.

Table 2. Clay-mineral and organic matter composition of soil (% dry matter by weight).

	0-30 cm	30-60 cm	60-90 cm
Organic matter	4.9	1.2	0.9
Amorphous material	7.2	8.2	10.1
Iron hydroxides	16.5	11.1	9.1
Feldspar	12.4	11.1	11.1
Montmorillonite	7.2	7.1	7.1
Kaolinite	9.3	8.0	7.1
Muscovite	11.3	19.2	19.2
Quartz	29.9	33.3	34.3
K_2O excess by difference	1.3	0.9	1.1

The field experiment, to be continued over several years, was laid down in 1982 in a randomised block with 4 replications of the following fertilizer treatments: K_0, K_1 (300 kg/ha K_2O), K_1P (K_1 + 400 kg/ha P_2O_5), K_2P (K_1P + 600 kg/ha K_2O). Sulphate of potash and superphosphate (19% total P_2O_5) were the materials used. PK was applied in April 1982 two weeks before planting and for the 1984 crop before autumn cultivation in 1983. N fertilizer and plant protection measures followed usual local practice.

The results from this rotation experiment quoted here apply to the potato crops of 1982 and 1984. In both years, two cultivars were planted: Hermes (second early table potato) and Zenith (mid to late season maincrop industrial type). These are the most popular kinds locally.

2. Results

2.1 Yields

From the practical point of view, tuber and starch yields are both important. Yields were much reduced on the K_0 treatment, in 1982 by 9.8 t/ha for Hermes and 15.0 t/ha for Zenith as compared with the K_2P treatment. Both cultivars yielded for the area when generously manured. Yields were generally lower in 1984 again with severe reduction (relatively greater than in 1982) on the K_0 treatment: 13.6 and 16.6 t/ha for Hermes and Zenith respectively. Yields on the K_2P treatment were 4.4 and 7.2 t/ha below those for 1982. Yields of those two *cvs* were generally lower in the area in 1984. The time of application (autumn) with consequent fixation over the winter months could have something to do with this.

2.2 Starch content

The two cultivars differed in the way starch content was affected by fertilizer treatment. In Hermes, increasing the PK rate had no effect on starch content in either year. In contrast, in Zenith starch content was increased by P and by K_2 as against K_1 in 1982 but not in 1984, when it was reduced to below that on the K_0 treatment (Table 3).

Table 3. Tuber starch content related to fertilizer treatment (% in fresh matter).

	1982		1984	
	Hermes	Zenith	Hermes	Zenith
K_0	14.9	17.1	14.6	17.7
K_1	15.4	17.7	15.0	17.6
K_1P	15.1	17.7	14.4	18.5
K_2P	15.0	18.0	14.6	16.8

2.3 Starch yield

Starch yields from both varieties in both years were mainly a reflection of tuber yield and so reacted favourably to PK manuring. The behaviour of Zenith in 1984 was anomalous due to the marked depression in starch content at the highest fertilizer level (Table 4).

Table 4. Starch yields (kg/ha)

	1982		1984	
	Hermes	Zenith	Hermes	Zenith
K_0	3104	3866	1902	2443
K_1	3179	4517	2016	3441
K_1P	4060	5107	3283	4967
K_2P	4513	6770	3849	5106

2.4 Leaf analysis

In 1982 leaf analysis was done at two stages: tuber initiation and onset of flowering. The uppermost fully developed leaf was taken. At stage two, soil samples were also taken. Table 5 shows the marked effect of treatment on leaf K content. Leaf K content fell between the first and second sampling dates and fell much more at K_1 than at K_2; it was only on the K_2P treatment that the leaf K content remained at the satisfactory level *(Bergmann and Neubert [1976])*.

Table 5. Leaf P and K content as related to treatment (% in dry matter).

	8th July				2nd August			
	Hermes		Zenith		Hermes		Zenith	
	P	K	P	K	P	K	P	K
K_o	0.36	2.47	0.44	2.43	0.24	0.71	0.26	0.72
K_1	0.34	2.86	0.42	2.44	0.22	1.02	0.26	0.83
K_1P	0.46	2.88	0.50	2.73	0.23	1.14	0.24	0.92
K_2P	0.52	4.58	0.51	3.32	0.22	2.44	0.24	1.72

Analysis of soil samples taken at the beginning of Ausgust showed no effects of fertilizer treatment nor any relation with yield. CAL values were uniform at 5.0 mg/100 g K_2O and by EUF the K/1 fraction was 4.0 mg, the K/2 fraction 2.7 and «total K» 6.7 mg/100 g K_2O. EUF P values were related to treatment, the content rising by about 5.7 mg P_2O_5 to 7.5 – 9.0 mg by the application of 400 kg/ha P_2O_5.

Soil samples were again taken two years later a few weeks before harvest. Potassium and phosphate values by CAL or in water extract were then well related to the amounts of nutrient applied and to crop yield.

2.5 Starch quality

Quality characteristics of the starch are also of interest. For instance, an increased P content of the starch is desirable since it indicates greater viscosity and improved yield of paste when the starch is for use in the textile and adhesive industries *(de Willingen [1954])*. 400 kg/ha P_2O_5 increased the PO_4^{3-} content of starch from *cv.* Hermes by 17% (Table 6).

Table 6. Starch P content 1982 (% PO_4 in dry starch).

	Hermes	Zenith
K_o	0.204	0.240
K_2P	0.238	0.246

The *molecular distribution* of the starch polysaccharides is closely connected with the desired properties of viscosity, swelling and frost stability *(Praznik [1985])*. Table 7 shows the connection between fertilizer treatment and mean molecular weight and degree of polymerisation of amylose in starch from the control (K_o) and high fertilizer (K_2P) treatments.

Table 7. Mean values of molecular weights and degree of polymerisation of amylose from *cvs.* Hermes and Zenith.

	$\overline{M}_W$ x 10^6 Dalton	$\overline{M}_n$	$\overline{P}_W$	$\overline{P}_n$	P_W/P_n
Hermes K_o	0.92	0.42	5670	2570	2.2
K_2P	1.01	0.40	6230	2490	2.5
Zenith K_o	1.02	0.44	6300	2730	2.3
K_2P	1.11	0.49	6880	3040	2.3

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Co-ordinator's Report on the 2nd Session

K. Mengel, Institute of Plant Nutrition, Justus Liebig University, Giessen/Federal Republic of Germany; member of the Scientific Board of the International Potash Institute*

The papers presented during the Session No. 2 stressed the important factors of the K balance sheet with different emphasis. Positive factors of the K balance sheet are: application of mineral fertilizer K, application of manure and slurry, K release from soil minerals. Negative factors are: K export from the field by plant parts, K leaching, K fixation and K^+ removal by erosion. Some of these factors are easily to assess in quantitative terms others not.

Pieri gave an example of K leaching under tropical conditions which was particularly severe under intensive cropping. Until now the problem of K leaching under heavy crops in the tropics, which require an ample K supply, is not yet resolved. The problem deserves further attention with the target to implement an optimum K nutrition of the crop and avoiding K leaching.

Quémener gave a very comprehensive review with particular emphasis on soil processes. He showed that the relevance of the exchangeable soil K as an indicator for K availability decreased the more the exchangeable K of the soil is depleted. This is a general observation valid for all soils with appreciable amounts of interlayer K. The latter plays an increasing role the more the exchangeable K is depleted. At a level of 20 to 50 mg exchangeable K kg^{-1} soil, the exchangeable soil K does not give any information about the quantity of K which still can be extracted from the soil by crops. At this low level optimum K supply of the crop may be possible, the crop may also be completely starved with K deficiency at this level, demonstrating the dilemma of exchangeable K as an indicator for K availability in cases in which the absolute level of exchangeable soil K is low.

This statement was well supported by research data presented by *Edelbauer*. He showed significant differences in potato yields which were not correlated with EUF or CAL extractable K. Both, EUF-K and CAL-K, were low. Since the K extracted by both methods is closely correlated with the exchangeable K it is obvious that in the case of *Edelbauer's* experiments not so much the exchangeable K but the K from the interlayers of minerals was feeding the crop.

The problem whether K is also released from feldspars in amounts which suffice to supply heavy crop stands was raised by *Sparks*. The soils cropped by him were poor in interlayer K but rich in feldspars. Since the maize crop did not respond to K fertilizer it was assumed that K^+ was released from feldspars in appreciable amounts. The question deserves further research.

* Prof. Dr. *K. Mengel*, Director, Institute of Plant Nutrition, Justus Liebig University, Südanlage 6, D-6300 Giessen/Federal Republic of Germany

Steffens stressed the fact that the exploitation of interlayer K is much dependent on crop species. Thus, grass was more aggressive in exploiting interlayer K than clover. This difference originates from the different root system being much more extensive in grass than in clover. Consequently clover requires a higher K concentration in the soil solution for optimum growth than grass. The latter may still grow statisfactorily at a rather low K concentration in the soil solution which allows a relatively high rate of K release from interlayers. Net K release from interlayers is primarily a question of the K^+ concentration of the soil solution being in close contact with the K releasing minerals. The lower the K concentration of the solution, the higher the net K release.

In this respect the K concentration of the soil solution is more important than soil pH. It is justified to generalize that grasses exploit interlayer K much better than dicots, because of the difference in root morphology and extension. This probably is the reason why dicots often respond much better to K fertilizer than grasses. Results of *Johnston* presented during this congress are in good agreement with this statement and they support earlier results of field experiments carried out by *van der Paauw* in the Netherlands and by *Schön et al.* in Germany.

It must be emphasized that this K response of dicots is not a question of K quantity as is often believed, because sugar beets and potatoes take up more K^+ than cereals. Soils with interlayer K bearing minerals often contain huge amounts of available interlayer K; much more than is required by a dicot crop. Low K concentration of the soil solution, however, with a restricted root system as is typical for dicots, will result in an insufficient K supply. Hence not the K quantity but the K intensity is the limiting factor. Potassium intensity is roughly reflected by the K concentration in the bulk soil solution. It is not reflected by the activity ratio which looks very scientific but is of no major relevance.

Future work should be focussed on the determination of available interlayer K and the level which will suffice for optimum crop production. This level certainly will differ for the various crop species.

13th Congress of the International Potash Institute
August 1986 in Reims/France

3rd Session

Changing production targets and techniques and their effect on the potassium balance sheet

Co-ordinator: *Dr. R. E. Wagner*, President, Potash and Phosphate Institute (P.P.I.), Atlanta/USA

Changing Production Targets and Techniques and their Effect on the Potassium Balance Sheet

Ch. H. Henkens, Wageningen/The Netherlands*

Summary

Over the past 30 years, the needs to increase farm income, to compensate for loss of land to agriculture, to support higher crop and milk yields have led to changes in farming which may be expected to alter requirements for P and K fertilizers. The most significant changes are: increased stocking rates with a shift from arable cash crops to the growing of fodder maize, intensification of grassland management and the feeding of housed stock with imported feeding stuffs on the smallest farms. In the former case there is transfer of nutrients from arable to grassland; in the latter nutrients are imported with concentrates but it is impossible to utilise all the manure on the home farm. It is difficult to forecast the effects of these changes on fertilizer needs especially as there has been a change in fertilizer policy from the satisfaction of crop requirements towards the improvement and maintenance of soil P and K status and there are difficulties in achieving distribution of manures from housed stock over the arable area of the country.

Introduction

Rapid economic growth over the past few decades has greatly affected agriculture. In order that the income per farm worker should keep pace with other sectors of the economy, it was necessary to increase net farm income. This could not be done in the Netherlands by increasing farm size for two reasons: much land has been taken out of agriculture, the cultivated area has decreased by 325 000 ha or 14% between 1960 and 1983 and farmers were jealous of their independence and reluctant to give up their holdings to allow other farms to expand. Production could only be increased by intensification which in many cases on livestock farms involved switching to housed stock fed on bought-in feeds.

This paper will discuss the intensification of both arable and grassland farms and its effect on fertilizer phosphorus and potassium requirements.

* Dr. *Ch. H. Henkens*, Nassauweg 15, NL-6703 C.G. Wageningen/The Netherlands

1. Arable land

1.1. Area and cropping pattern

In Table 1, showing changes in arable land and cropping pattern in the Netherlands since 1960, arable fodder crops, mainly maize, are excluded. The arable area excluding fodder crops has decreased by 37% or 342000 ha over this period partly because of the increase in growing fodder maize on sandy soils and there has been considerable change in the relative importance of the different crops; thus sugar beet increased from 92700 to 123000 ha and its relative importance from 11 to 22%. Winter wheat has increased from 87900 ha to 142000, potatoes by 25000 ha and beet by 30300 ha. Other cereals have declined seriously with the replacement of rye and oats by fodder maize on sandy soils.

Crop specialisation was coupled with increase in yields (Table 2); yields of winter wheat, potatoes and sugar beet increased by 60, 31 and 27%, respectively.

Table 1 Area of arable land not under fodder crops in the Netherlands and the relative importance of different crops between 1960 and 1983

Area			Relative importance of				
	x 1000 ha	rel.	sugar beet	potatoes	winter wheat	other cereals	other crops
1960	868.6	100	11%	16%	10%	49%	14%
1965	782.2	90	12%	15%	12%	49%	11%
1970	680.3	78	15%	23%	15%	38%	8%
1975	594.0	68	23%	25%	11%	30%	10%
1980	563.3	65	21%	31%	23%	17%	8%
1983	547.1	63	22%	30%	26%	12%	10%

Table 2 Mean yields of winter wheat, table potatoes and sugar-beet between 1960 and 1983 in the Netherlands.

	Yield kg/ha Winter wheat	Table potatoes	Sugar-beet
1961/1965	4600	30000	42000
1966/1970	4700	34500	47000
1971/1975	5200	36700	45600
1976/1980	6100	35200	46900
1981/1984	7400	39500	53500

1.2. P and K requirements

Farmers are mainly interested in the economic return from fertilizer so fertilizer recommendations have been based solely on plant needs. Crop fertilizer requirements have been extensively investigated in large numbers of field experiments mostly laid down before 1965. Table 2 shows that there has been a steady increase in yields since that time resulting from better varieties, higher nitrogen dressings and better plant protection etc. It is natural to ask the question whether or not P and K recommendations need to be increased to suit the increased yields. The answer to this question depends on the purpose of the recommendations; whether they aim to improve crop growth or to improve and maintain soil fertility.

1.3. Crop growth

A new variety will only supersede an old if, at the same rate of fertilizer, it gives higher yields or better quality. The new variety must either show higher nutrient uptake from the soil or give a higher yield with the same uptake. If nutrient uptake from the soil is better, the same will apply to fertilizer nutrient and in that case one would expect a lower rather than a higher fertilizer requirement (Figure 1). Though the *cv* Prof. Broekema outyields the other two varieties, it is less responsive to potassium.

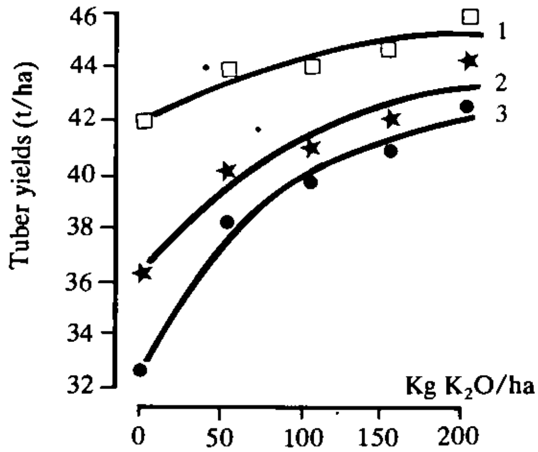

Fig. 1 Response of different potatoes varieties to potassium; 1 = Prof. Broekema; 2 = Ambassadeur; 3 = Rival

Increasing nitrogen dressings will only increase yield when other nutrients are sufficient. If P and K are adequate the result of increasing yield by using more N will be to increase P and K uptake, *i.e.* to improve their efficiencies. P response by potatoes at two levels of N with and without green manure was investigated at the *Soil Fertility Institute*, Haren (Figure 2). Both N and green manure increased yield but the P response curves at the two N levels and green manure levels were more or less parallel so we may conclude that a higher yield level does not necessarily require a higher P recommendation.

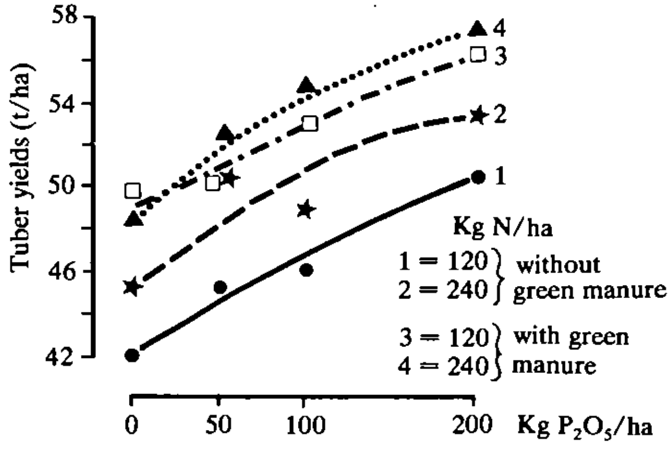

Fig. 2 Response of potato to phosphorus at different nitrogen levels with and without green manure (from: *Institute of Soil Fertility*, Haren/NL)

Nitrogen-potassium experiments both in the Netherlands and in France *(Loué [1979])* show that higher N dressings do not demand higher K. Figure 3, giving results from an experiment at Haren show that no more K is required at the higher N level. *Loué's* results are similar.

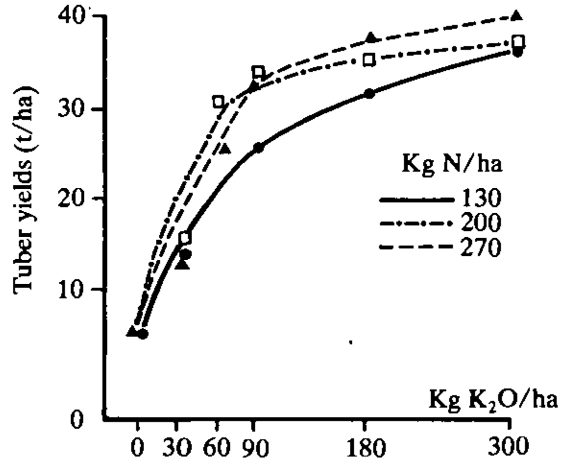

Fig. 3 Response of potatoes to potassium at different nitrogen dressings (from: *Institute of Soil Fertility*, Haren/NL)

Present-day plant protection measures allow crops a longer growing season. Results relating plant disease and phosphorus and potassium requirements fail. The effect of length of growing season can be deduced from experiments with two harvesting dates. Figure 4 shows the effect of potassium on yield at the end of July and end of September: the optimum rate at both is the same. In any case, it would seem unlikely that lengthening of the growing period through plant protection would increase the P and K requirements.

In summary, it cannot be concluded that present-day higher yields demand reconsideration of phosphorus and potassium recommendations provided the purpose of the recommendations is «to obtain optimum yield» and this, up to now has been the fertilizer «philosophy» in the Netherlands.

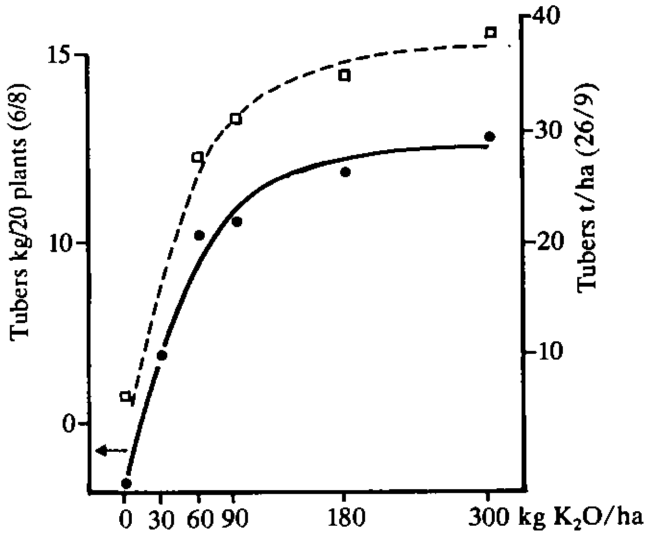

Fig. 4 Effect of potassium on tuber yields of 20 potato plants on August 6 and at harvest on September 26 (from: *Institute of Soil Fertility*, Haren/NL)

2. Soil nutrient status

An alternative basis for fertilizer recommendations could be «to apply fertilizer to maintain soil nutrient status» which corresponds with the philosophy of France and Germany. If this is the policy then higher yields do demand higher P and K dressings. Table 3 gives P and K removals by the rotation: potatoes, wheat, sugar beet, wheat at the yield levels obtaining in 1961/65 and 1981/84. This rotation, widely used in the

Netherlands, now removes 75 kg P_2O_5 and 175 kg K_2O more than was the case in 1961/65. Since fertilizer recommendations have not changed, soil P and K levels will decline. Table 4 gives soil test values for K on marine soils and shows a gradual decline in K levels. This shift is all the more serious on other soils (loess).

This decline would not matter if the decrease in soil nutrient status did not influence yield, in other words if the same yield as that on richer soils were obtainable with restitution P and K dressings based on crop removal on the better soils. But recent research has shown that potato and beet yields on both sandy and clay soils low in P remain below those on richer soils even when much P is applied. To prevent yield loss of over 1% soil P levels should be maintained at 25 mg/l on clay and 30 mg/l P_2O_5 on sandy soils. *van der Paauw's [1955]* view that on clay soils K status is important for quality as well as yield is also important. Tubers high in K are less susceptible to internal blackening and this is an important aspect of quality (Figure 5). It is clear from Figure 6 that much potassium is needed to increase the K content of tubers on low K soils, so to reduce susceptibility to internal blackening it is desirable to grow table potatoes on soils with ample K status.

These results have led to a change in Netherlands fertilizer philosopy. For rotations including potatoes, sugar beet and other P responsive crops the policy is to apply P fertilizer to achieve and maintain optimum soil P status. The same applies for potassium fertilisation of clay soils for rotations including potatoes. On sandy soils K status *per se* is not so important and fertilizing is directed to satisfying crop need. However, if we neglect soil nutrient status it is essential that applied potassium should be 100% effective and it is known that the effect of freshly applied K varies, while the weather has an effect. Therefore the recommendation is to avoid low K status also on sandy soils.

Table 3 Removal of phosphorus and potassium by rotation of potatoes, sugar-beet and 2 x wheat at yields of 1961/1965 and 1981/1984

Crop	Removal P_2O_5 kg/ha 1961/1965	Removal P_2O_5 kg/ha 1981/1984	Removal K_2O kg/ha 1961/1965	Removal K_2O kg/ha 1981/1984
Potatoes	40	55	165	220
Wheat (+straw)	40	60	65	85
Sugar-beet (+tops)	90	110	280	360
Wheat	40	60	65	85
Total	210	285	575	750

Table 4 Development of the potassium status of marine soils (arable land) in the Netherlands

Potassium status	71/72	75/76	80/81	83/84
< amply sufficient	16	26	30	27
amply sufficient	34	33	36	36
rather high	29	23	21	22
> rather high	21	18	13	15
number of samples	11032	13914	9732	13683

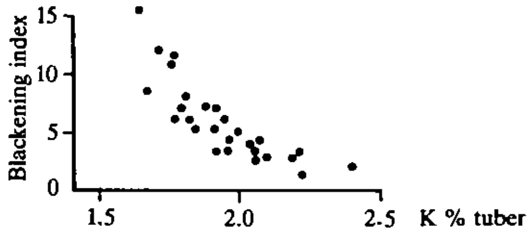

Fig. 5 Relation between internal blackening of table potatoes and the potassium content of tubers *(Prummel [1981])*

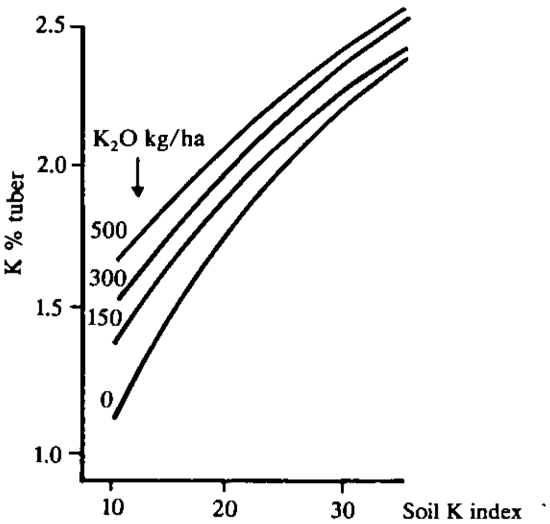

Fig. 6 Influence of potassium status of the soil (K-index) and potassium application on the potassium content of potato tubers in clay soils *(Prummel [1981])*

To summarise, soil analysis in the Netherlands was formerly interpreted on the principle that where soil content of available nutrient was high in comparison with crop need, dressings could be small while they should be larger on poor soils. The consequence was that dressings in excess of crop removal were applied on poor soils resulting in improved nutrient status while on rich soils the nutrient status was allowed to decline. Fertilizer recommendations were concerned exclusively with crop needs and soil fertility was virtually ignored so that the view was that higher yields did not require higher recommendations.

There has been a change in pilosophy as it is now realised that potato yields on poor soils, even when they receive large dressings, are lower than yields on the better soils which only receive maintenance P and K dressings. Recommendations for rotations including potatoes and sugar beet now aim for optimum soil P and K status. This means that higher yields require higher recommendations. The average rates of phosphate and potash as mineral fertilizers applied to arable land in the Netherlands are now respectively 65 kg/ha P_2O_5 and 85 kg/ha K_2O. The rate of potassium application is expected to increase further as yields and crop removal go up, unless the manures produced by housed livestock are distributed all over the country.

3. Grassland

Animal husbandry has been intensified in two ways: on farms of sufficient size by intensifying grassland management and converting arable to grass on mixed farms; this does not guarantee sufficient income on small farms and here farmers often opt to keep housed stock.

From Table 5, which gives areas under grassland and arable fodder crops it is seen that the grassland area increased slightly between 1960 and 1970 but then declined. From 1970 on, however, the area of arable fodder crops increased especially maize which covered 157000 ha in 1983. The total area used for cattle feeding did not change but cattle numbers increased greatly, from 118 cows per 100 ha in 1960 to 188 in 1983. Average milk yield increased from 4300 to 5500 kg. This intensification was achieved by changing production techniques.

Table 5 Acreage of grassland and fodder crops and number of dairy cows and cows in calf per 100 ha in the Netherlands between 1960 and 1983

	Grassland ha × 1000	Rel.	Fodder crops ha × 1000	Rel.	Grassland + fodder crops ha × 1000	Rel.	Dairy cows and cows in calf per 100 ha grassland + fodder crops	
							Number	Rel.
1960	1326.8	100	11.3	100	1338.1	100	118	100
1965	1337.2	101	12.2	108	1349.4	101	126	107
1970	1374.5	104	12.5	110	1387.0	104	137	116
1975	1286.2	97	80.8	715	1367.0	102	162	137
1980	1197.6	90	141.4	1248	1339.0	100	176	149
1983	1181.3	89	159.0	1407	1340.3	100	188	159

In the past, animals were fed on farm-produced feeds and the manure produced was regarded as a scarce and valuable commodity for maintaining fertility. So long as the manure was used on the farm nutrients remained within the cycle (Figure 7) except for some losses in storage and transport and nutrients secreted in the milk and stored in meat. Thus it follows that in order to maintain the nutrient status of the soil there had to be some recourse to fertilizers.

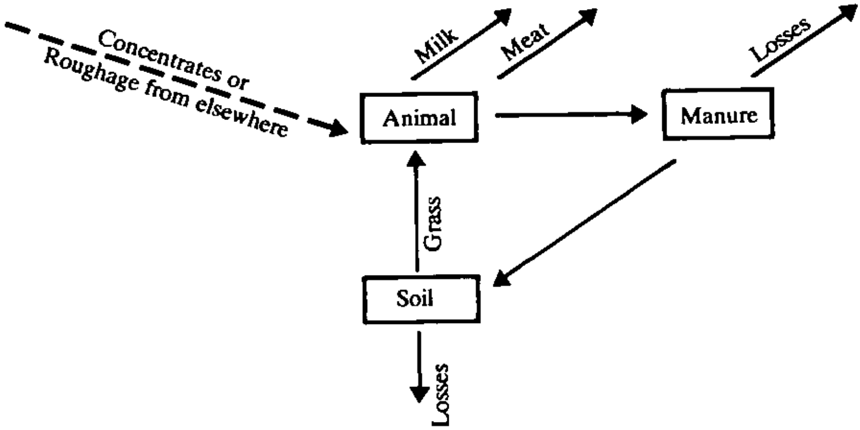

Fig. 7 Nutrient cycle on dairy farm

The increased stocking rates of today mean that the farmer can no longer rely solely on farm-produced feeds; he has to buy in concentrates and concentrate consumption has increased 3.3 times between 1965/66 and 1982/83 (Table 6). Considerable quantities of mineral nutrient are imported onto the farm in the concentrates which can thus be regarded as a kind of fertilizer. With 2 or more cows per ha and 0.92 followers per cow it is necessary to supplement the roughage from grassland with other fodders – hence the increase in fodder maize.

Nutrients are transferred with the maize from the arable area to the grassland and calculation shows that when the stocking rate amounts to 2 to 2.5 cows per ha with followers the P and K balance is in equilibrium on the grassland. With even higher stocking rates there is more than enough manure to maintain the P and K balance.

Unlike the mineral nutrients in concentrates, nutrients in maize silage originate from the farm itself or from nearby. At a stocking rate of 2.5 cows/ha with followers, 0.38 ha fodder maize is needed. Maize silage yielding 13 000 kg/ha dry matter containing 0.57% P_2O_5 and 1.80% K_2O removes 74 kg P_2O_5 and 234 kg K_2O. On a farm relying on home produced maize silage there will never be sufficient manure to compensate for the removal of K from the maize land. Accepting that all the manure is used on grass, fertilizer has to be used to replace the P and K removed from the maize land.

Table 6 Consumption of concentrates by cattle in the Netherlands in 1000 ton

1965/1966	1970/1971	1976/1977	1980/1981	1982/1983
1595 (100%)	2066 (129%	4212 (269%)	4697 (294%)	5280 (331%)

3.1. Effect of housed stock on fertilizer P and K consumption

The effective size of the smaller farms can be increased by housed stock. The feed does not originate on the farm so, to all intents and purposes, there is no soil in the cycle illustrated in Figure 7 and the manure produced cannot be used on the farm, neither is there room for this manure on grassland, because of the high stocking rate on grassland. Manure from housed pigs and poultry must therefore be used on arable land.

Table 7 estimates the total removal of P and K by arable crops and fodder maize in the Netherlands. By 1980, the P_2O_5 content of pig and poultry manure at 91565 t was almost twice as much as that removed in arable crops and fodder maize and has since increased. K_2O in these manures amounted to 110628 t, roughly sufficient to replace K removal but, depending on time of application there is serious leaching of K on sandy soils. New legislation is expected to prohibit winter application on sandy soils but we still have to allow for leaching losses of some 25%. It is estimated that if the manures were evenly distributed over the whole arable area there would remain a requirement for about 40000 t K_2O to maintain the K balance on the non-grassland area.

However, this estimate is quite hypothetical because it will take time to organise the necessary transport and it is doubtful whether the arable farmers will be willing to accept the manure.

Table 7 Removal of phosphorus and potassium, arable land and land under fodder crops.

	acreage × 1000 ha	mean uptake kg/ha		total removal ton	
		P_2O_5	K_2O	P_2O_5	K_2O
arable land	547.1	60-71[1]	128-187[1]	32826-38844[1]	70028-102308
fodder maize	159.0	75	234	11925	37206
Total	706,1	—		44751-50769[1]	107234-139514[1]

[1] highest when beet tops are harvested.

4. Conclusion

Notwithstanding the generally high stocking rate on grassland, there are still farms which are not so intensive and need to use P and K fertilizers, and the average usage on all grassland in the Netherlands is still 17 kg/ha P_2O_5 and 11 kg/ha K_2O.

Whether or not the changes in animal husbandry will affect K fertilizer usage in the short term is difficult to say when account is taken of the change in fertilizer «philosophy» towards maintaining soil nutrient status.

With the adoption of this philosophy, the main purpose of soil analysis is to check whether the desired soil status has been achieved and whether it is being maintained. If the results of analysis are to be truly representative samples should always be taken at the same stage in the rotation and the plough depth should not change but this may do so as the heavy equipment now available is an invitation to deeper cultivation.

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The Effect of Different Cultivation Methods on the Distribution of Potassium in the Soil Profile and on Plant Uptake

L. Rixhon, G. Droeven, J. P. Destain, M. Frankinet and Y. Raimond, Agricultural Research Centre, Ministry of Agriculture, Gembloux/Belgium*

Summary

In a long-term experiment (1967-1983), method of cultivation – direct drilling (SD), reduced cultivation (D) and conventional (L) affected crop yield but did not affect K content of crop.

The distribution of exchangeable K was affected by the method of cultivation but not the quantity of K_2O to 50 cm, except for direct drilling, where it was higher.

The root system was able to exploit the different distribution of K supplies.

The K balance derived from determinations of exchangeable K was always less than would be expected from K balance-sheet.

1. Introduction

Traditional methods of cultivation with the necessity for deep tillage are being increasingly challenged by the use of herbicides and rising costs (fuel and labour). There has been increasing interest in minimum cultivations and direct drilling of crops. It is likely that the new methods will affect the distribution of nutrients in the soil profile and that this will have consequences for plant nutrition. This problem, as it relates especially with regard to potassium has been studied in long-term experiments (1967-1983) on four fields each carrying one course of the following four course rotation so that each course was present in every year:

1. Roots: sugar beet
2. Spring cereal: oats or barley
3. Forage maize or horse beans
4. Winter cereal: wheat.

* *L. Rixhon,* directeur, Station de Phytotechnie, Chemin de Liroux, B-5800 Gembloux/Belgium; *G. Droeven,* directeur, Station de Chimie et de Physique agricoles, Chaussée de Wavre 115, B-5800 Gembloux/Belgium.

2. Experimental

The experiment was established on a deep fertile loamy soil and all crop residues were returned *(Frankinet et al. [1979])*. There were three main treatments:

SD – no cultivation or direct drilling by «triple disc» drill
D – cultivation to 15 ± 3 cm depth
L – normal cultivation to 30-35 cm.

The following sub-treatments were superimposed on the above:

- The effect of supplementary nitrogen with no or reduced cultivations
- The effect of a return to normal cultivation after 3 years on some plots under treatments SD and D.

Experimental design remained exactly the same during the 16 years period of experimentation.

Here, we shall discuss only the effects of the three main treatments at equivalent rate of nitrogen fertilizer.

Each year, yields were recorded and the harvested crop analysed for N, P, K, Ca and Mg. Soil samples were taken regularly after harvest, generally to 50 cm depth (exceptionally to 100 cm) at 5 cm intervals to 30 cm depth and 10 cm intervals below 30 cm. Exchangeable K was measured by the *Egner et al. [1960]* method for all depths of sampling, although this method is specially adaptable for arable layers.

All results are expressed as K_2O.

Plot size was 4 ares and yields were recorded on 3.2 ares.

After harvest, the crop residues were uniformly spread on the appropriate plot and incorporated by superficial cultivation on treatments L and D, while on treatment SD there was no cultivation between harvest and sowing of the next crop. Conventional drills were used on treatments D and L.

With the exception of the control of weeds with total herbicides (paraquat or glyphosate) on treatment SD all other operations including nitrogen fertilizer application were in conformity with normal farm practice.

Phosphate and potash fertilizers were uniformly applied over all treatments immediately after spreading residues but before cultivating them in. The rates applied were:

1967 to 1974 – 140 kg/ha P_2O_5 and 240 kg/ha K_2O for beet,
120 kg/ha P_2O_5 and 160 kg/ha K_2O for other crops.

from 1975 P and K dressings were calculated from crop removals. Generally, beet received 115 kg/ha P_2O_5 and 240 kg/ha K_2O, the following cereal receiving no PK. 115 kg/ha P_2O_5 and 138 kg/ha K_2O were given to other crops; when silage maize occurred, a supplement of 100 kg/ha K_2O was given.

Table 1 shows details of all the K applications.

Table 1 K fertilizer applied (kg K_2O ha^{-1})

Year	Field 1		Field 2		Field 3		Field 4	
	Crop	K	Crop	K	Crop	K	Crop	K
1967	Beet	240	Wheat	160	H. Beans	160	Oats	160
1968	Barley	160	Beet	248	Wheat	160	H. Beans	160
1969	H. Beans	160	Oats	160	Beet	240	Wheat	160
1970	Wheat	160	Maize	160	Barley	160	Beet	240
1971	Beet	240	Wheat	160	Maize	160	Oats	160
1972	Oats	160	Beet	240	Wheat	160	Maize	160
1973	Maize	160	Barley	160	Beet	240	Wheat	160
1974	Wheat	164	H. Beans	156	Oats	30	Beet	314
67-74	Total	1444	Total	1444	Total	1310	Total	1514
8 years	Mean	180	Mean	180	Mean	164	Mean	189
1975	Beet	300	Wheat	125	Maize	133	Barley	0
1976	Oats	0	Beet	268	Wheat	138	Maize	237
1977	Maize	240	Oats	0	Beet	240	Wheat	140
1978	Wheat	138	Maize	238	Oats	0	Beet	298
1979	Beet	240	Wheat	138	H. Beans	84	Barley	0
1980	Barley	0	Beet	238	Wheat	138	Maize	84
1981	Oats	183	Wheat	0	Beet	237	Wheat	84
1982	Maize	152	Winter Barley	90	Wheat	0	Beet	220
1983	Wheat	138	Oats	84	W.Barley	84	Wheat	0
75-83	Total	1391	Total	1181	Total	1054	Total	1063
9 years	Mean	155	Mean	131	Mean	117	Mean	118
67-83	Total	2895		2625		2364		2577

3. Results and Discussion

3.1 Effects of cultivation method on yield, K_2O content and removals of crops

Table 2 gives mean yields, mean K_2O contents and K_2O removals. Yields of beet, maize, barley and oats were lower with direct drilling (SD), slightly higher for wheat and more so for horse beans. Yields under reduced cultivation (D) were slightly better than with conventional cultivations except in the case of forage maize. K_2O content was not affected by cultivation treatment *(Frankinet [1982])* so that removals were almost directly related to crop yield.

Table 2 Yields, K_2O contents and removals
Mean yields (kg ha^{-1})

	Sugar beet	Oats	Barley	Maize silage	H. Beans	Wheat
Treatment Mean of:	Sugar 16 results	Grain 10 results	Grain 6 results	DM 10 results	Grain 5 results	Grain 18 results
SD	7452	4774	3622	8084	3591	6150
D	9447	4993	4121	9393	3443	6128
L	9381	4942	4084	9917	3365	6118
K_2O contents (average in ‰ of DM)						
SD	13. 13	6. 84	7. 11	19. 52	15. 70	5. 77
D	12. 72	6. 94	6. 93	18. 76	15. 82	5. 76
L	13. 18	7. 25	7. 10	19. 95	15. 73	5. 86
Alpha	0.112	0.165	0.843	0.792	0.591	0.224
Average K_2O removals (kg ha^{-1})						
SD	108.03	29.1	28.4	146.1	47.4	30.2
D	145. 0	30.7	31.6	167.9	45.7	30.0
L	142. 0	30.6	31.6	183.9	42.0	30.2

3.2 Changes in exchangeable K_2O content in the soil profile

Since exchange equilibria and K fixation are affected by weather, there were large inter-year fluctuations in exchangeable K_2O content.

Exchangeable K contents expressed as kg/ha K_2O and calculated from exchangeable K content and bulk density are given in Table 3. In order to facilitate comparisons, second degree regression curves, even though they may not truly represent actual phenomena, are given in Figure 1 for each depth of sampling and field by field for the 3 main treatments, the common Y intercept being obtained by calculation.

At first sight it seems that field 1 differs from the others especially at depth (30-40 and 40-50 cm). Here the curves are concave towards the top while the reverse is the case elsewhere. Aerial photographs taken in 1948 and 1952 indicate a different cultural history for this area and may offer some explanation.

There is little difference between the fields in the surface layers (0-30 cm). The rising curves up to 1974-75 reflect the excess of K applied over removals. From the 8th year on, the exchangeable reserves diminish steadily as a result of adjustment of fertilizer application. K application having been adjusted to a more moderate level, the potassium equilibrium is shifting towards a new equilibrium level, a change recorded in some earlier work *(Barbier et al. [1957])*.

Table 3 Amounts of exchangeable K_2O (kg ha^{-1})

Depth (cm)	1968			1970			1972			1974			1976			1978			1980			1982			1983		
	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L
Field 1																											
0- 5	373	260	257	271	182	151	302	125	125	324	220	169	331	246	187	463	264	241	324	192	180	308	183	172	367	254	275
5-10	292	272	209	288	206	149	212	198	161	354	265	211	275	255	186	312	241	183	323	231	214	241	191	184	227	211	183
10-15	—	—	—	208	244	169	152	256	157	268	266	240	249	236	185	254	268	203	278	251	194	217	206	194	214	224	199
15-20	308	252	284	169	221	184	133	217	175	206	233	251	180	200	209	198	226	221	214	244	224	198	201	215	204	231	213
20-25	—	—	—	144	178	191	121	162	208	172	184	234	158	165	234	178	182	231	194	212	253	167	178	221	181	215	223
25-30	198	175	272	140	146	196	114	137	212	139	139	204	139	139	203	147	135	217	156	169	248	154	164	209	156	196	240
30-35	—	—	—	252	252	359	251	230	294	254	238	310	248	222	292	128	109	169	134	142	197	138	152	195	130	172	204
35-40																111	93	132	115	119	153	121	129	152	125	156	189
40-45	—	—	—	211	230	252	198	202	223	229	208	233	204	190	234	99	82	108	100	99	123	114	117	153	120	146	140
45-50																90	77	95	86	81	106	113	95	124	115	114	121

Depth (cm)	1968			1969			1971			1973			1975			1977			1979			1981			1982			1983		
	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L
Field 2																														
0- 5	211	190	152	312	269	281	312	208	170	437	258	258	363	248	176	302	192	164	403	264	207	365	205	152	321	220	203	313	230	214
5-10	252	218	164	180	182	149	275	235	184	302	271	214	327	261	203	272	218	172	343	273	197	289	243	165	261	223	200	215	207	174
10-15	—	—	—	190	187	130	175	208	181	199	235	211	260	268	215	229	242	184	273	252	186	235	221	188	256	258	204	219	215	192
15-20	244	270	275	121	124	137	134	173	173	162	180	216	198	246	221	182	205	204	209	210	187	184	194	186	235	259	215	194	216	212
20-25	—	—	—	119	121	144	131	150	164	145	161	241	171	180	225	158	165	205	176	166	205	167	156	183	176	202	255	171	188	211
25-30	185	178	206	118	126	138	127	136	155	130	155	223	151	133	196	140	148	183	140	126	184	158	139	170	136	160	230	143	168	192
30-35	—	—	—	200	185	196	233	240	259	272	270	301	248	227	250	252	256	277	121	116	157	142	120	158	107	112	193	124	126	148
35-40																			113	107	122	123	105	130	91	93	137	105	113	110
40-45	—	—	—	190	163	163	222	211	227	252	236	245	216	209	203	243	250	243	106	100	97	105	101	109	96	85	104	104	104	99
45-50																			103	94	94	103	100	102	80	76	81	105	89	98

Depth (cm)	1968			1969			1970			1972			1974			1976			1980			1982			1983		
	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L
Field 3																											
0- 5	319	248	224	306	223	182	397	217	182	335	226	208	318	175	143	363	219	183	433	236	193	300	171	158	296	168	171
5-10	280	246	187	214	214	144	298	223	172	287	217	185	286	220	167	308	247	182	363	215	169	223	187	139	213	159	148
10-15	—	—	—	179	192	155	191	217	157	198	199	164	220	253	194	258	246	188	295	229	167	203	208	153	196	178	156
15-20	266	271	290	150	163	167	162	197	163	166	192	161	185	203	212	211	218	201	184	227	177	188	209	182	195	188	179
20-25	—	—	—	149	155	169	148	163	199	149	168	163	161	154	198	171	175	211	153	181	198	174	170	174	175	156	184
25-30	191	179	220	144	139	149	140	139	197	138	143	167	146	134	171	136	143	196	129	141	177	154	159	154	147	148	177
30-35	—	—	—	251	218	235	274	272	292	266	265	288	274	247	276	247	248	297	119	114	126	134	134	142	133	121	154
35-40																			108	95	107	123	115	121	131	117	140
40-45	—	—	—	208	190	180	212	208	212	245	230	233	252	241	226	220	221	220	103	84	100	116	114	109	125	116	116
45-50																			94	78	80	119	104	105	118	112	115

Depth (cm)	1968			1969			1971			1975			1977			1979			1981			1983		
	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L	SD	D	L
Field 4																								
0- 5	268	227	166	228	235	190	359	210	178	335	240	184	400	271	240	413	221	179	349	208	178	310	188	184
5-10	292	262	200	191	202	143	236	196	167	338	262	212	378	291	212	332	268	179	265	204	179	223	184	158
10-15	—	—	—	164	179	140	166	188	164	276	272	214	335	308	233	275	308	221	239	217	190	212	221	162
15-20	269	252	348	132	149	139	154	164	168	206	230	215	263	275	248	215	236	254	199	201	196	210	219	203
20-25	—	—	—	127	133	142	143	142	173	167	167	220	217	219	257	197	175	241	193	174	202	204	192	212
25-30	191	190	210	116	121	128	134	132	175	142	138	188	176	166	218	156	143	194	172	155	194	172	184	191
30-35	—	—	—	222	214	208	269	276	283	263	230	261	311	281	281	141	115	143	149	118	165	150	148	168
35-40																119	98	113	129	102	131	129	118	40
40-45	—	—	—	173	173	168	251	241	238	247	212	220	250	205	223	102	91	98	116	103	105	112	106	121
45-50																91	88	95	101	103	91	112	94	105

SD: direct drilling – D: reduced cultivation – L: conventional cultivation

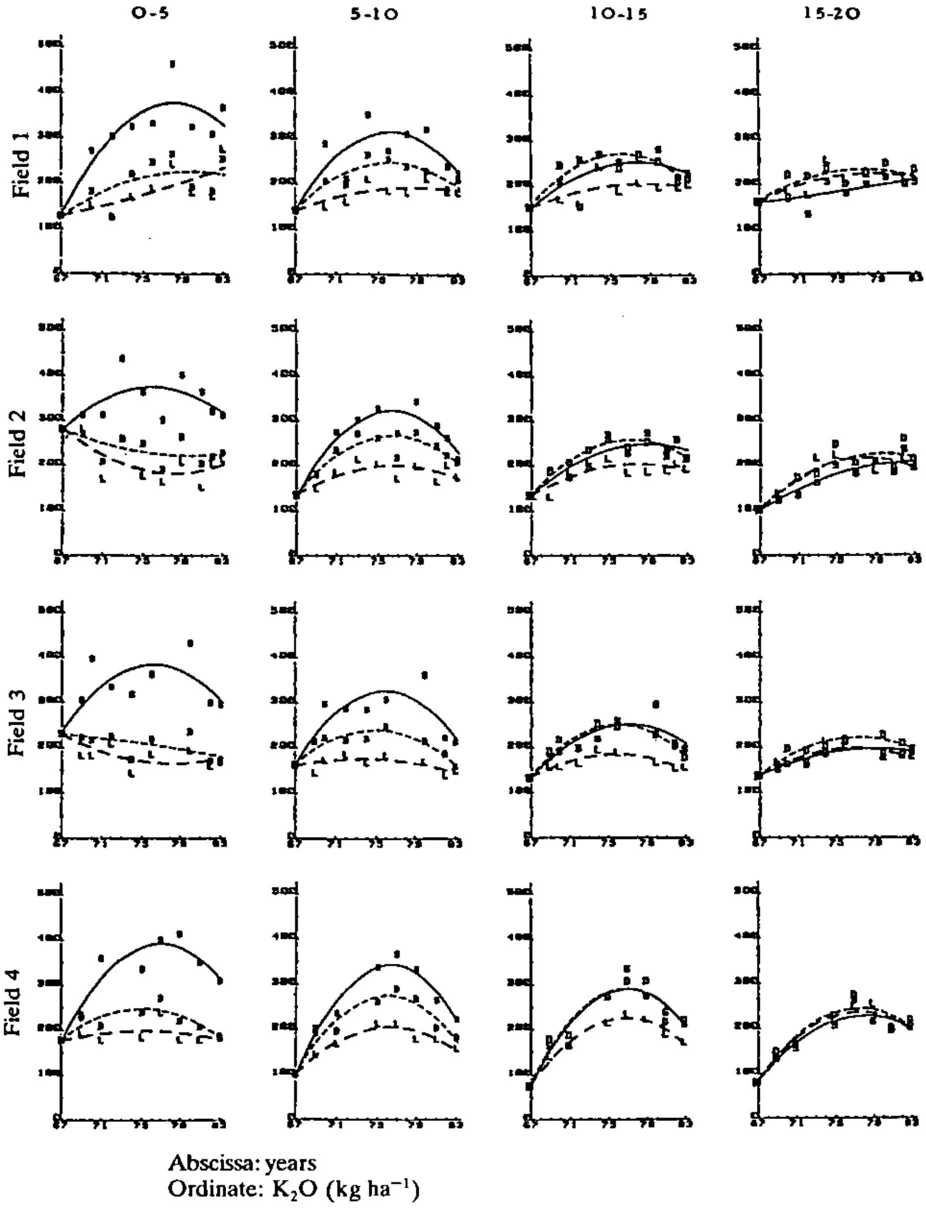


Fig. 1 Change in exchangeable K_2O by fields and sampling depth (kg ha^{-1})

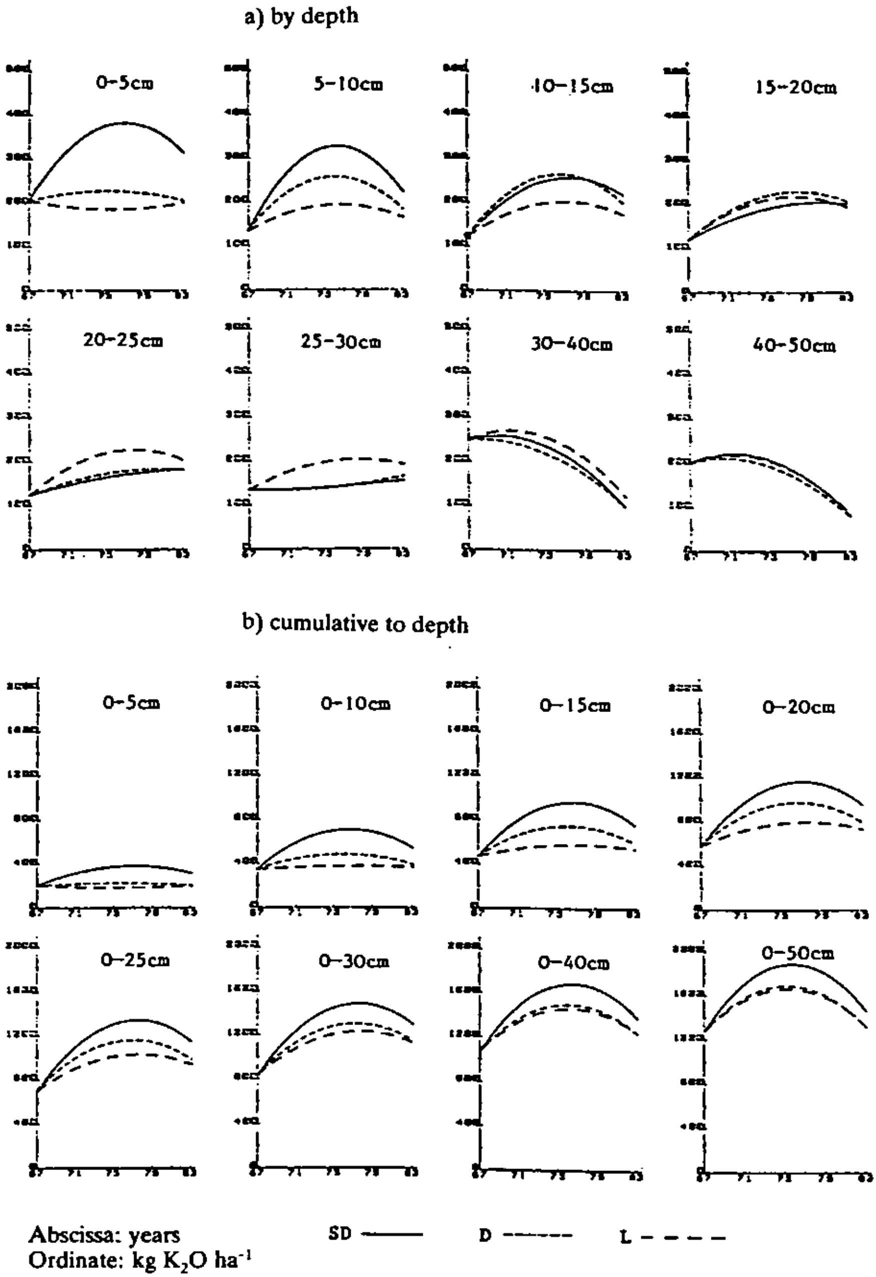


Fig. 2 Change in exchangeable K_2O. Mean of 4 fields (kg ha^{-1})

There would seem to be nothing against grouping the fields together for the different sampling depths as is done in Figure 2a. There is definite and rapid enrichment of the 0-5 cm layer in treatment SD as a result of accumulation of fertilizers and crop residues which were not ploughed in. In the 5-10 cm layer there is still enrichment, though to a lesser degree under treatment SD. Treatment D shows more rapid enrichment than L and approaches SD. In the 10-15 cm layer SD and D are virtually the same and remain greater than L, though the latter shows greater enrichment than in the layers above. There is a transition between the top 3 layers and the others.

At 15-20 cm, differences between cultivation treatments are slight (D is slightly above L while in SD the contents are the lowest). From 20-30 cm, treatments SD and D are similar and below L. The similarity between D and SD is due to the fact that cultivation does not affect this layer.

These situations were already described from the second year by *Raimond [1969]*. From 30 to 40 cm slightly higher levels are evident in the conventionally cultivated treatment (L) and below 40 cm the curves on all treatments are virtually the same. Figure 2b shows cumulative enrichment curves layer by layer for the mean of the fields. They all show enrichment for the first 8 years followed by a decline. The constantly higher levels under treatment SD are probably explained by lower removals with less fixation of residual fertilizer K by clay minerals of the montmorillonite and illite type in the experimental soil due to the protective role of organic matter which accumulates in the surface layer in treatment SD.

As far as 20 cm the increase is more in D than in L, then the difference between treatments becomes steadily less; until from 40 cm depth there is no difference between the two. The distribution between depths differs between these two treatments but over the profile as a whole the total stock of K_2O is equal.

3.3 Distribution of K_2O in the profile and root activity

The effects of cultivation treatment on K nutrition of the crop has two aspects – distribution of K_2O through the profile and root activity. The cumulative curves of Figure 3 show that in the case of autumn 1983, in order to make contact with 50% of the total exchangeable K_2O present to 50 cm depth, roots of winter wheat would have to extend to 18.5 cm in treatment SD, to 20.6 cm in treatment D and 22.5 in L, that is a difference in depth of 4 cm between the extremes.

A profile of root activity for winter wheat at the terminal leaf stage in May 1983 was determined by *Ellis and Barnes's [1973]* ^{86}Rb technique adapted to the conditions of the experiment. Ignoring the surface (0-5 cm) layer which was contaminated, it appears from Figure 4 that the root system was affected by cultivation method. In SD, root activity is maximum in the top layer, declines steeply to 40 cm, recovers slightly from 45 cm and tails off to depth. For D, maximum activity is in the layer 10-15 cm, declines sharply to 30 cm to recover at 35 cm to decline steadily thereafter. In L there are two peaks of activity, between 5 and 10 cm and between 20 and 25 cm below which it declines steeply to recover from 50 cm.

Even though there may be no relation between root development and exchangeable K supply, maximum root activity is found in the profile at depths corresponding with maximum exchangeable K supply.

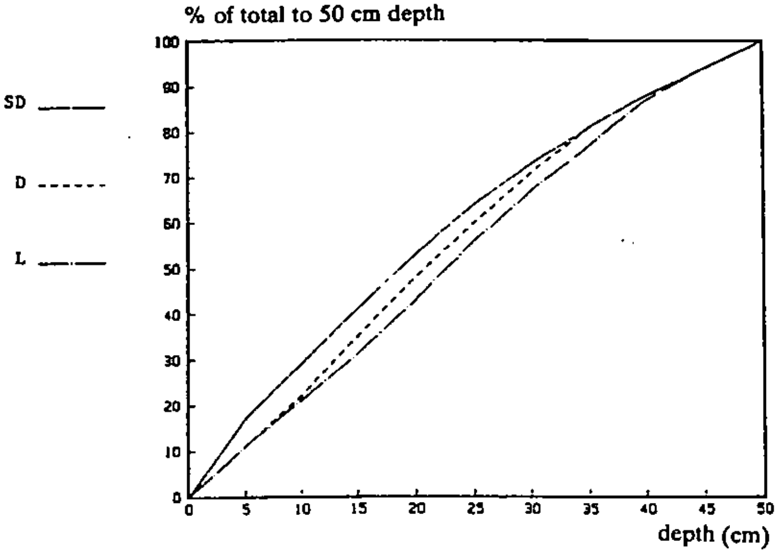


Fig. 3 K_2O distribution as % of total to 50 cm depth

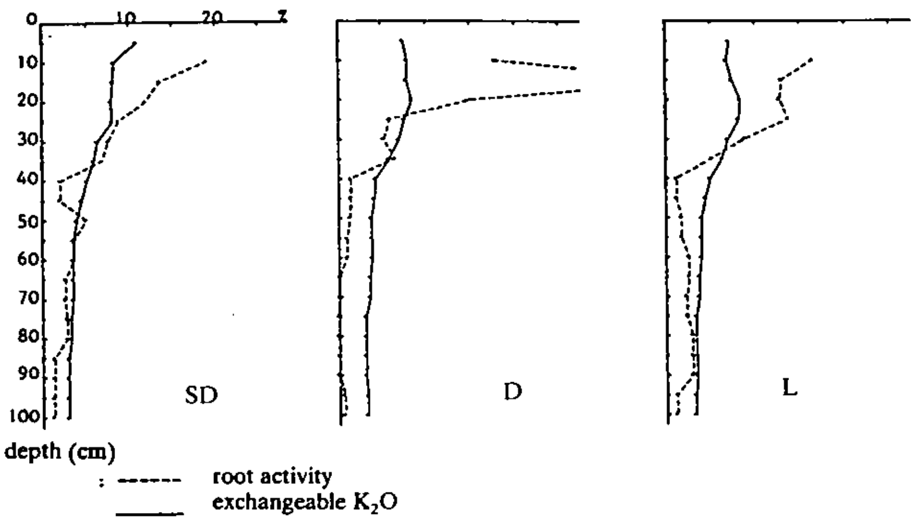


Fig. 4 Distribution of root activity and exchangeable K_2O.

4. K Balance-Sheet and Balance by Soil Analysis

The amounts of K_2O applied, those removed in harvested crop produce and the differences between the two for the periods 1967-74 and 1975-83 and for the whole run of the experiment are shown in Tables 4, 5 and 6. The annual rates applied in the former period were considerably higher than in later years. On account of the generally lower yields the positive balance is greater in treatment SD than in D and L between which there is little difference.

The total amounts in kg/ha of exchangeable K_2O to 50 cm depth were calculated by curvilinear regression for the years 1967, 1974 and 1983 and these values are given in Table 7 with the balances for the two periods and over the whole period. For the first period, all the balances are positive with marked enrichment in treatment SD. All the values are negative for the second period. The deficits were less in field 1 than in the rest, reflecting the more generous fertilizer treatment thereon. Over the whole period the balance by soil analysis does not account for the whole of the positive balance-sheet (K applied – K removed in crop). Only treatment SD shows a positive balance in all fields and it is always more positive than in D and L. Furthermore D and L values are definitely negative in field 3.

Table 4 Fertilizer applied (kg/ha K_2O)

Period	Field I		Field II		Field III		Field IV	
	Total	Annual mean	Total	Annual mean	Total	Annual mean	Total	Annual mean
1967-74	1444	180.5	1444	180.5	1310	163.7	1514	189.2
1975-83	1391	154.5	1181	131.2	1054	117.1	1063	118.1
1967-83	2835		2625		2364		2577	

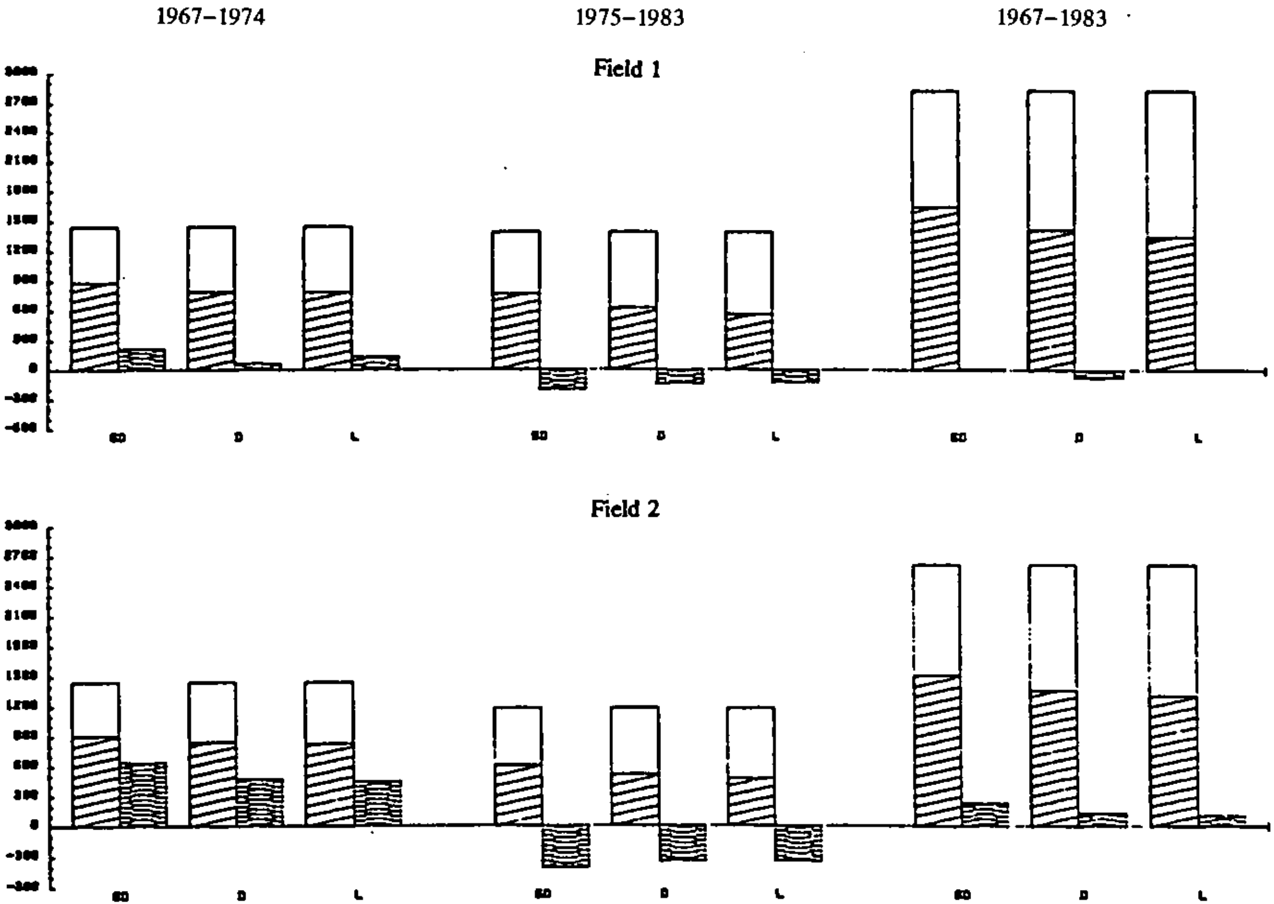
Table 5 K_2O removals (kg/ha K_2O)

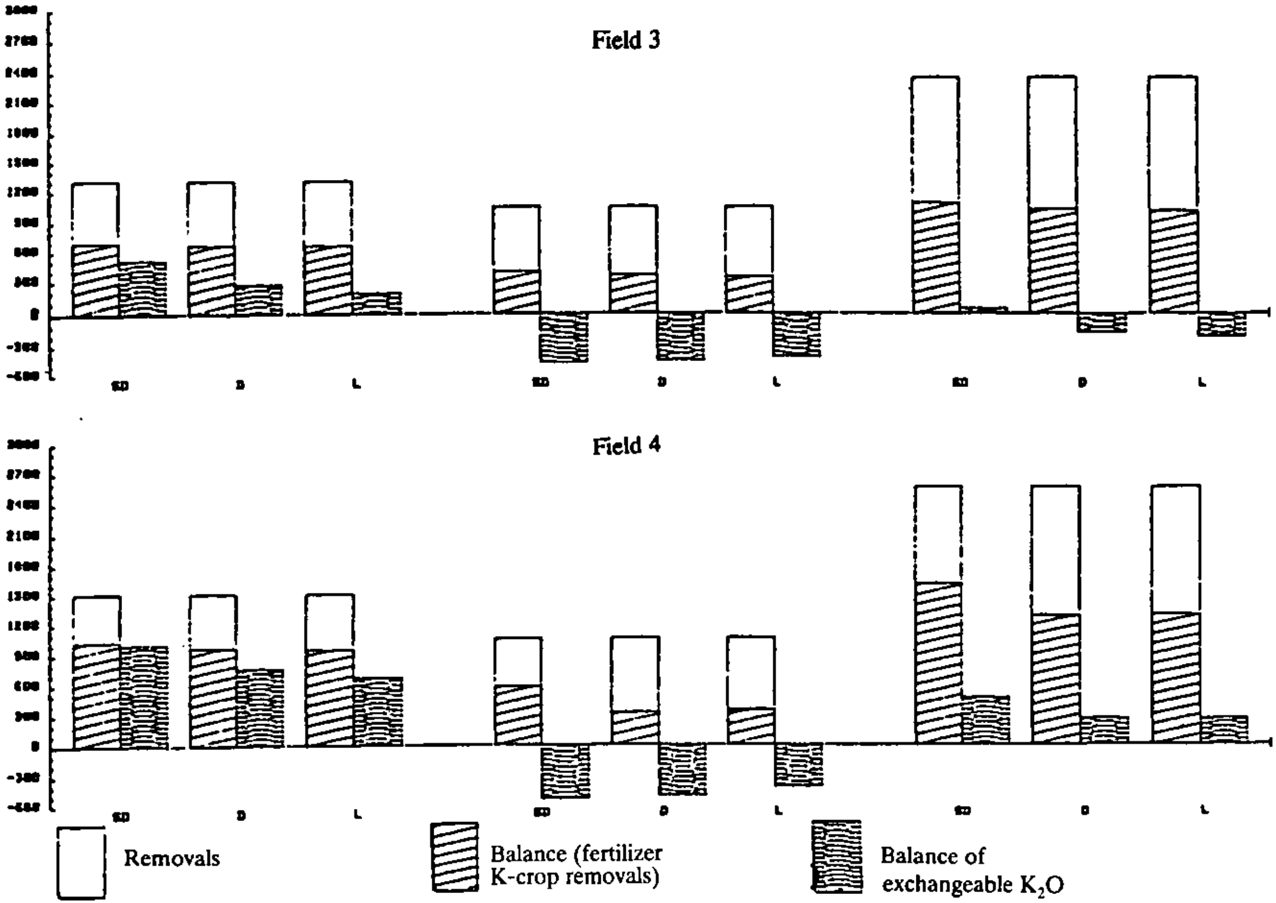
Period	Field I			Field II			Field III			Field IV		
	SD	D	L	SD	D	L	SD	D	L	SD	D	L
1967-74	559.4	653.6	656.9	537.8	598.3	613.4	615.9	641.4	643.1	482.6	542.1	559.2
1975-83	621.5	763.0	827.4	574.0	664.8	704.5	650.8	686.0	702.7	478.4	742.2	716.1
1967-83	1180.9	1416.6	1484.3	1111.8	1263.1	1317.9	1266.7	1327.6	1345.8	961.0	1284.6	1275.3

Table 6 K_2O balance (kg/ha)

Period	Field I			Field II			Field III			Field IV		
	SD	D	L	SD	D	L	SD	D	L	SD	D	L
1967-74	884.6	790.4	787.1	906.2	845.7	830.6	694.1	668.6	666.9	1031.4	971.4	954.8
1975-83	769.5	627.0	563.6	607.0	516.2	476.5	403.2	368.0	351.3	584.6	320.8	346.9
1967-83	1654.1	1417.4	1350.7	1513.2	1361.9	1307.1	1097.3	1036.6	1018.2	1616.0	1292.2	1301.7

Fig. 5 K_2O balance





Abscissa: cultivations
Ordinate: K_2O (kg ha^{-1})

Table 7 Kg/ha exchangeable K_2O to 50 cm depth (by regression)

Year	Field I			Field II			Field III			Field IV		
	SD	D	L	SD	D	L	SD	D	L	SD	D	L
1967	1546.2	1546.2	1546.2	1219.1	1219.1	1219.1	1389.1	1389.1	1389.1	1027.7	1027.7	1027.7
1974	1768.0	1617.5	1682.8	1862.0	1697.3	1670.9	1906.0	1668.2	1582.2	2034.4	1793.2	1706.1
1983	1562.0	1474.0	1556.0	1453.0	1350.0	1327.0	1440.0	1222.0	1181.0	1503.0	1290.0	1291.0
1967-74	+ 221.8	+ 71.3	+ 136.6	+ 642.9	+ 478.2	+ 451.8	+ 516.9	+ 279.1	+ 193.1	+ 1006.7	+ 765.5	+ 678.4
1975-83	− 206.0	− 143.5	− 126.8	− 409.0	− 347.3	− 343.9	− 466.0	− 446.2	− 401.2	− 531.4	− 503.2	− 415.1
1967-83	+ 150.8	− 72.2	+ 9.8	+ 233.9	+ 130.9	+ 107.9	+ 50.9	− 167.1	− 208.1	+ 475.3	+ 262.3	+ 263.3

The two balances are compared in Figure 5. For the first period, both crop and analytical balances are positive. The analytical balance for field 1 is lower than in the others and this difference is ascribed to its different cultural history. For all fields both balances in SD are higher than in D and L. For SD, on the average, the rise in exchangeable K content over the first period accounts for from 25 (field 1) to 98% (field 4) of the excess of fertilizer K over crop removal. The corresponding values for the other fields are 9 to 78% for D and 17 to 71% for L.

For the second period, fertilizer K – crop removal is still positive but less, due to reduced fertilizer rates. The analytical balance is always negative: rapid enrichment (generous excess of fertilizer in the first period) succeeded by decline and establishment of a fresh equilibrium between fixed and exchangeable K in the second period. Again field 1 shows lower values. In all cases, the decline was greater under treatment SD.

The balance between K applications and removals over the whole period is positive and large, but this is not apparent in soil analysis, which sometimes shows a negative balance (2 cases in D and 1 case in 4 in L). In SD it is always positive and above D and L.

5. Conclusion

Method of cultivation – direct drilling (SD), reduced cultivation (D) and conventional (L) – affected crop yield differently. Direct drilling reduced yield of sugar beet, maize, barley and (slightly) oats, did not affect wheat and improved horse bean yield. Reduced cultivation was inferior to conventional only for maize. Cultivation method did not affect K content of crop so K removals were almost proportional to yield. Under SD, there was concentration of exchangeable K at the surface; it was more evenly distributed in tilled layers of D and L. Root activity of wheat determined in May 1983 was maximum in the surface layer under SD and in horizons affected by cultivation in other treatments. Under D and L it was reduced in deep (compacted) layers. The root system was able to exploit the different distributions of K supplies. Exchangeable K content rose during the first phase (1967-74) as a result of generous K fertilizer treatment and declined thereafter tending towards a lower equilibrium value related to lower K supplies. Surface enrichment under SD was such that the whole profile to 50 cm depth was enriched as compared with D and L, partly because of lower crop K removals and partly because of the protective role against K fixation of accumulated organic matter from the mulch of crop residues.

The K balance derived from determinations of exchangeable K was always less than would be expected from the K balance-sheet (K fertilizer applications – crop removals), while some negative values for this balance were recorded for treatments D and L it was always positive for SD.

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Potassium Distribution in a Sandy Soil Exposed to Leaching with Saline Water

Sala Feigenbaum, ARO, The Volcani Center, Bet Dagan/Israel*

Summary

The distribution and movement of potassium was studied in a sandy soil exposed to leaching with saline and sodic waters. The data reported and discussed were from laboratory and field experiments.

Downward movement of applied potassium was related to the level of total salt and the amount at the leaching solution.

From the calculated potassium balance sheet some of the added potassium was not found in the ammonium acetate extract. The unaccounted potassium increased with increasing salinity in the irrigation water. It seems, that this potassium was fixed by the soil clay minerals. The data of both, columns and field experiments suggest that the exposure of a soil to leaching with saline and sodic solution effects the process of K fixation.

1. Introduction

Potassium fertilizer applied to a soil is adsorbed to exchangeable and non exchangeable sites and does not move beyond the zone of application *(Munson* and *Nelson [1963])*. Losses of potassium reported by *Bertsch* and *Thomas [1985]* from irrigated soils are relatively low, in the range of 1.5 to 57 kg ha^{-} per year. Movement of applied potassium into deeper soil layers is expected in a coarse-textured sandy soil, with very low CEC. *Farina* and *Graven [1973]* reported losses of potassium by leaching up to 100 kg K ha^{-1} year below the rooting depth in a sandy soil. When some crops are irrigated with water, containing high levels of Na, Mg, and Ca salts, potassium adsorption, desorption and dissolution processes will be affected and there may cause some movement into deeper soil layers *(Pratt* and *Laag [1967]; Meiri et al. [1984]; Ganje* and *Page [1970])*. Leaching excess salts is an essential management practice in irrigation with saline water. In a leaching program to remove soluble and exchangeable Na from exchange sites, calcium salts are usually used *(USDA Handbook 60)*. During this process not only sodium but also potassium might be displaced and could be lost from the rooting zone.

* Dr. *Sala Feigenbaum*, Agricultural Research Organization, The Volcani Center, P.O.B. 6, Bet Dagan 50250/Israel

Some experiments conducted in semi-arid regions have shown no response to potassium fertilizers. The potassium-supplying power of soils from arid and semi-arid regions is usually so great, that large quantities of K removed by cropping hardly affected the available K fraction *(Cook* and *Hutcheson [1960]).*

Soils in semi-arid regions are slightly weathered and high in potassium-bearing minerals (micas) with a high rate of K release *(Schroeder [1974]).* In loessial soils K supplying power is so large that crop responses to potassium additions are not expected even after many years of intensive cropping *(Feigenbaum* and *Kafkafi [1972]).* In sandy soils with low CEC and low clay content that have been intensively cropped and irrigated with saline waters potassium is expected to decrease. The depletion of potassium from the root zone can be either by exchange and downward leaching by the percolating salts, or by uptake by high K requirement crops like potatoes (300-500 kg K/ha/year).

The objective of this study was to measure the distribution and losses of native and applied potassium fertilizer in a sandy soil exposed to leaching with saline waters.

2. Materials and methods

A sandy soil Quartzipsamment from non K-fertilized plots of a field experiment irrigated with saline water was used to study the donward movement and leaching of potassium in soil columns. Approximately 650 g of soil was packed to a bulk density of 1.65 g/cm^3 into the column (50 mm diameter and 200 mm long) using a long-stemmed powder funnel. Special care was taken to produce a homogeneous soil packing throughout the column, to minimize particle size separation. Filled soil columns were uniformly packed by dropping each column 10 times from a height of two centimeters. The soil columns were saturated with distilled water to displace as much air as possible from the soil pores. Following saturation, a constant height of water was maintained at the surface. Two treatments of K adding with time were carried out, one to non leached soil, the other to preleached soil column with saline solution. Potassium at 3.14 me K per soil column, was added to the surface as a concentrated solution of KCl, equivalent to fertilizer application in the field at the rate of 600 kg K per hectare. The above treatments were selected so that K movement through a finite depth in the column could be observed.

The leaching solution used in the experiment contained a salt mixture of NaCl and $CaCl_2$, at two total concentrations of 5 and 50 me/L with SAR of 1.6 and 5.2 respectively. The flow rate was kept constant at 10 ml/h in all the treatments during the leaching periods. The amounts of solution leached through the column were 280, 560, 840 and 1620 ml, equivalent to 140, 280, 420 and 820 mm surface irrigation. Leachate was collected in 20 ml fractions and its K and Na content determined. At the end of the leaching periods the soil columns were dismantled, and the soil was horizontally sliced into 20 mm increments. Potassium was extracted by ammonium acetate and determined by the standard method. Potassium values were expressed in me/100 g air dried soil and represent the amount of soluble plus exchangeable K in the soil water system.

3. Results and discussion

Potassium concentration in the effluent, leached with the two salt solutions (5 and 50 me/L) for treatments receiving no K are presented in Figure 1.

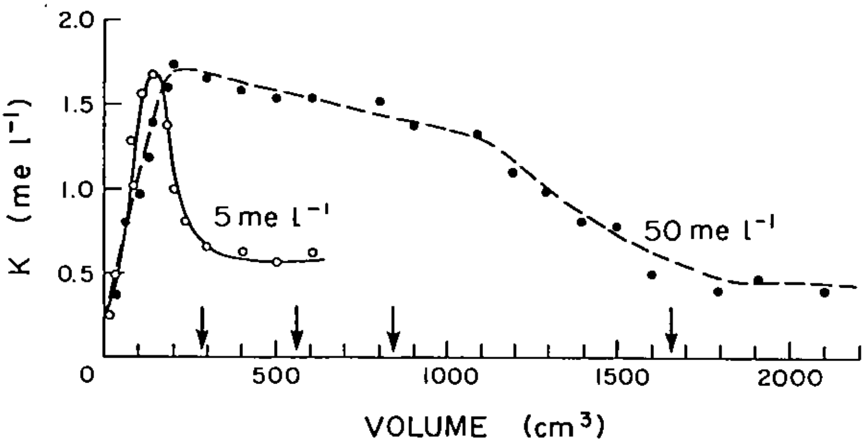

Fig. 1 Potassium concentration in the percolating solution for non treated soil

In both salt solutions the concentration of potassium in the effluent was high, about 1.7 me K/l and decreased with increasing leaching volume until a constant level of K release was obtained. In the treatment containing low salt in the leaching solution, a sharp peak of displaced K could be seen after the first two pore volumes (280 ml) and followed by a sharp drop. A constant K-level (0.6 me K/l) was observed after 400 ml solution had passed through the soil column. In the treatment containing high salt concentration, two rates of K release – slow and fast – were observed with increasing leachin volume. The first, up to 1000 ml and the second up to 1700 ml, respectively. The final rate of K release was found to be 0.4 me/L, and was comparatively lower than the constant K release value found for low salt leaching solution.

The K accumulated in the effluent from columns with applied potassium, after previous leaching are presented in Figure 2. The total amount of potassium removed from the soil columns was 0.8 and 2.18 me K/col. in the low and high salt percolating solutions, respectively. After leaching the soil columns with about 840 ml of low and high salt solutions, 15% and 50% of the applied K was found in the effluent, respectively (Figure 2).

The 840 ml percolating solution assumed to simulate a field irrigated continuously with 420 mm water. It could be assumed that a previously leached sandy soil, with a low cation exchange capacity (5.2 me/100 g) (Table 1), can still hold 50% of the applied potassium even after leaching with a saline water. In field practice where such continuous irrigation rate is seldom applied and there are drying periods between irrigations, a lower leaching efficiency of applied potassium would be expected.

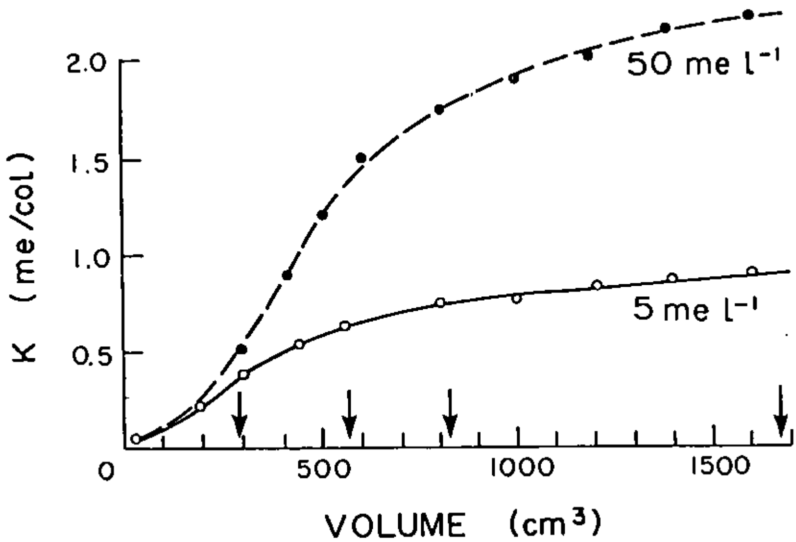

Fig.2 Cumulative amount of leached K as a function of the volume and concentration of the effluent

Table 1 Characteristics of the soil

Depth	Coarse sand	Fine sand (Particle size)	Silt	Clay	pH	$CaCO_3$ %	EC dS m^{-1}	CEC	Exch. K me 100 g^{-1}	Exch.Na
	%									
0- 20	25.7	66.2	3.6	4.5	7.82	3.6	0.94	5.0	0.57	0.20
20- 40	26.0	66.8	3.2	4.0	7.76	3.5	0.85	5.2	0.62	0.22
40- 60	21.1	65.0	6.9	7.0		5.9	0.87	4.9	0.70	
60- 90	15.0	68.0	9.0	8.0		7.2	1.04	5.6	0.83	
90-120	15.5	67.0	8.2	9.3		3.2	1.07	5.8	0.67	

The distribution of K in the soil column, where potassium was applied on the surface before leaching of the columns with the two salt solutions, are presented in Figure 3. After leaching the soil columns with 280 ml solution (equivalent to 140 mm irrigation), the exchangeable K moved only to a depth of about 8 cm for the low perculating salt solutions. In the soil column leached with the higher salinity level (50 me/l) potassium was leached from the surface, increased with depth and then fell to the level of the original exch. K (about 0.6 me/100 g soil). Leaching the columns with 560 ml solution showed the same pattern for the movement of K in the column for the low salt leaching solution, as was found in the 280 ml. Most of K in the profile of soil column, leached with high salt concentration, was found in the bottom. The data suggest movement of applied K to a deeper layer with increasing salt concentrations and amount of the percolating solution. These observations could be explained by the competition between Na and Ca in the leaching solution and the K applied to the soil, or by displacement of the exchangeable K by the added Na and Ca cations.

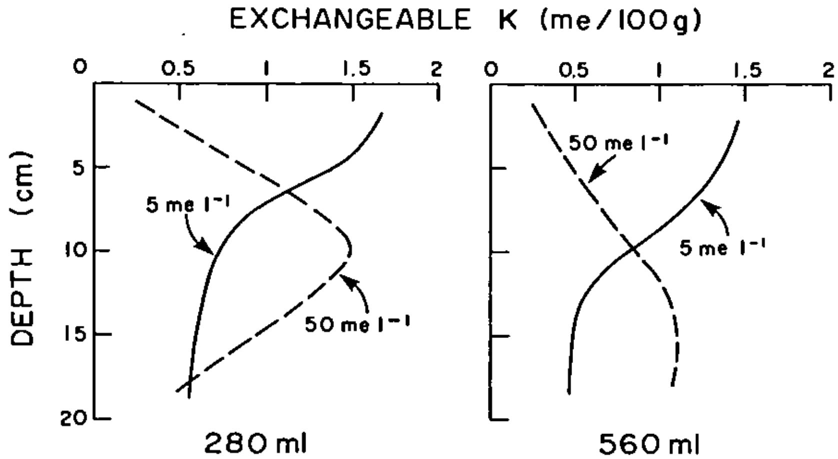

Fig. 3 Downward movement of surface applied potassium in a soil column as related to quality and amount of percolating solution. The lines represent actual results taken every two cm.

The effect of salt concentration and the amount of the percolating solution on K balance are summarized in Table 2. The amount of K in the effluent increased with increasing concentration and amount of the solution percolating through the soil columns (A). Potassium application to the leached and unleached soil affect K exchangeable level in the soil, leached by high salt concentration (B).

Taking into consideration the initial 3.70 and applied 3.14 me K/col. some potassium was unaccounted for after a balance was calculated (C). This suggests that during the continuous leaching with salt mixture some of the added K becomes non-extractable by ammonium acetate. When the column was leached with good quality water (5 me/l mixed salt solution) only a small fraction of K was not accounted for. Increasing concentration of the salt in the percolating solution (50 me/l), resulted in much K being unaccounted for. The volume of the leaching solution had a small effect on this fraction, assuming that fixation of added K could occur in the presence much Na *(Volk [1938])*.

Results of K analysis from a field experiment carried out (by *Meiri et al. [1984]*) on the same soil (as for the columns) and irrigated with three levels of saline water are presented in Table 3. The salinity levels in the water were 1.3, 3.3 and 4.0 dSm/cm. Two months after potassium was applied it was found that exchangeable K decreased slightly with increasing salinity compared within the layers for the two K treatments. The data for soluble K in that field experiment were not consistent, but were taken into consideration for calculating K balance. The distribution of Cl with depth can serve as an indicator of the effective depth of leaching in the field. It is clear that until the data when total irrigation amounted to 280 mm, no leaching beyond that depth could be observed.

Table 2 The effect of salt ($NaCl + CaCl_2$) concentration and the amount of the percolating solution on K-balance.

Treatments				Potassium		
Surface added K	Leaching solutions			Potassium		
	Conc.	Amount**	SAR	In the leachate (A)	In column as exchangeable + soluble (B)	Fixed calculated (C)
me/col.	me/l	ml/column			me/col	
Applied K to the leached soil column						
3.14*	5	280	1.6	0.30	6.05	– 0. 6
3.14	5	560	1.6	0.60	6.10	– 0. 1
3.14*	5	1680	1.6	0.80	5.70	– 0. 6
3.14	50	280	5.2	0.50	4.65	– 0.90
3.14	50	560	5.2	1.30	3.85	– 1.20
3.14	50	1680	5.2	2.20	2.25	– 1.20
Applied K to unleached soil column						
3.14	5	280	1.6	0.35	6.05	– 0.40
3.14	5	560	1.6	0.50	5.93	– 0.35
3.14	50	280	5.2	0.30	5.75	– 0.80
3.14	50	560	5.2	0.80	4.20	– 1.10
3.14	50	1680	5.2	2.18	3.65	– 1.00

* 3.14 me is equal to 600 kg K/ha.
** 140 ml = 1 pore volume. The initial amount of exch. K was 3.70 me/col.

A potassium balance in soil was calculated from the differences between total initial K (soil extractable + applied) and total final K (soil extractable + plant removed K) (Table 4).

Since beyond Cl^- did not move beyond 40 cm, it is hardly expected that applied K will be found in the field below that depth. The unaccounted potassium increased with increasing salinity in the irrigation water. The deficit of K was 4.5, 13.0 and 18% of the applied fertilizer for the three saline waters, respectively. This deficit of K in the root zone was not entirely explained by leaching from that depth (40 cm). If leaching is not the answer, it is suggested that there is K fixation. In the field where soils are subjected to wetting and drying cycles, as well as increase of Na^+ in the soil, losses of potassium by fixation are much more serious than losses by leaching.

The data from both columns and field experiments carried out on the sandy soil suggests that exposure of a soil to leaching with saline and sodic solution affects the process of K fixation.

It is expected, therefore, that in a soil containing clay with high fixing capacity (like vermiculite) the relative K fixation could be more pronounced when brackish water is used for irrigation.

More detailed studies in this direction are needed to clarify the effect of Na^+ salt addition on K^+ fixation.

Table 3 Exchangeable and soluble K and Cl, as affected by potassium fertilization and irrigation with saline water*

	17.2.83		10.4.83					
Potassium rate kg ha^{-1}	K-0	K-30	K-0			K-30		
Salinity level dSw/cm^{-1}	1.3	1.3	1.3	3.3	4.0	1.3	3.3	4.0
Irrigation rate mm	100		180					
Depth cm	Exchangeable K me/100 g soil							
0-20	0.57	0.87	0.46	0.40	0.41	0.64	0.53	0.49
20-40	0.62	0.71	0.55	0.40	0.47	0.63	0.56	0.54
40-60	0.70	0.74	0.66	0.52	0.67	0.60	0.57	0.54
	Soluble K me/100 g soil							
0-20	0.016	0.037	0.016	0.020	0.024	0.036	0.052	0.034
20-40	0.019	0.024	0.021	0.019	0.027	0.030	0.059	0.030
40-60	0.019	0.025	0.027	0.020	0.037	0.031	0.029	0.023
	Soluble Cl me/l							
0-20			12.5	28.4	20.0	13.5	28.5	25.0
20-40			5.1	22.3	13.5	8.6	21.3	10.2
40-60			2.3	3.0	5.5	3.5	6.5	3.6

* These data were taken from a report by *Meiri et al., [1984].*

Table 4 Potassium balance sheet of soil (0-40 cm) irrigated with saline water*

Salinity treatment dSm/m	Initial extr. K	Applied potassium kg/ha	Final extr. K	Potassium removed by plant	Unaccounted K %
1.3	1470	300	1640	49	4.5
3.3	1470	300	1490	49	13.0
4.0	1470	300	1390	52	18.0

* Calculated from the differences between total initial K (soil extractable + applied) and total final K (soil extractable + plant removed K).

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Choice of Cropping Systems in Relation to Water Resources – Effects on Potassium Balances

J.-R. Marty, A. Hilaire and R. Blanchet, I.N.R.A. Research Centre, Agricultural Station, Toulouse/France*

Summary

Data from long-term rotation experiments started in 1969 incorporating irrigation treatments have been used in devising a mathematical model for apportioning crops to the available area and optimising the rotations. The availability of water for spring sown crops is a critical matter. In connection with the model, the fertilizer policy for K is discussed. The policy has been to arrange for some enrichment of the soil in K, adjusting the applications to nutrient removals in crops and with the aim, which has been largely achieved, of avoiding the setting up of differential soil K levels between the treatments tested. The K balance derived from fertilizer applications less crop removals (F – E) is compared with the change in exchangeable soil K levels over the experimental period. Change in exchangeable K does not account for the whole of the K balance and reasons for this are discussed.

Introduction

In today's constantly changing technical and socio-economic environment, the farmer must be prepared to change his policies and is presented with difficult choices. Any change in conditions can outdate current detailed and specialised scientific advice *(C.C.E. [1983])*. For several years cropping systems have been studied against the wide socio-economic environment either via the experimental route or by the collection of farm data and the application of these in modelling *(C.E.E. [1980]; Sebillotte [1982]; Dent et al. [1971])* and progress has accelerated. We were already interested in these problems in 1965 when we embarked on long term experiments comparing different rotations and the effects of irrigation and their implications for fertilizer policies based on the rotation as a whole.

Such an experimental approach is particularly appropriate to sub-Mediterranean conditions where there is a summer water deficit and the moisture reserves available to summer crops play a major role in the choice of cropping system: the ratio of au-

* *J.-R. Marty, A. Hilaire, R. Blanchet,* I.N.R.A., Centre de Recherches de Toulouse, Station d'Agronomie, B.P. 27, F-31326 Castanet-Tolosan/France

tumn-sown to spring-sown crops is a matter of great practical importance. In systems dominated by grain crops except for forage production, there are possibilities in this region for 9 crop species: maize, sorghum, sunflower, soybean, as summer crops and wheat, barley, rapeseed, peas, or beans, autumn sown. Thus, the choice may be a difficult one and, while water availability may be a critical factor, we shall show that it is not always the most important.

To facilitate the choice between different possible cropping systems, we have set up a model to distinguish between cultural systems in relation to various biological, agronomic, technical and economic constraints. The simulations are based on results from long-term experiments using techniques best suited to crop and rotation and with particular attention to fertilizer usage directed to obtaining satisfactory and stable yields and the maintenance or improvement of soil fertility while minimising costs of cropping. It is important that fertilization should not be a limiting factor in the basic data used in modelling the optimisation of cropping systems, neither should it result in running down soil fertility which would render the results obtained unsuitable for practical application. Such a limitation applies whatever may be the water resources or pedo-climatic conditions (soil water reserve + rain available to summer crops) or whether or not irrigation is available. Thus, potassium fertilization has been adjusted to the needs of individual crops, and the yields obtained, and the rotation as a whole in the manner described below.

This paper is divided into three parts: in the first we describe the modelling of cropping systems with examples of results for the apportionment of crops and rotations; in the second, we examine the consequences for the potassium balance in chosen examples; though they are quite distinct, the two approaches interact. Finally we discuss the problem as a whole.

1. The choice of rotation

1.1 Description of the model

The procedure used to select the apportionment of crops and the rotations to be followed for optimum exploitation of the environment and available resources is briefly described *(Marty and coll. [1984; 1986])*.

We have used a series of results from an experiment comparing different rotations at the *INRA Agricultural Station*, Toulouse. Other results obtained at different sites and on different soil types have also been included: they originate from surveys by the *Midi-Pyrénées Chamber of Agriculture (C.R.A.M.P.)* the Management Company of the *Coteaux de Gascogne (C.A.C.G.)* the *Interdisciplinary Technical Centre of Metropolitan Oilseed Producers (C.E.T.I.O.M.)* and the *Technical Institute for Cereals and Forages (I.T.C.F.)*. These results were card-indexed according to soil type and water resources, crop and rotation, cultural methods, inputs used including fertilizers, average yields and their variability. Each record can be considered as a «production level» related to a sub-system «rotation». Starting from these technical and agronomic data, the cropping systems are optimised by linear programming in relation to the various constraints, the criterion for comparison being the gross margin, that is: gross income from crop produce less variable costs of production.

1.2 Identification of constraints

1.2.1 Soil-climate constraints

Under our conditions the chief of these is water deficit which is a limiting factor for yield of summer crops: maize, sunflower, sorghum and soya. The water available during growth and development of these crops may come from soil reserves, varying with the nature of the soil profile, and the depth of root exploration or from rainfall or possibly from irrigation as dictated by the size of water resources. A statistical relationship between yield and water consumption has been established (Figure 1A) and we can show that, if we include economic parameters (Figures 1B & 1C) – price ratios between crop product and production costs, the response to water by the four crops is much modified. In the simulation calculations we have used 3 levels of water consumption corresponding to 3 sets of soil-climate conditions (270 mm on shallow soils with low summer rainfall, 350 mm on soils of medium depth and mean summer rainfall of 170 mm and 420 mm on deep soils with 220 mm summer rainfall).

According to the availability of water in the summer, the inclusion of summer crops may be decisive for the profitability of the rotation taking account of their cost/price ratios in relation to those of other possible crops.

1.2.2 Agronomic constraints

Under this heading we consider response by the various crops to fertilizer nutrients (N, P, K) including direct and residual effects.

The wide range of results available has enabled us to set up levels for the absence of response to the various nutrients *(Bosc [1976]; Decau [1970, 1973]; Hilaire [1980])*. Using these results it was possible to draw up a fertilizer policy, principally for P and K, which would avoid yield limitation on these soils. So far as K is concerned, this will be explained in Section 2.

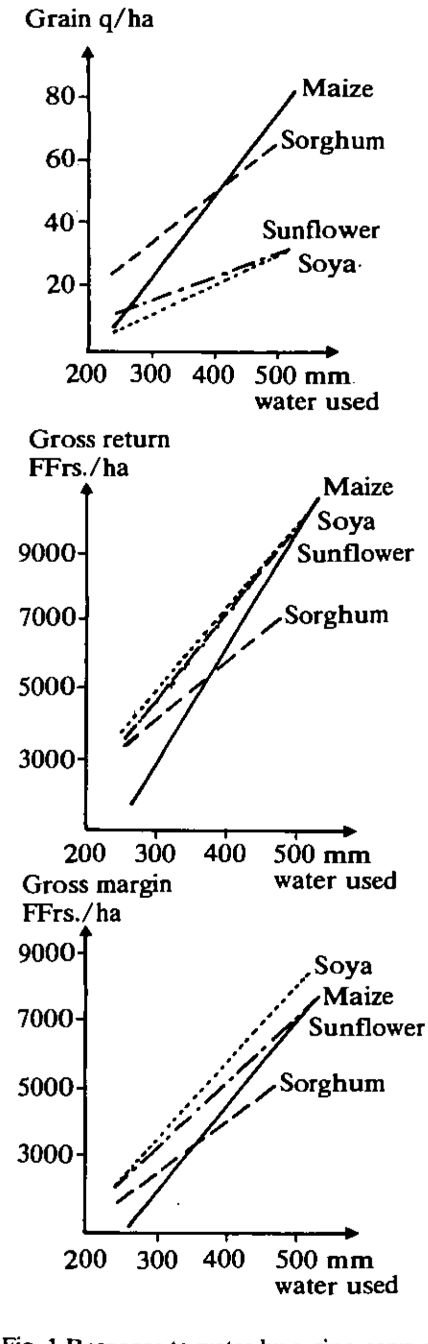
In the experiment comparing different rotations, we have been able to evaluate the effects of preceding crops on yields and production costs of the following crops and the possible ill-effects of certain rotations *(e.g.* maize monoculture) on them. Similarly, recommendations of technical bodies *(C.E.T.I.O.M., I.T.C.F.)* on the too close succession of oilseed crops and legumes in the rotations have been included in the model. For example: the yield of winter wheat is dependent on previous crop and the costs are different *(Marty* and *Hilaire [1979])*.

Structural and water-holding properties of soils (excessive wetness in winter, capping, bearing capacity can adversely affect planting and growth of some winter crops (rapeseed, peas, beans) as is the case on our poorly drained alluvial silts (boulbènes) and thus limit the range of suitable rotations. These have consequences for yield, production costs and the feasibility of rotations.

1.2.3 Constraints on cultural operations

These are related both to:

- the succession of necessary field operations dictated by crop and rotation which define the working calendar;



A Dry grain yield related to water consumed or available

B Gross return (yield × price related to water consumed or available (1984 prices)

C Gross margin (FFrs./ha) (gross return – variable costs) in function of water consumed or available (1984 prices)

Fig. 1 Response to water by spring sown crops

- the number of days available for essential operations depending on soil properties and vagaries of the climate (rain, wind);
- competition for available time between different fields of the rotation.

The long-term investigation which has, for the clay-loam soils, covered a dozen typical rotations including the 9 main crops has established working programmes for the most frequently required operations (8 years out of 10) the days available and the corresponding yield levels and their variability. Similar data are available for other conditions on silts *(C.A.G.G.)*.

These reference data have been updated in recent years to take account advances in plant-breeding and cultural practices.

1.2.4 Socio-economic constraints

These comprise mainly level of equipment, availability of labour, produce prices, input costs and, finally, farm structure.

As a result of farm surveys *(C.A.G.G., C.R.A.M.P.)* and adopting as standard a family holding of 40-60 ha, we have set up two hypothetical levels for equipment and for availability of labour using a working day of 8-12 hours according to circumstances:

- the availability of equipment affects the time needed to complete the various operations;
- high or low availability of labour for carrying out the operations.

The combination of the two, equipment and labour, gives a range of possibilities for satisfying peak requirements and these are of dominant importance in establishing the feasibility of cropping systems.

The final criterion upon which choice of system is based is the gross margin attained and the model includes produce and input prices which can be updated whenever the model is used.

1.3 Operation of the model

The data on soil, climate, technique, production and prices are stored in a data bank with the help of our biometrician colleagues *(Kaan, Rellier [1980])*. Taking into account the above constraints, linear programming will then indicate the optimum rotations *(Boussard [1980])* by maximising the gross margin per hectare *(Foulhouze and coll. [1981])*.

The model used which, on account of the numerous constraints, is of large dimensions, is based on 6 distinct situations: 2 soil types × 3 levels of water availability. The results cover a wide range of rotations which are technically and agronomically feasible and economically profitable representing 336 possibilities for each soil type. The procedure is outlined in Figure 2.

We thus have at our disposal a method which will indicate the cropping system which is best suited to local soil and climatic conditions and to the farm resources and which takes into account the economic environment and changing conditions.

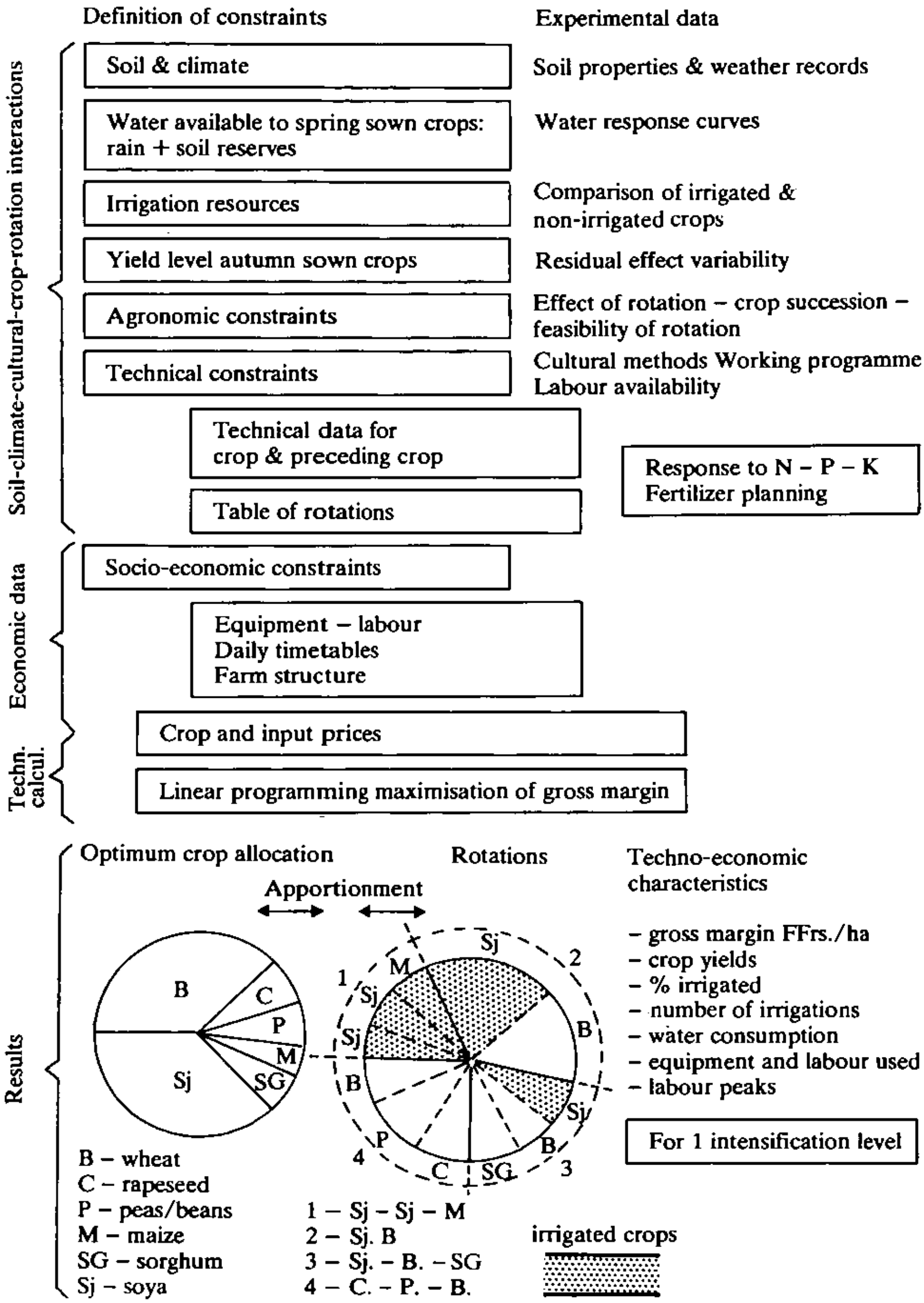


Fig. 2 Outline of model for optimisation of crop allocation

1. Example No. 1: Irrigated cereal system

Constraints
soil: clay-loam average depth
water available for spring sown crops: 350 mm
irrigation available: 1500 m^3/yr
low level of equipment (capital F1000/ha)
labour available: 21 hours ha/yr

Allocation: % cropped area

Rotations	% cropped area
Sg – B –	38%
M – B --- 0 ---	48%
M – M	14%

irrigated crops M, Sg	49%
autumn sown crops B, O	51%

irrigation used – 970 m^3/ha cropped
annual K_2O app'd: 87 kg/cropped ha.
annual N app'd: 170 kg/cropped ha.

2. Example No. 2: Non-irrigated system with oilseeds-legumes

Constraints
soil: shallow clay-loam
water available for spring sown crops (natural sources): 270 mm,
available irrigation: 0
low level of equipment (capital F1000/ha)
low labour availability: 21 m.d./ha/yr.

Allocation: % cropped area

T.Sj.B.C.	20%
C.B.P.B.	12%
M.B.	12%
C.F.B.	56%

irrigated crops:	0
autumn sown crops:	B.C.P.F. (84%)
irrigation used:	0
annual K_2O app'd:	107 kg/cropped ha
annual N app'd:	80 kg/cropped ha

B = wheat; 0 = barley; C = rapeseed; T = sunflower; P = peas; F = beans; M = maize; Sj = soya; Sg = sorghum

Fig. 3 Examples of optimised crop allocations (1984 prices)

1.4 An example

In Figure 3 two examples, selected from results discussed elsewhere *(Marty and coll. [1984]; Marty and coll. [1985])* of optimum rotations are given. Note the effects of differences in water resources originating from soil reserves, rainfall and the provision of irrigation. The ratio between autumn sown and spring sown crops is greatly altered; without irrigation and when natural water resources are limited, the proportion of autumn sown crops is as high as 84% and, most notably, with a high proportion (56%) of oilseed crops.

2. The behaviour of potassium in some rotations used from 1969 to 1982

From our accumulated case studies, we have selected 5 systems which are included in our long-term experiment in order to study the agronomic consequences of our potassium fertilizer policy.

2.1 The soils of the experiment

These are deep alluvial brown soils, more or less well developed, of clay-loam texture, neutral or slightly calcareous (terreforts, typical of the molassic slopes of the eocene, oligocene and miocene of South-Western France).

The whole experiment occupies 12 ha with 92 plots without and 92 plots with irrigation. There is some plot-to-plot variation in physico-chemical soil characteristics. Thus the mean clay content of the non-irrigated area is 26.3% ± 3.2 and that of the irrigated area 26.7 ± 4.1. The clay mineral composition has been investigated (Table 1, *(Blanchet and coll. [1966])*. The soils are relatively high in clay showing the usual physical properties (plasticity, swelling and shrinking). They contain large reserves of potassium but the availability of this to the more demanding crops (oilseeds) is not all that high. Our potassium fertilizer regime was based on early work on the dynamics of P and K.

Table 1 Clay characteristics of experimental soil

CEC me/clay	Specific surface m_2/g clay	% of clay		K_2O fixation capacity % clay	Clay minerals %		
		MgO	K_2O		Kaolinite	Illite	Expanded minerals*
0.58	330	2.55	3.37	1.37	10	35	35

* Interstratified illite – montmorillonite. Very little vermiculite

2.2 Fertilization in relation to rotation and irrigation

Before planting the first crops in 1969, we applied 420 and 210 kg/ha K_2O to irrigated and non-irrigated areas, respectively. Following this, up to 1982 we opted for slight K enrichment by applying 1.2 times the amount of K removed by crops with an allowance for losses estimated at 20 kg/ha/yr K_2O. In 1973, realising the high K demand by the oilseed crops and legumes, we applied further supplementary dressings of 150 and 250 kg/ha K_2O according as to whether or not the rotations included oilseeds *(Blanchet and coll. [1973])*. Our idea was to avoid introducing differences in K status between the plots, caused by the differing crop uptakes. In effect, between 1969 and 1982, all plots have been enriched in K by 2 to 2.3 times crop K removals. These are the values which have been used in the optimisation model presented above and which have been used in calculation of fertilizer costs. *(Marty and coll. [1983])*.

2.2.1 Changes in exchangeable K content

The 5 selected rotations are:

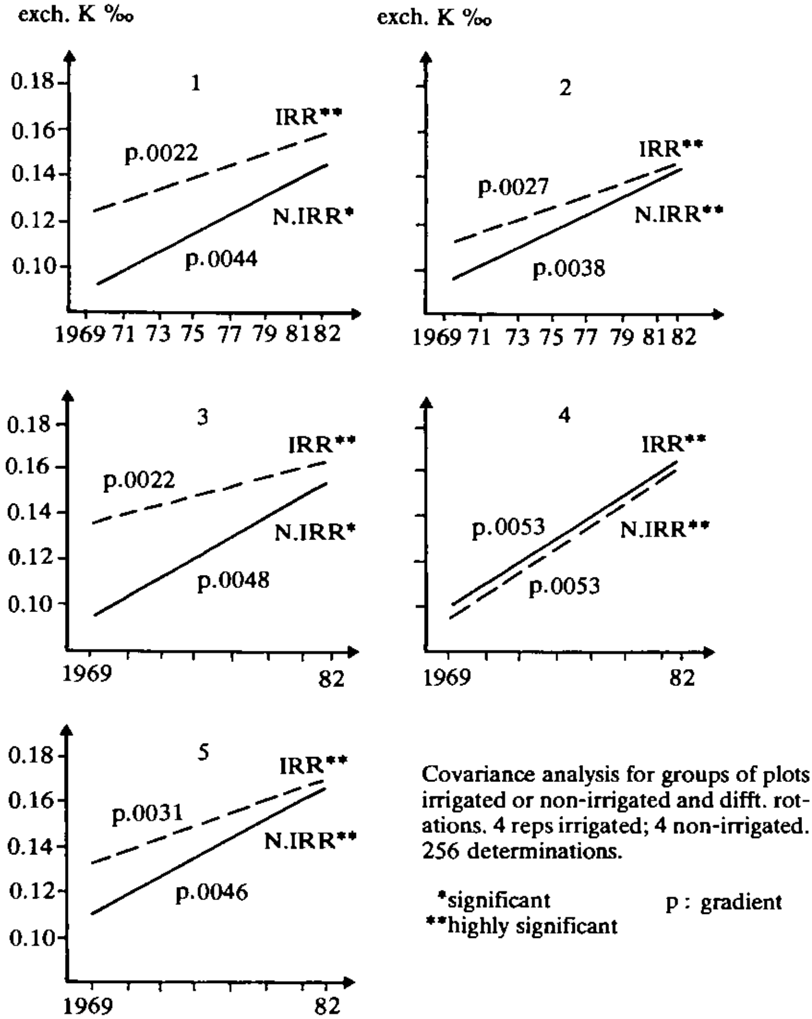
1. Maize monoculture.
2. Maize – wheat.
3. Sorghum – wheat.
4. Rapeseed – wheat – peas – wheat (with irrigated catch-crop of soya after rape and peas on irrigated plots).
5. Sunflower – soya – wheat – rapeseed (with irrigated soya catch-crop after rape on irrigated plots).

Soil analysis was done every other year from 1969 to 1981 and again in 1982. All samples were taken in autumn after harvest and before cultivation. Crop residues were ploughed in after crushing.

Exchangeable K_2O is plotted against time in Figure 4 for the 5 rotations irrigated and non-irrigated. The values plotted are the outcome of covariance analysis* and are means for the sets of plots corresponding to rotations and irrigation treatments. The enrichment over the period is significant in all cases and highly significant in 8 out of 10 cases. The difference in enrichment between irrigated and non-irrigated in 1969 is significant in 4 out of 5 rotations.

Thus, the fertilizer policy has achieved its objective; there is similar enrichment whatever the rotation, and the initial difference between irrigated and non-irrigated has lessened progressively. However, the K removals and the K additions differ considerably between the rotations. The utility of exchangeable K determinations to reflect the K balance is limited *(Bosc [1985; Quémener [1984])* especially if samples are taken to 30 cm only *(Blanchet and coll. [1974])*. We shall therefore examine the balance by other means.

* Non-orthogonal multivariate analysis – programme *CONOR*.



Covariance analysis for groups of plots irrigated or non-irrigated and difft. rotations. 4 reps irrigated; 4 non-irrigated. 256 determinations.

*significant　　p : gradient
**highly significant

Rotations: 1 = (M) × 12; 2 = (M.B.) × 6; 3 = (S.B.) × 6
4 = (C + cd. B. P. + cd. B) × 3
5 = (T. Sj. B. C. + cd.) × 3

M = maize; B = wheat; S = sorghum; C = rapeseed
P = peas; S = soya; T = sunflower;
cd. = soya catchcrop only in irrigated systems

Fig. 4 Change in exchangeable K content under different irrigated and non-irrigated systems (0-30 cm layer)

2.2.2 K balance for different rotations 1969-1982

Total K uptakes* over 12 years (Figure 5.1) or removed in crops (Figure 5.2) are always higher under irrigation. However the former are less differentiated than the latter. Both increase with increasing proportion of oilseeds and legumes in the rotation and with intensification of the system. They are relatively small in cereal systems (rotation 1,2 and 3) much larger when oilseeds and irrigated catch crops are included (rotations 4 and 5).

Consideration of K fertilizer policy suited to each rotation meant that the amounts applied differed considerably (Figure 5.3). This has resulted in the same value for K application – K removal for all the rotations whether or not irrigated (Figure 5.4) amounting to between 650 and 800 kg/ha K_2O in 12 years.

2.2.3 Relationship of enrichment in exchangeable K to K balance (F-E)

The percentage enrichment given by the ratio: $100 \cdot \Delta K_2O$ exch. 0-30 cm/(F-E) (Figure 5.5) is larger without (37-45) than with irrigation (22-35). Thus only a fraction of the K enrichment is reflected in soil analysis, less in the irrigated systems. This can be partly explained by the effects of irrigation cycles on clay mineral swelling and contraction *(Blanchet and coll. [1972])*. Again the analysis refers only to the top 30 cm of soil which is insufficient to account for the whole balance as nutrient and water uptake takes place through the whole profile, which, under our conditions extends to 1.5 m and sometimes more. Further, with irrigation, in years when irrigation is used, K uptake by crops is increased, the main source being the surface soil enriched by fertilization. This layer, being kept moist, is the site of root proliferation and more active uptake. In the absence of irrigation, a large part of K uptake (20-24% according to year) is from deeper layers, while fertilizer and crop residue K is confined to the surface *(Blanchet and coll. [1973])*. Further we have to account for K transferred to depth in drainage which is more dependant upon the rotation than on irrigation *(Puech and coll. [1978])* though this is relatively slight in silty clay soils. Again, the first analysis made a few months after the initial heavy K application to all plots accounted for only 38 % of the difference between irrigated and non-irrigated areas (420 *vs.* 210 kg/ha K_2O) as is indicated in Table 2. Such a result is quite usual, taking account of clay mineral composition.

Table 2 Mean exchangeable K_2O content after initial application of 210 or 420 kg/ha K_2O in 1969

No. of plots	K_2O applied kg/ha	Exch. K_2O	
		‰	kg/ha
92	210	0.155	674
92	420	0.173	753
Diff. of K_2O enrichment:	210	0.018**	79

F: 9.0** highly significant

* K_2O in above-ground biomass at harvest.

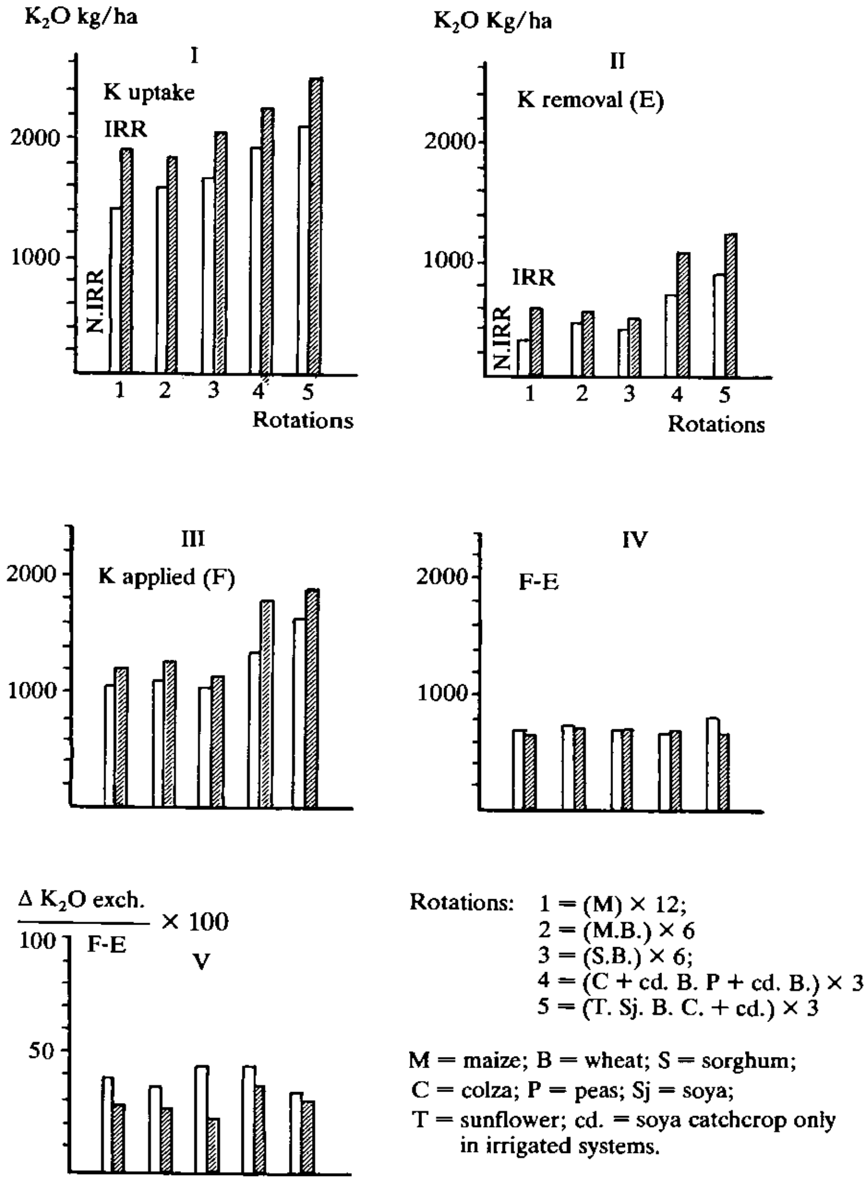


Fig. 5 K_2O balances for various rotations over period 1969-1982 and enrichment of soil exchangeable K_2O as a percentage of F-E

3. Optimum cropping systems and costs of potassium fertilization

We have chosen some examples (Table 3) to demonstrate the part played by fertilization, and notably that with potassium, in the costs. Thus while in irrigated cereal systems, the cost of potassium fertilizer amounts to only 4% of variable costs, it attains 10% in non-irrigated systems with oilseeds. In all cases the cost of potassium applications is less than or equal to costs for N and P. For these reasons, on soils already well supplied with potassium and where K liberation is high, K fertilizer policy looms less importantly than that of N, especially in systems dominated by cereals (the same applies to P). This is even more the case with irrigation, where fertilizer costs in relation to total variable costs are proportionately less and fertilizing with potassium, notably on clay soils tends to be overlooked.

Table 3 Fertilizer costs as percent of total variable costs

Crops under rotation	%	% of variable costs		
		N	P_2O_5	K_2O
1) Systems with irrigation				
(incl. of irrigation cost)				
Wheat	40	12	10	4
Maize	60			
Soya	38			
Sorghum G	10			
		7	14	7
Sunflower	6			
Peas/beans	12			
Wheat	30			
2) Systems without irrigation				
Wheat	33			
Barley	33	19	15	7
Rapeseed	33			
Wheat	30			
Sorghum G	10			
Rapeseed	9	12	21	10
Peas/beans	9			
Soya	42			

Fertilizer cost in FFrs./kg: N 4.9; P_2O_5 5.1; K_2O 2.1

The rationalisation of fertilizer programmes is all the more important in systems which include crops more K demanding than cereals. Thus potassium fertilization accounts for a greater proportion of total fertilizer costs as oilseeds in the rotation increase, though total fertilizer cost is not increased; it decreases as the proportion of legumes increases through economy in N fertilizer.

These examples from very different systems show that change from one to another system does not necessarily result in savings in fertilizer but that adjustment of fertilizer policy should result in better division of costs between N, P and K fertilizers by adapting the regime to the cropping system.

4. Discussion and conclusion

We have shown that the choice of cropping system involves a global approach taking notice of biological, agronomic, technical and economic factors. While the availability of water for spring sown crops is a dominant factor, there are other constraints which will modify its importance: price ratios between produce, inputs and charges for equipment. In order to optimise systems in relation to these numerous constraints two approaches have been used: field experimentation and farming surveys.

The experiment comparing irrigated and non-irrigated rotations over the period 1969-1982 has provided data for use in modelling. The reliability of these data depends largely on the care given to consideration of technical methods adapted to crops and rotations. They should at the same time accurately reflect practical farming conditions and take account of the most recent scientific knowledge.

As concerns P and K fertilization, it is essential in this type of experimentation to ensure that fertilizer applications will conserve or improve nutrient status equally on plots under different treatments in accordance with nutrient requirements and removals. Fertilizer planning is related to the other techniques used and to the type of rotation. It is based on comprehensive investigation to lead to better understanding of the mechanisms involved so as to enable extrapolation to a wider set of conditions.

We have started on another overall approach based on as detailed as possible description of all phenomena involved and applied not to the rotation but on a field to field basis. This is based on a model differing from that we have described here which can simulate growth and production of several crop species in relation to various cultural factors (cultivation, fertilization, irrigation) to describe plant-soil interactions with the aim of simulating a succession of crops and the eventual effects on the soils. In 1984, using this type of model, we began collaboration with a group of workers in the USA *(U.S.D.A.-A.R.S.-Temple,* Texas) *(Williams et al. [1984]: Erosion productivity impact calculator),* adapting it to our conditions. Some provisional results have been obtained *(Charpenteau et al. [1986]; Cabelguenne et al. [1986])* and we hope that this model will soon be able to simulate non-experimental conditions and be of use in the making of decisions in the practical field. We shall thus be able to integrate fertilization with all the other techniques to simulate the development of production, crop requirements, and yield, taking account of soil-climate conditions. In addition, the development of soil physical, chemical and hydrological characteristics is simulated and it is possible to envisage the corrections to be applied and eventually to be able to eliminate errors in fertilization and irrigation.

We shall have predictive models based on an overall approach and integrating a number of parameters upon which to base the choise of system suited to a particular locality or to manage the crop rotation on a field basis. Standardisation of such models must be based on experimental data whose reliability and applicability are assured.

In the matter of potassium fertilization, we have shown that rational application from the outset of the experiment has resulted in the realisation of similar soil K status under all rotations. Measurement of exchangeable K content, while it does not exactly equate with the K balance does reflect the course of change. It is adequate for monitoring the K status of plots provided the samples are taken often enough (every 2 or 3 years) and taken at the same time of year and in the same conditions. It is thus a valuable indicator of soil fertility.

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K-displacement within Orchard Soils and its Impact on the Nutrition of Fruit Trees

P. Delver, Research Station for Fruit Growing, Wilhelminadorp/The Netherlands*

Summary

For over ten years, K dressings in Dutch orchards have been on a low, often marginal level. This restrictive fertilizer policy is partly based on considerations concerning possible adverse effects of high K dressings upon storage disorders such as bitter pit and breakdown in apple. On the other hand leaf analysis has shown that the grass strip system with chemical weed control and mulching of grass on the tree strips is highly efficient in making soil-K available to the trees. This system is currently used in at least 85% of all fruit plantings. The wholesale shift to grass strips, since the introduction of herbicides in the sixties resulted in a general increase both in K contents of leaves and fruits and in losses due to bitter pit and breakdown. Therefore, K dynamics in orchard soils, particularly as affected by the grass strip system, have been studied in several field and pot experiments. Omission of tillage for weed control and, to a lesser extent, displacement of K by mulching grass cuttings on the herbicide strips are responsible for the generally high K content of fruit crops. The vertical and horizontal displacement of K as affected by uptake by the grass and the mode of mulching, the concomitant accumulation in herbicide strips and depletion in grass strips, and their effect on the fruit tree are demonstrated in a number of case studies.

Introduction

Until about 1965, fruit growers in The Netherlands practised various soil management systems. In newly planted orchards weed control was done by shallow tillage, sometimes combined with green manure or catch crops in the alleys. Heavy, moist soils were usually grassed down after the trees had become productive. The sward was mown several times a year, but competition for moisture and nitrogen often caused poor growth and nitrogen deficiency. On dry soils, mechanical weed control, either on the entire orchard area or along the trees only, was maintained during the whole life-span of the orchard to avoid competitive effects. In the alleys, green manure crops were temporarily grown and sometimes even grass strips were tried for the sake of better trafficability. Crop protection and other activities increasingly required good

* Dr. *P. Delver*, Research Station for Fruit Growing, Brugstraat 51 NL-4475 AN Wilhelminadorp/The Netherlands.

accessibility. Besides, many orchards are situated on clay soils, susceptible to puddling, and picking of late apple cultivars suitable for storage increasingly involved fruit transport under wet soil conditions.

Initially, the grass strip system was found too laborious because it involved both frequent mowing and mechanical weed control. Moreover, rototilling or disk-harrowing prevented root development in the upper 5-8 cm and carried with it a risk of damage to the stem and lower branches. Therefore it was discontinued after summer rains had sufficiently moistened the soil.

From about 1960 onward, the availability of herbicides induced growers to change over completely to the grass strip system because, besides good trafficability, it offered several advantages such as low operating costs and reduced competition for moisture resulting in a somewhat higher productivity compared with tillage. Also, the risk of spring frost damage was reduced compared with other systems. Currently, grass strips are found in at least 85% of all orchards.

The new system appeared to have disadvantages too. In the light of experience, some growers suggested that losses due to bitter pit and breakdown in stored apples had increased since they used herbicides. K contents of leaves turned out to be relatively high and soil samples from herbicide strips had higher K contents than samples from grass strips *(Hidding* and *Das [1968])*. Since a high K status of the crop tends to increase susceptibility to bitter pit (Figure 1) and breakdown, it was decided to confine soil sampling in orchards to herbicide strips only *(Hidding [1968])*. Also, recommended K dressings based on level of soil-K were lowered. This ultimately resulted in considerably reduced potassium consumption in orchards. Inquiries amongst growers conducted by the *C.B.S*[1]. and the *L.E.I.*[2] showed that in 1963 average annual dressings amounted to some 140 kg K_2O per ha; this amount varied considerably with soil texture; for instance, an average of 51 kg K_2O was calculated for sandy loams and 293 kg K_2O for heavy silty clay soils (data compiled by the author). In 1980 the overall average calculated from the inquiries was only 48 kg K_2O per ha and this low consumption has probably remained the same for some 10 years or more. In productive orchards, annual removal in fruits is estimated at 35-70 kg K_2O and leaching losses at 5-60 kg K_2O per ha *(Delver [1986])*, hence in many orchards K-nutrition is at the expense of the K-level in the soil. Considering the current appearance of K deficiency symptoms, it is expected that fruit growers will increasingly be faced with unfavourable consequences of a marginal K supply such as too small fruit size, particularly in years of heavy bearing (Figure 1), K deficiency on soils with a poor structure, and a loss of flavour in long-stored fruits due to too low content. Frequent checking of the K status by means of leaf analysis therefore seems necessary.

In view of the importance of well-balanced K nutrition the effect of the herbicide strip system on the dynamics and displacement of potassium in the soil and on the nutrition of the tree has received ample attention in pot and field experiments. Of course, the effects of K on the tree cannot fully be separated from those of other nutrients present in the mulch. Some of the experimental findings from a number of case studies are reported here.

[1] *Central Bureau of Statistics*
[2] *Institute of Agricultural Economics*

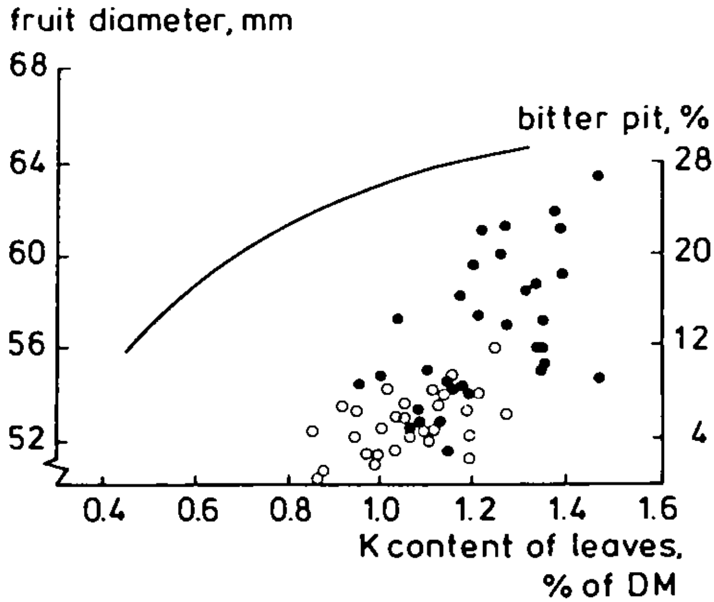

Figure 1 Relationship between fruit diameter (—), percentage of bitter pit after storage (o,●) and K contents in the leaf of Cox's Orange Pippin apples. Grass strip system with mulching on weed-free strips either rototilled (o) or treated with herbicides without tillage (●).
Experiment Oosthuizen, 1971.

The herbicide strip system

Fruit trees are usually planted in single rows, 3-4 m apart, and spaced 1-2 m in the row. In some cases double rows, three rows or beds are planted. The effect of mulching under the trees is then absent or confined to the border rows. Soon after planting a grass mixture is sown in the alleyways to form a firm sward 1.6-2.0 m wide covering about 50% of the orchard area. Several growers do not sow grass but let weeds develop into a natural, rather weak but less competitive sward in which after frequent mowing annual meadow grass *(Poa annua)* may dominate. Main species used for orchard grass mixtures are smooth-stalked meadow grass *(Poa pratensis)*, timothy *(Phleum pratense)*, meadow fescue *(Festuca pratensis)* and perennial ryegrass *(Lolium perenne)*.

White clover *(Trifolium repens)* is sometimes added. The grass strip is mown 10-14 times a year with a rotary mower. In this way $^2/_3$-$^3/_4$ of the cuttings is thrown onto the herbicide strip as a mulch. Depending on the botanical composition of the sward, level of nitrogen fertilization, exposure, weather and soil moisture conditions, the quantity of dry matter in the grass cuttings may range from 1500-7000 kg per ha of grass strip area. The cuttings may then contain 50-250 kg K_2O, so about 35-190 kg

K_2O per ha is placed on the herbicide-treated area annually, assuming that grass and tree strips are about equally wide *(Delver [1973])*. Under moist conditions the young protein-rich grass decomposes rapidly, producing an almost constant flow of readily available potassium and other minerals. The mulch contributes but little to the build-up of stable organic matter, but there is a marked effect on the vertical distribution of chemical and physical soil fertility properties. Even worm life is noticeably activated *(Poppenk [1975])*.

Mulch under the trees in April-May, however, increases the risk of spring frost damage. Therefore, and also for the purpose of limiting the potassium effect of the mulch, some growers leave the grass on the alleys by using an adapted rotary mower. Sometimes even a specially designed rotating «tree strip brush» is used to remove leaves, grass and prunings from the herbicide strips. In this case, where mulching takes place on the frequently mown grass strips, the recycling of minerals released, in particular of nitrogen, results in an extra grass (DM) production of 40-25%, depending on the quantity of nitrogen applied *(Delver [1973])*. In that case there is no question of horizontal displacement of potassium onto the tree strip.

The soils in the grass strip and in the herbicide strip represent widely different substrates for root development. Because of the soils' better structure, higher moisture content, proximity to the tree and possibly better aeration, tree roots are concentrated in the herbicide strip, as is shown in Figure 2. Judging from several root studies, an estimated 60-70% of all fine roots are in the herbicide strip. The uppermost layer of this soil is of paramount importance for the nutrition of the tree, not only because some 12-20% of all fine roots are in the 0-10 cm topsoil, but also because this layer is undisturbed, has a good structure, is relatively high in potassium, other minerals and organic matter, and availability of nutrients in this bare strip is often promoted by summer rains.

Displacement of potassium

The distribution of potassium over herbicide strips and grass alleys is reported in the following two case studies

1. Experiment on newly reclaimed IJsselmeer lake-bottom clay soil with various groundwater regimes and nitrogen dressings

The polder East Flevoland was reclaimed from the IJsselmeer (former Zuyder sea) in 1957. In 1964, an experiment was started in which various constant groundwater levels between 40 and 130 cm were established by means of drainage and infiltration. The groundwater plots were split up into subplots with three levels of annual nitrogen dressings. Apple trees were planted in 1965 and in the same year grass strips, a mixture of meadow fescue and thimothy, were sown. Throughout the experimental years the grass cuttings were mulched on the herbicide-treated tree strips (50% of the orchard area). The experiment was conducted by the «Rijksdienst voor de IJsselmeerpolders», until 1976 under the scientific supervision of *Visser [1983])*, and was continued as from 1977 for another 4 years by the author *(Delver [1986])*.

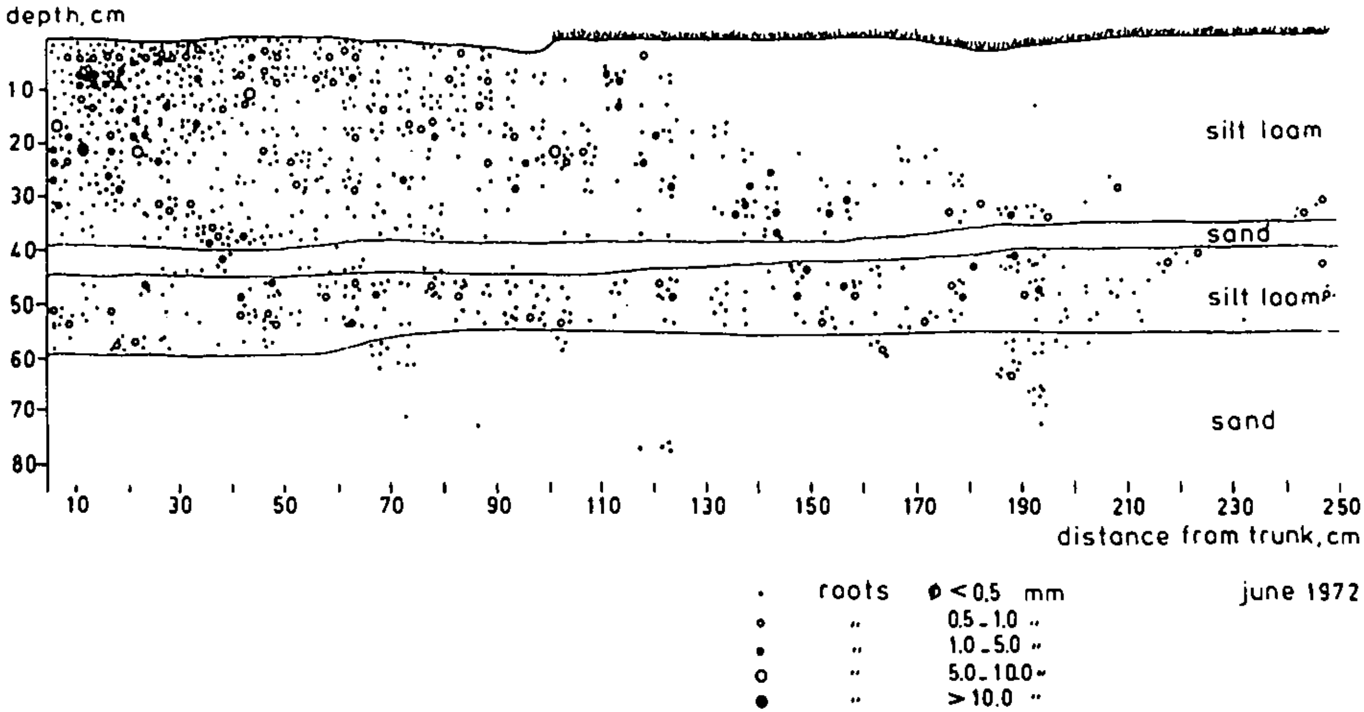

Figure 2 Root distribution of a 9 year-old Conference pear on Quince A transversely across the tree row in a grass strip orchard on a marine siltloam with a shallow root zone, underlain by a sandy subsoil.

In 1977, 12 years after commencement of the treatments, samples were collected from successive soil layers to a depth of 60 cm both in the grass alleys and in the herbicide strips. Figures 3-5 give examples of the K-distribution in relation to the groundwater levels and two nitrogen levels. The plots received no potassium fertilizer. It should be noted that the K-contents reflect not only the displacement of K due to mulching, but also differences in quantity and depth of K taken up by the grass and the tree and possibly even the effect of K released from leaves dropped from the tree.

Figure 3a demonstrates that on well-drained plots the greater depletion of potassium in the alleys resulting from increased grass production due to N fertilization was evident to a depth of at least 60 cm. Although the grass cuttings were mulched on the herbicide strips and roots were removed from the samples, the sod layer (0-5 cm) apparently still had a relatively high K content, whereas the depletion was strongest in the densely rooted 5-20 cm layer. The effect of mulching with the larger amounts of grass cuttings from the 150 kg N-plots was reflected in higher K contents in the herbicide strips (b), again to a considerable depth. Root studies by *Visser [1983]*, have shown that the roots extended deeply into both strips in the «130 cm» plots.

A somewhat more complicated relationship appears when plots with widely different water tables are compared. Figure 4a shows that, although equally high quantities of nitrogen were applied, the uptake of K in the grass strips of the 40 cm plots lagged far behind K uptake in the 130 cm plots, at least in layers deeper than 10 cm. Apparently this was compensated for by greater uptake from the topsoil in the 40 cm water table plots where only grass roots were present. Due to the high water table, grass production on the 40 cm plots was very poor and in root studies in 1976 *Visser [1983]* found no tree roots under the grass, in contrast to the better drained plots. Also, as a consequence of traffic movement the wet soil in the alleys of the 40 cm plots was compacted and aeration was very poor. In the undisturbed soil of the herbicide strips, however, soil structure was much better and rooting of the trees, although limited to somewhat less than 40 cm, was very dense. Due to far smaller quantities of mulch and more K uptake by the denser root system, K-contents to a depth of 40 cm in the herbicide strips (Figure 4b) were lower in plots with the 40 cm water table compared with the 130 cm water table. However, in the 40-60 cm layer K-contents were highest in the 40 cm groundwater plots due to the absence of roots and uptake.

Figure 5 shows the K-distribution in plots with a constant high groundwater level as related to level of N. Due to absence of roots and lack of uptake below groundwater level there was no difference in K-content below 40 cm between tree strips and grass strips, irrespective of N level. When no nitrogen was given (Figure 5a) and consequently grass production was very poor, the effect of mulching on soil-K in the herbicide strip was only noticeable as a small positive difference in K in the 0-5 cm layer. The considerably lower K-content at 10-40 cm in the herbicide strip probably resulted from relatively high K-uptake by the dense tree root system in contrast to the same but compacted layer in the alley where the grass was far less able to take up potassium. The increase in grass production brought about by annual dressings of 150 kg N per ha (Figure 5b) resulted in a far greater difference in K-content between the two strips, but this difference was confined to the 0-20 cm layer only. Again, at the 20-40 cm depth the higher uptake by the tree roots may have been responsible for the reversal of this difference.

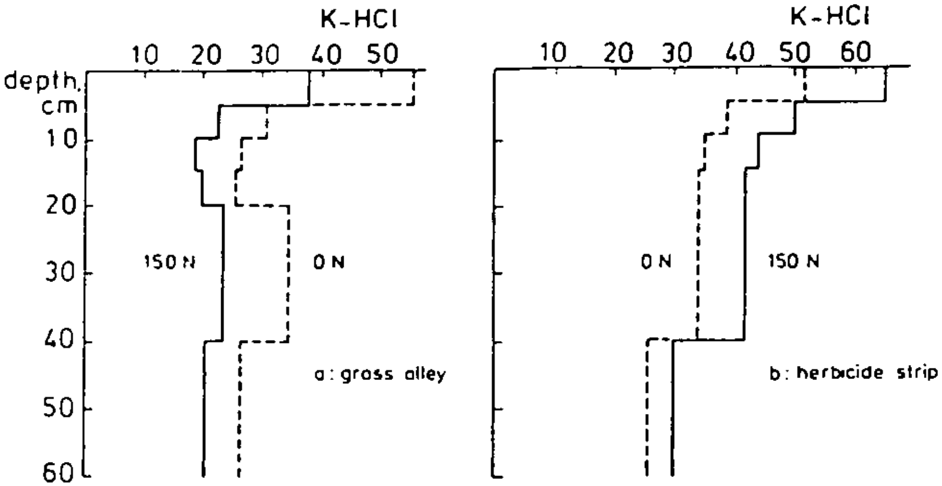

Figure 3 K-distribution in the soil profile in grass and herbicide strips in plots with constant (winter-summer) groundwater level of 130 cm and two rates of annual nitrogen application (0 and 150 kg $N.ha^{-1}$). K soluble in 0.1 N HCl, in mg K_2O per 100 g soil.

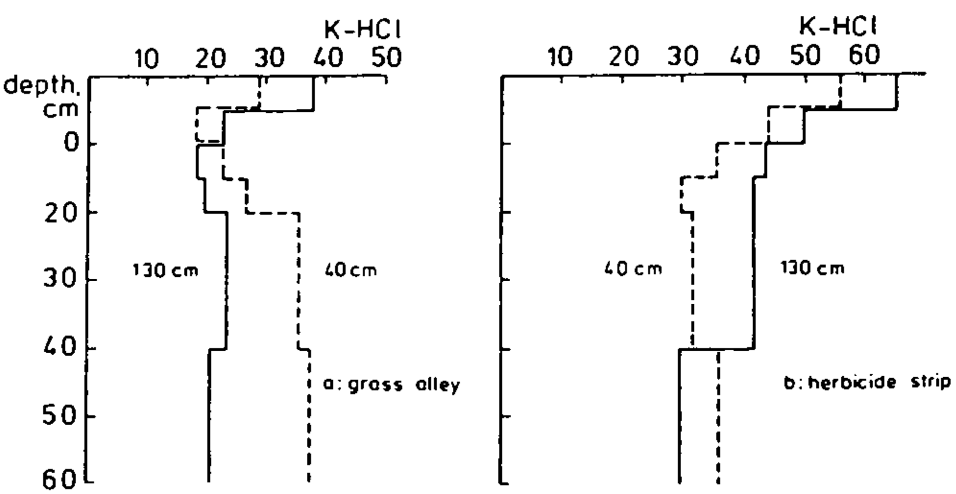

Figure 4 As Figure 3, for plots with an annual application of 150 kg $N.ha^{-1}$, but with constant groundwater levels of 40 or 130 cm below the surface.

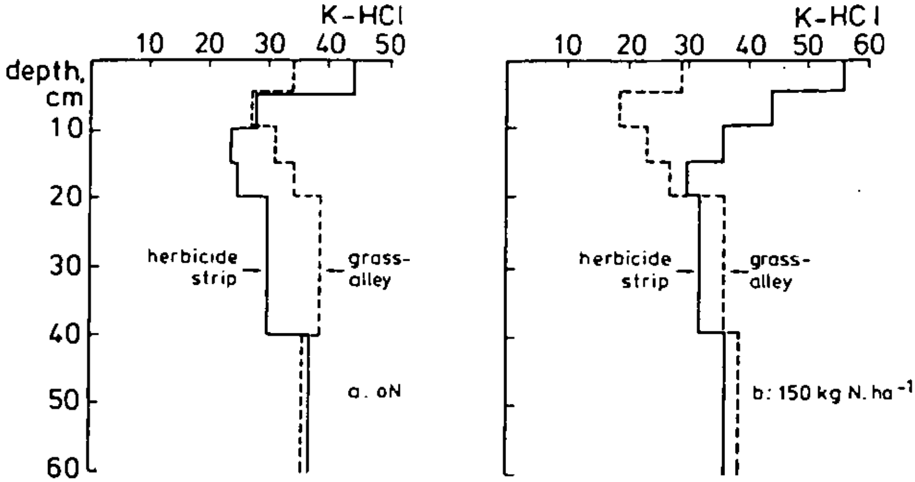

Figure 5 K-distribution in the soil profile in herbicide and grass strips in plots with a constant high water table of 40 cm, for two rates of annual nitrogen application.

2. Experiment with different methods of mowing and weed control on a marine loamy soil with a shallow root zone, Wilhelminadorp

In 1975 an experiment with apple trees was started on a field of the *Experiment Station for Fruit Growing* at Wilhelminadorp/NL. In the same year the alleys were sown to a mixture of smooth-stalked meadowgrass and some perennial ryegrass. The soil was somewhat dry and grass production was moderate. All plots received annual broadcast fertilizer applications of 80 kg N.ha^{-1} and an additional 300 kg K_2O.ha^{-1} was applied annually to a number of plots. As from 1975, four combinations of methods of mowing and weed control were used: the alleys were mown with a rotary mower (mulching on the tree strips) or with a lawn mower (mulching on the grass alleys), and weed control was done either by rototilling to a depth of 6 cm or by herbicides, without tillage. Both strips were 1.8 m wide. In June 1981, 6 years after commencement of the treatments, the 0-20 cm topsoil of the herbicide and grass strips was sampled and K-contents were determined. By then, plots with K fertilization had received a total quantity of 1950 kg K_2O.ha^{-1}.

Table 1 shows that the effect of annual K fertilization was far more pronounced than differences between tree strips and grass strips or the effect of mulching. Yet, in most cases K contents were higher in the tree strips than in the grass strips, but according to statistical analysis this difference was significant at the $P = 0.05$ level only in the case of mulching on the tree strips, with or witouth tillage. Also, the average mulching effect (K in mulched *versus* non-mulched grass strips and K in mulched *versus* non-mulched tree strips) resulted in just significantly higher K contents. Contrary to expectation tree strips also had slightly higher K contents than grass alleys when the grass cuttings were left in the alleys (in three out of four cases). Obviously the contrast in «K-displacement» between the two methods of mowing is not very marked. Possible reasons are the short duration of the mowing treatments, soil sampling early in the season, moderate grass production, uneven distribution of mulch over the tree strips or leaching of K from mulch into deeper layers. On the other hand as has been observed in other experiments, there was a general tendency towards higher K contents near the trees than in the alleys, even in all-grass or all-herbicide orchards. This may be due to the combined effect of leaf droppings concentrated under the trees and interception of rain by the tree canopy resulting in less leaching from the topsoil. After correction for these differences, determined in all-grass and all-herbicide plots in a number of soil management trials, *Van der Boon and Das* still found the highest K contents in the herbicide strips and the difference with the grass strips increased as the age of the orchard increased (loamy soil). Also, in a soil test survey in 83 commercial orchards on various soils they found the highest K contents in the herbicide strips, but the average difference with K in the grass strips per textural group was significant only in loamy and clay soils *(Van der Boon* and *Das [1978])*.

Table 1 K-HCl contents (mg K_2O per 100 g soil) in the 0-20 cm layer of grass alleys and tree strips as related to method of weed control, mulching and K-fertilization.

		Weed control			
K-fertilization, total kg K_2O. ha^{-1} 1975-81	Soil sample 0-20 cm layer in	herbicides without soil tillage, mulching on		rototillage without herbicides, mulching on	
		grass alley	herbicide strip	grass alley	tree strip
0	grass alley	27.5	24.5	24.0	25.7
0	tree strip	25.7	29.7	27.5	27.5
1950	grass alley	48.4	45.6	48.2	46.0
1950	tree strip	48.9	54.2	50.9	49.7

3. Effect of K displacement due to mulching on K contents in apple leaves

In the preceding experiment (2) leaf samples of two cultivars, Cox's Orange Pippin and Belle de Boskoop were analysed annually. Figures 6a, b, c demonstrate the effect of mode of mulching (a), weed control (b) and K-fertilization (c) on K in basal shoot leaves of Cox's Orange Pippin. Figures 6a and b refer to plots without K-dressings. K-displacement due to mulching of grass cuttings on the herbicide strip compared with mulching on the alley (a) had a slight positive effect (0.05-0.10% higher K contents), but this effect was smaller than that of omission of soil tillage on the tree strips (b) and far smaller than that of heavy annual K-dressings (c; *cf* Table 1). There was almost no difference between the two modes of mulching in the more vigorously growing Belle de Boskoop trees with probably more roots under the grass alley, whereas the effect of chemical weed control compared with tillage, and K-fertilization, averaged over 1977-1985, resulted in 0.09 and 0.38% higher K contents, respectively. To

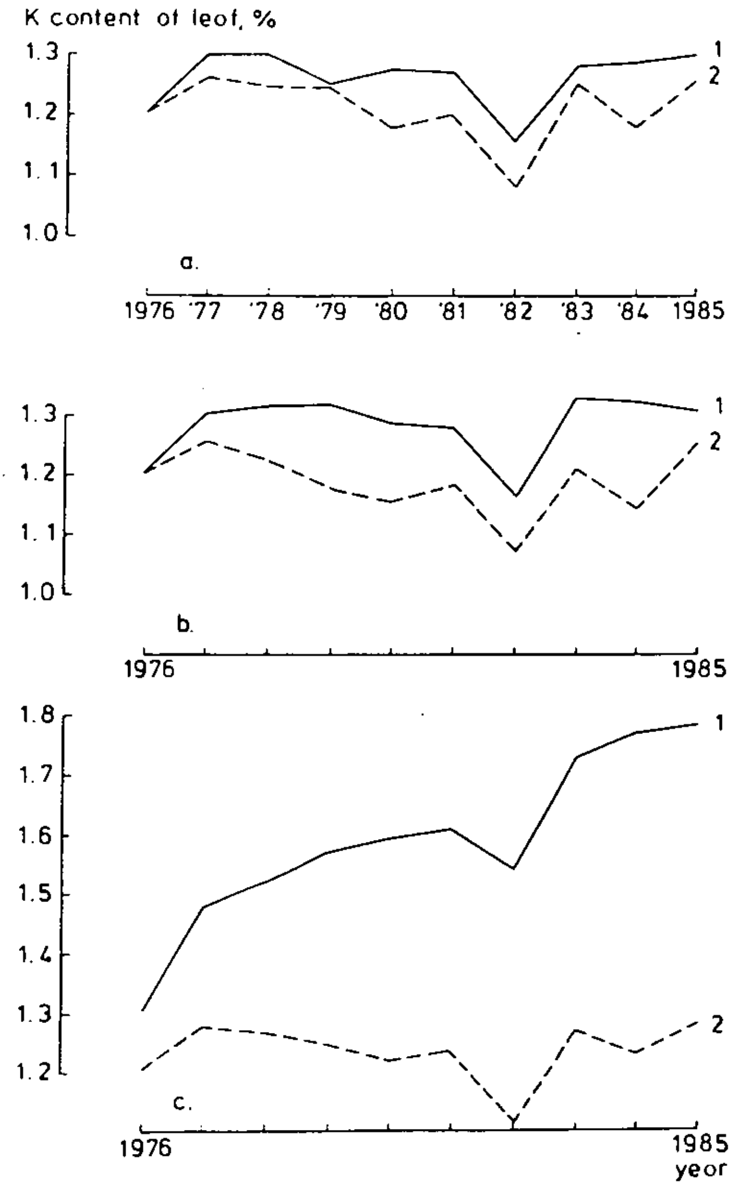

Figure 6 Effect of mode of mowing, tillage on tree strips, and K-fertilization on K contents of basal shoot leaves of Cox's Orange Pippin apples; a, 1, 2: mulching grass on tree strips and grass strips, respectively; b, 1, 2: herbicide treatment without tillage and weed control by rototilling, respectively; c, 1, 2: with and without annual K-dressings of 300 kg K_2O per ha, respectively, Experiment Wilhelminadorp.

explain the weak effect of horizontal K-displacement on K-contents in the leaves it should be borne in mind that the effect of K from mulch on the herbicide strip may be counteracted by depletion in the alley and that even self-mulching on the grass strip may be of advantage to the tree due to K released from the grass cuttings, provided there are sufficient tree roots in the soil under the sward. The different response of the two cultivars to the mode of mulching could then possibly be attributed to different lateral root expansion, but root studies to support this explanation were not done.

4. Experiment on marine loamy soil high in organic matter with different modes of mowing and weed control, Oosthuizen

The above findings confirm data from an earlier field experiment conducted in 1966-77 on marine loamy soil with 5-10% organic matter. The same mowing and weed control treatments as in experiment 2 were executed in an apple orchard planted in 1966 with Cox's Orange Pippin on rootstock M.9. As from 1971, fruits were stored to establish treatment effects on bitter pit and breakdown susceptibility. Table 2 summarizes average K-contents of leaves and storage losses. Also, yield data for 1976 are given. In general, the method of mowing had almost no effect on yield, but tillage compared with non-tillage resulted in slight reductions of 2-9%. Only in the extremely dry year 1976 did the treatments markedly affect production. The data show that tillage rather than mode of mulching affects K status of the leaves, keepability and productivity.

Table 2 Effect of method of weed control and mulching on K-content of the leaves, storage disorders and yield of Cox's Orange Pippin apples. Experiment Oosthuizen.

Treatment[1])	K-content of leaf, % 1971-1975	Bitter pit 1971-77, % (1974 excl.)	Breakdown, % 1971 + 1977	Yield, kg per tree 1976
H Tr	1.30	14.0	9.8	13.7
H Gr	1.18	12.2	8.7	11.5
R Tr	1.11	10.0	6.4	10.4
R Gr	1.08	8.4	6.0	7.7

[1]) H Tr, H Gr: Herbicides, no tillage, combined with mulching on tree strip or grass strip, respectively.
R Tr, R Gr: Rototilling to 6 cm depth, no herbicides, with the same methods of mulching, respectively.

Significance of successive soil layers in herbicide strips for the K nutrition of apple trees

The marked effect of omission of tillage on herbicide strips, resulting in increased leaf-K contents compared with trees on tilled soil, even at corresponding K contents in the 0-20 cm top layer (experiment 4; *Delver [1978]),* prompted us to conduct a detailed study on K uptake in a pot experiment.

5. Experiment with apple trees in pots filled with soil from herbicide strips, Wilheminadorp

In a fertilizer trial in 1963, pear trees were planted on marine, loamy soil. In 1964, a mixture of smooth-stalked meadow grass and perennial ryegrass was sown in the alleys. The herbicide strips received no nitrogen, but the alleys received annual quantities of 0-90-180-240 or 360 kg $N.ha^{-1}$ of grass area. As from 1964, the widely different quantities of grass cuttings were mulched on the herbicide strips. In February 1974 after 10 seasons of treatment, soil layers at approx. 0-2, 2-4, 4-9, 9-12 12-20 and 20-25/30 cm depths in the herbicide strips adjacent to the grass grips receiving either no nitrogen or 360 kg $N.ha^{-1}$ were sampled and analysed for 0.1N HCl-extractable K-contents. Pots of 26 l capacity were filled with this soil; half of the pots received 4g K_2O as potassium sulphate incorporated in the soil. In February, two-year old Belle de Boskoop trees were planted. Each tree (pot) received 1g N as a solution of calcium nitrate both in April and May. Moisture supply throughout the 1974 season was about optimum.

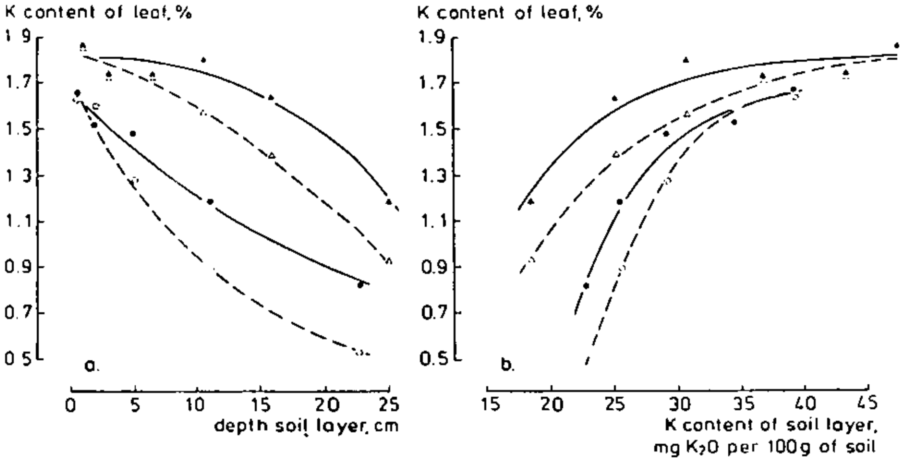

Figure 7 K contents of spur leaf of Belle de Boskoop apple trees as related to average depth of soil layer from herbicide strips (a) and K contents (K-HCl) of this soil (b). No nitrogen on adjacent grass alley, little mulch on herbicide strip, without and with 4 g K_2O per pot: o and •, respectively. High nitrogen dressings (360 kg $N.ha^{-1}$) on grass alley, high quantities of mulch, without and with 4 g K_2O per pot: Δ and ▲, respectively.

K-contents of spur leaves sampled in August are presented in Figure 7. The data demonstrate not only the importance of the uppermost soil layers for K uptake, but also the effect of increased quantities of mulch due to heavy N dressings (Figure 7a, 360 kg $N.ha^{-1}$ compared with no N on the adjacent grass alley). This effect outweighs that of added potassium sulphate (4 g kg K_2O, comparable with a broadcast dressing of about 400 kg $K_2O.ha^{-1}$). Figure 7b suggests that the mulching effect cannot be explained solely by the higher quantity of potassium displaced with the grass, but that mulching involves other factors important for K-uptake as well. Analysis of the soil layers showed that the highest contents of organic matter occurred in the upper layers and besides, on examination of the roots after termination of the experiment, far better branching and a better soil structure were observed to exist in this soil compared with deeper layers. It is therefore concluded that mulching not only results in displacement of K to the herbicide strip, but also in far better K-availability due to improved soil physical and chemical conditions. It is then easily understood why tillage, which makes the 0-6 or 8 cm top layer inaccessible to roots, has a definite negative effect upon the K-nutrition of the crop.

Impact of K depletion in grass alleys on a subsequent fruit crop

In an existing orchard a possibly negative effect of K-depletion from the grass alley is offset by improved K-uptake in the herbicide strip. However, when young trees are replanted in soil where rotary-mown grass alleys were previously located, the depletion may affect the initial K status of the young tree. This was demonstrated in the following experiment.

6. K-status of young apple trees, replanted after grubbing pear trees of a grass strip fertilizer experiment, Wilhelminadorp

The pear trees in the trial with mulching on herbicide strips, mentioned in example 5 were grubbed in the autumn of 1974. The soil was then ploughed and in February 1975, one-year old Cox's Orange Pippin trees on M.9 were replanted in the same row direction as the pear trees in the preceding experiment, but at a different row distance. Consequently a number of the new rows more or less coincided with the middle of the former grass alleys or herbicide strips. Accurate localisation of former and new experimental plots, and annual leaf analysis made it possible to draw up the relationship presented in Figure 8.

The K-depletion of the former grass strips due to increased grass production brought about by nitrogen dressing was confirmed by soil testing. Figure 8, left, shows that when the newly-planted tree was still young and lateral root extension was confined to the former grass area, the depletion was clearly reflected in the K-content of the apple leaves. The effect faded as trees became older and roots reached former herbicide strips, but it remained apparent for a few years. The generally low contents in 1976 and 1977 can be attributed to extremely dry and rather dry weather and soil conditions in these two years.

Contrary to expectation, the mulch-related K-enrichment of the herbicide strip (*cf.* Figure 7) had but little after-effect on the apple crop (Figure 8, right). Obviously, the ultimate effect of K-uptake by the pear tree and the small K-supply from the «oN»-mulch quantity (1964-1974) did not result in a sub-optimum K-content of the soil. However, this assumption is contradicted by the findings in the pot experiment (Figure 7). A possibly interfering factor could have been the reversal and disturbance of the typical accumulation profile of K (*cf.* Figure 3b) and organic matter by ploughing before replanting, resulting in loss of readily available K due to processes such as adsorbtion of K by unsaturated subsoil clay particles, and deterioration of the structure of the original topsoil.

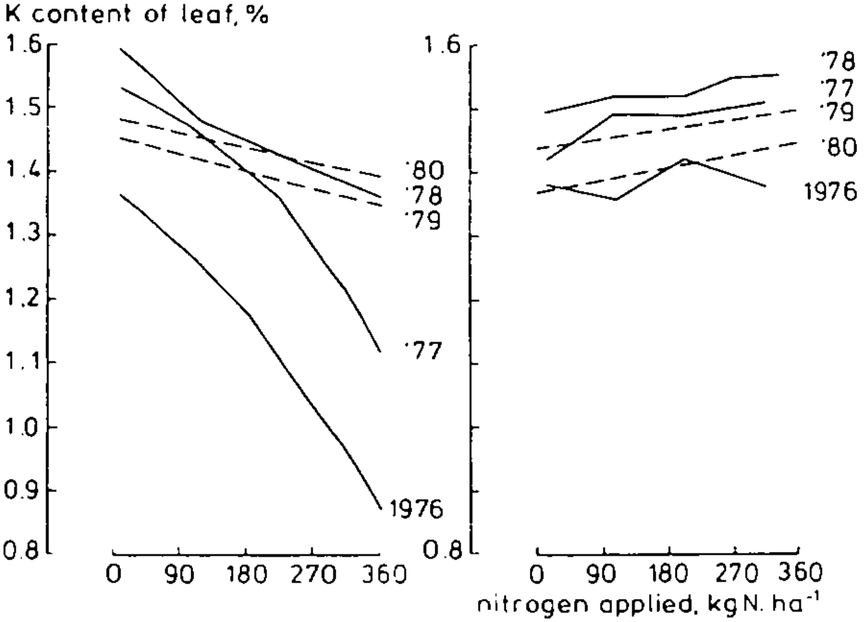

Figure 8 K contents of leaf of 2-6 year old Cox's Orange Pippin trees planted in 1975 on spots where former grass alleys (left) or mulched herbicide strips (right) in a trial with pears were ploughed down, as related to average annual nitrogen dressings 1964-1974, on the former grass alleys (1) or adjacent grass alleys (r).

Concluding remarks

The grass strip system in orchards with chemical weed control under the trees is characterised by absence of tillage, recycling of nutrients by mulching, and heterogeneous distribution of nutrients and soil moisture, both vertically and horizontally. Finally, the tree roots are concentrated in the herbicide strips, particularly in the topsoil. An annual amount supplied due to mulching of 35-190 kg K_2O per ha tree strip area, the concomitant accumulation of K and organic matter and hence the high K availability, further promoted by a good soil structure and moisture from summer rains, make the upper layers of the herbicide strip of paramount importance for the potassium nutrition of the fruit tree.

In terms of K availability and K consumption by the tree, the system seems to be highly efficient, with probably a low adsorption of K in K-unsaturated soil layers, relatively low leaching losses in the grass alley and high K depletion of the soil by the grass in favour of the tree. These factors, in addition to a certain caution on the part of fruit growers in view of adverse K effects on quality of fruits in storage, explains why low amounts of K fertilizers are used in Dutch orchards. It also explains the diminishing effect of shallow tillage for weed control on K nutrition of the fruit tree in comparison with herbicide use without tillage.

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Co-ordinator's Report on the 3rd Session

R. E. Wagner, Potash and Phosphate Institute, Atlanta/USA*

Pressures to increase farm income the world over have led to changes in farming that may be expected to alter requirements for potassium fertilizers. The subject of the *Third Working Session* was designed to take a look at some of these alterations.

Unlike any time in the past, we live in a world plagued with overproduction of both food and fertilizer... except for pockets of severe hunger. Costly subsidies are of grave concern to governments around the world, low prices haunt farmers, and low fertilizer prices have forced some primary producers into bankruptcy.

There are no easy answers. For sure, address of real and relevant problems by scientists is essential. Basic research should not be neglected, but more effort on the economics of crop production systems is a vital need.

More and more, farmers will be forced into maximum economic yield (MEY) systems... or systems of the same concept under some other name... not so much because they want more yield but because of the low unit costs that efficiently produced high yields can give.

The Third Working Session of this Congress addressed the dynamics of potassium in some of these changing production patterns and techniques.

Dr. *Henkens* discussed the very interesting and significant changes in Netherlands farming the past 25-30 years: striking increases in stocking rates; a shift from arable crops to fodder maize; intensification of grassland management; and the feeding of housed stock with imported feeding stuffs on small farms. He pointed out that it is difficult to forecast the effects of these changes on fertilizer needs especially as fertilizer policy has changed from supplying crop needs to soil P and K improvement and maintenance.

There are large interactions in high yield intensive systems between N and P and K. To ensure efficient use of N, more P and K usually are required. Adequate K is also essential to ensure that potatoes are not damaged by internal blackening disease. It is estimated that even if the animal manures were evenly distributed over the whole arable area, about 40000 tons K_2O would be required to maintain K balance on the non-grassland area.

Dr. *Rixhon* discussed his and colleagues' work on the effect of cultivation methods, with specific reference to the increasingly popular minimum tillage, on the distribution and uptake of K. Methods used were direct drilling, reduced cultivation, and conventional cultivation.

* Dr. *R. E. Wagner*, President, Potash and Phosphate Institute, 2801 Buford Hwy. N. E., Suite 401, Atlanta GA 30329-2199/USA

K balance (calculated from exchangeable K) was always positive in the experiments that were done with direct drilling, but some balances were negative for reduced and conventional cultivations. This appeared to be due to the soil surface being enriched with exchangeable K under direct drilling partly because K fixation was lessened by the crop residues which formed a mulch.

Although there was apparently no relationship between root development and exchangeable K supply, maximum root activity was found in the profile at depths corresponding with maximum exchangeable K supply. Yields under reduced cultivation were slightly better than with conventional cultivation except in the case of forage maize.

Dr. *Sala Feigenbaum* pointed out in her paper that potassium adsorption, desorption, and dissolution processes will be affected when some crops are irrigated with water containing high levels of sodium, magnesium, and calcium salts and there may be some movement to deeper soil layers. Leaching excess salts is an essential management practice in irrigation with saline water. She said her studies suggest that exposure of a sandy soil to leaching with saline and sodic solution affects the process of K fixation. Dr. *Feigenbaum* concluded that in soil containing clay with high fixing capacity, the relative K fixation could be more pronounced when brackish water is used for irrigation.

Dr. *Marty* described mathematical cropping system models that he and colleagues are developing. Fertilizer planning is closely related to other techniques used, and it is based on comprehensive investigation leading to better understanding of the mechanisms involved so as to enable extrapolation to a wider set of conditions. As concerns P and K fertilization, Dr. *Marty* pointed out it is essential to ensure that fertilizer applications will conserve or improve nutrient status equally on plots under different treatments in accordance with nutrient requirements and removals. He further stated that exchangeable K is adequate for monitoring the K status of soils and is thus a valuable indicator of soil fertility.

Models are becoming important tools in some aspects of crop management and will become more so as progress is made. They are no substitute for experiments but they are valuable research and extension tools. Experimental work is required to validate the theoretical model, which may then be applied to provide advice on crop management. Dr. *Marty's* presentation was a good illustration of these facts.

Dr. *Delver* reported on his studies of potassium dynamics in Dutch orchards, including research on the grass strip system, which is characterized by chemical weed control, the absence of tillage, and a recycling of nutrients by mulching. The grass strip between rows is cut and the herbage diverted on to the soil around the trees which supplies potassium taken from the soil under the grass.

In terms of K availability and K consumption by the tree, the system seems to be highly efficient with probably a low adsorption of K in K-saturated soil layers, relatively low leaching losses in the grass alleys, and high K depletion of the soil by the grass in favor of the tree.

13th Congress of the International Potash Institute
August 1986 in Reims/France

4th Session

Potassium fertilization to maintain a K-balance under various farming systems

Co-ordinator: *A. Dam Kofoed*, Director, Agricultural Experiment Station, Askov-Vejen/Denmark; member of the Scientific Board of the International Potash Institute

Potassium Fertilization to Maintain a K-balance under Various Farming Systems

A. E. Johnston, Rothamsted Experimental Station, Harpenden, Herts/United Kingdom*

Summary

Whilst the soil may supply sufficient K for the needs of a crop, more often such supplies have to be augmented by dressings of fertilizers and manures. For soils which supply little K by weathering it is preferable to maintain adequate reserves of soil K rather than try to fertilize to meet the needs of each crop, especially those which are responsive to K. Maintenance of a satisfactory level of exchangeable K in soil depends, in part, on the extent to which this K is replenished by non-exchangeable K reserves. Various factors affect the relationship between K balance and exchangeable and non-exchangeable K. A larger proportion of added K remains exchangeable in acid rather than neutral or calcareous soils. Leaching of K occurs before K has occupied all possible exchange sites in the surface soil. Organic matter derived from farmyard manure increases the number of exchange sites but organic matter which accumulates under grassland in neutral soils during periods of K manuring enhances retention of K in top soil by a mechanism related to binding of Ca^{2+}. As the period of manuring increases smaller proportions of a positive K balance remain exchangeable.

The release of matrix K is a fundamental soil property but is probably of little practical importance on many cultivated and manured soils where release of non-exchangeable K is more important. Release of non-exchangeable K depends on the stress put on the soil to supply K. Removing any constraint on yield *e.g.* disease control, or altering the farming system, which improves yield will affect K offtake and hence K balance. Negative K balances may affect the yields of following crops on some soils but not on others. A chalky boulder clay soil at Saxmundham, Suffolk was cropped for 80 years without applying K before winter cereals responded to K fertilizer.

1. Introduction

The preparation of nutrient balances should not be an end in itself. At global, continental, national and individual farm level nutrient balances often have different objectives, some of which are discussed below. The unifying theme, however, must be to understand and maintain soil fertility. Factors which affect the relationship between K balance and the accumulation and depletion of exchangeable and non-exchange-

* *A. E. Johnston,* B.Sc., Acting Head, Soils Division, Rothamsted Experimental Station, Harpenden, Herts. AL5 2JQ/United Kingdom

able K reserves in soil are discussed here. Examples are given of the effects of removing large amounts of soil K on the yield, K offtake and response to a fresh K dressing by subsequent crops. These examples are taken from long-term experiments on silty clay loam soils, 25-30% clay, at Rothamsted, a sandy loam, 10% clay, at Woburn and a sandy clay loam, 25% clay, at Saxmundham. In these soils the clay mineralogies are mainly mica-smectite types and have been variously described as: randomly interstratified montmorillonite-vermiculite *(Weir et al [32], Avery et al [2])*, illite and complex interstratified smectite: illite *(Catt et al. [3])* and interstratified expanding minerals *(Goulding* and *Talibudeen [11])*.

1.1 National Nutrient Balances

Cooke (this Congress) has given a number of examples of national nutrient balance sheets and has emphasized their importance as an aid in decision making for those seeking to develop national fertilizer policies. Getting such policies right is especially important when exports of agricultural produce figure prominently in the national economy. He also pointed out that nutrient balances can be altered by changing any input, not necessarily fertilizer, that changes yield. The data can also be used to identify possible deficiencies or imbalances in inputs so that advisory effort can be focussed on attempts to rectify such deficiencies and hence increase yield.

Johnston and *Cameron [23]* published a plant food balance sheet for the United Kingdom for the year 1874. They used the small annual losses typical of a four-course rotation of turnips, barley, clover hay or beans and wheat, in which only grain and meat were sold off the farm, and they allowed for only those imports of nutrients which were likely to find their way into the soil. For the 9.5 million hectares under arable cropping their calculations showed that annual losses exceeded additions for N P and K; for potassium the negative balance was 37 000 tonnes. *Cooke [6]* produced a similar balance sheet for 1956 and concluded that, within the accuracy of the data, the balance was then positive for all three nutrients, that for K by 75 000 tonnes. More recently *Church* and *Skinner [5]* published average P and K balances for 1982 for England and Wales for winter wheat, spring barley, oilseed rape and potatoes (see Table 1 for K). For all four crops the K balance was positive, but for wheat, barley and oilseed rape the balance was small, for potatoes it was quite large. But, because potatoes are not grown frequently on many soils the overall national balance for arable rotations is likely to be small. The authors had also observed only very small changes over a ten-year period, in the exchangeable K levels in arable soils collected for the *Representative Soil Sampling Scheme*, which aims to monitor changes in the nutrient status of the farmed soils of England and Wales. They concluded that these small changes were related to the very small positive K balance.

The usefulness of such national balances depends upon having reliable data on fertilizer use and yields of harvested produce removed from the farm, this data may or may not be collected by national agencies. Average composition of the crops grown requires data from field experiments conducted on a range of soil types. Many organizations, for example *Kali und Salz A. G.* in Germany and the *Agricultural Development and Advisory Service* in England and Wales, publish tables which show the average content, in kg element per tonne of crop, of many elements for many crops.

Table 1 Average K balance for selected crops grown in England and Wales in 1982

	Crop					
	Wheat		Barley		Oilseed rape	Potatoes
	grain	straw	grain	straw	seed	tubers
Mean yield*, t/ha	6.2	4.8	4.9	3.2	3.3	37.3
K content kg/t produce	4.6	6.8	4.6	6.8	9.1	4.8
Balance, kg K/ha						
Offtake	29	13**	23	9**	30	180
Fertilizer***	46		53		42	249
Fertilizer *minus* Offtake	4		21		12	69

* Average yield in England and Wales, 1982 *(MAFF, [25])*

** Assumes that nationally only 40% of cereal straw is removed from the field *(Staniforth, [28])*

*** Average amount of inorganic fertilizer *(Church, [4])* plus an allowance for the immediately available K in FYM to that area of the crop which gets a dressing

1.2 Farm nutrient balances

At the whole farm or individual field level, nutrient balances can be much more accurate because fertilizer inputs and yields should be known with greater precision than at the national level. Nutrient offtakes can be measured directly or derived with reasonable accuracy from data for crops grown on similar soils and in similar farming systems. Manuring policy can then be related to management decisions about the level of fertility at which the soils should be maintained. For example, much of Rothamsted farm is cropped on a seven-course rotation. Amounts of P and K, given twice in each rotation, are based on the total calculated offtake by average yields of the seven crops. Soil analysis, once per rotation, is used to monitor changes in soil nutrient levels to check that soil reserves are not being depleted *(Johnston, Poulton* and *McEwen, [20])*.

1.3 Nutrient balances – research problems

To the research scientist negative and positive nutrient balances pose interesting problems especially in the case of potassium. If the balance is positive, how large should it be, what will happen to the excess K, will it benefit succeeding crops, will it ever be recovered? If the balance is negative, would the crop have responded to extra fertilizer K or would soil supplies have satisfied demand, would adding K have diminished the amount released by weathering and if not would that K have been lost from the soil? Some results pertinent to these questions are presented in the following sections.

1.4 Presentation of results

Any change in exchangeable K in soil is usually less than the K balance whether this is positive or negative. To compare results from experiments the change in exchangeable K is often calculated and presented here as a percentage of the K balance. This also indicates the relative amounts of K removed from exchangeable and non-exchangeable sources (see Section 3)

2. Value of K residues

Lawes and *Gilbert [24]* at Rothamsted found that giving a crop only as much P and K as it took up, failed to give large yields and in their experiments they always supplied more P and K than the maximum offtake. Subsequently they modified some of their experiments to measure the residual value of dressings of farmyard manure (FYM) and fertilizers. The results showed that when manuring continued for many years and then ceased, soils with residues yielded better than unmanured soils and the effect of P and K residues often lasted many years. Recently it has been shown that yields on such enriched soils often exceeded those on impoverished soils at all levels of freshly applied P and K fertilizers. This was so on both the silty clay loam soil at Rothamsted and the sandy loam at Woburn *(Johnston, Warren* and *Penny, [21]* and on a sandy clay loam at Saxmundham *(Johnston et al. [16])*. Similar results have been obtained recently for high yielding wheat crops (Table 2). On many soils therefore it is worthwhile to accumulate residues by maintaining positive P and K balances.

Table 2 Effect of new and old residues of K manuring and of fresh K dressings on yields of winter wheat, grain t/ha, Agdell, Rothamsted 1984-85

	Manuring 1848-1951			
	None		PKNaMg*	
K added in 1964, kg/ha**	0	1465***	0	1465***
0	7.80	8.20	8.36	8.90
260	7.84	8.42	8.99	8.81
520	8.09	8.21	8.64	8.63
1040	8.07	8.17	9.23	8.51
mean	7.95	8.25	8.80	8.71

* K applied once per 4-course rotation, 130 kg/ha in 1848-95, 220 kg/ha in 1896-1951

** as one single dressing

*** K (kg/ha) applied during 1973-85; 715 kg/ha during 1973-76 and then as 3 dressings, each of 250 kg/ha in the autumn before wheat was sown

3. Relating K balances to soil K analysis

3.1 Potassium fractions in soil

Soil potassium is often divided into at least four categories following the early work of *Hoagland* and *Martin [12]*, although not all workers use their terminology. Potassium ions, K^+, present in the soil solution and potassium as a structural element in soil minerals, often called matrix or mineral K, represent the extremes in terms of plant availability. Soil colloids, such as clay minerals and organic matter, hold some K as K^+ exchangeable to NH_4^+ ions, exchangeable K. Much work has identified at least one other category of K which is non-exchangeable to NH_4^+ but which seems to be released to plants on exhaustive cropping at a faster rate than matrix K, often called non-exchangeable, or fixed K. Positive and negative K balances affect the amounts of K in some of these fractions.

3.2 Total potassium

Changes in total K in soil should relate to K balance. However, total K can change as the clay content of the soil changes and, in all but the lightest textured soils, clay content can vary appreciably over quite small distances. In many long-term experiments at Rothamsted there have been relatively large K balances but comparisons between treatments within experiments show that these balances do not relate to total soil K (Table 3).

Table 3 Total K, % in air dry soil, manuring and estimated K balance, kg/ha, at time of sampling in the 1950s in long-term experiments at Rothamsted and Woburn

Experiment and year started							
Agdell 1848	Manuring	none	none	PK	PK	NPK	NPK
	K balance	−1450	−1200	+600	+1580	+790	+1450
	Total K	1.03	1.03	1.14	1.14	1.16	1.21
Broadbalk 1843	Manuring	none	PKNaMg	FYM	NPKNaMg	NPK	
	K balance	−1470	+7940	+12750	+4900	+5300	
	Total K	1.17	1.21	1.20	1.18	1.17	
Exhaustion Land 1856	Manuring	none	N	PK*	NPK	FYM**	
	K balance	−930	−1430	−460	+1410	+1430	
	Total K	1.31	1.39	1.37	1.41	1.40	
Continuous Wheat experiment Woburn 1876	Manuring	none	none	PK	NPK	NPK	FYM
	K balance	−490	−510	+2550	+2350	+2200	+1520
	Total K	0.712	0.694	0.778	0.686	0.668	0.705

* K, 1856-75 only

** FYM, 1876-1901; all other treatments applied 1856-1901 on Exhaustion Land

3.3 Exchangeable K

Many experiments show that exchangeable K ranks soils better than other rapid analytical methods. For example, *Johnston* and *Addiscott [15]* cropped soils with contrasted manuring histories from the Classical and Long-term experiments at Rothamsted and Woburn for 608 days in pots in the glasshouse. They showed that 95% of the variance in K uptake by ryegrass was accounted for by exchangeable K. Often other reagents extract amounts of potassium that are well correlated with those exchanged by ammonium acetate. Excellent relationships between K soluble in 0.3 *M* HCl and 0.5 *M* NH_4Ac:0.5 *M* HAc and exchangeable K were given by *Johnston [14]* using data from a sandy loam soil in which exchangeable K ranged from 100-400 mg/kg and where K had been added as fertilizers, FYM and in various composts. K balances will, wherever possible, be related to exchangeable K in soils in this paper.

3.4 Water soluble K

Mengel and *Kirkby [27]* recently pointed out that K^+ concentration in the soil solution very largely controls the K diffusion rate towards plant roots and therefore the uptake of K^+ by plants. It may be worthwhile for annual arable crops to try to relate variations between soils, in their responsiveness to K fertilization, to the proportion of

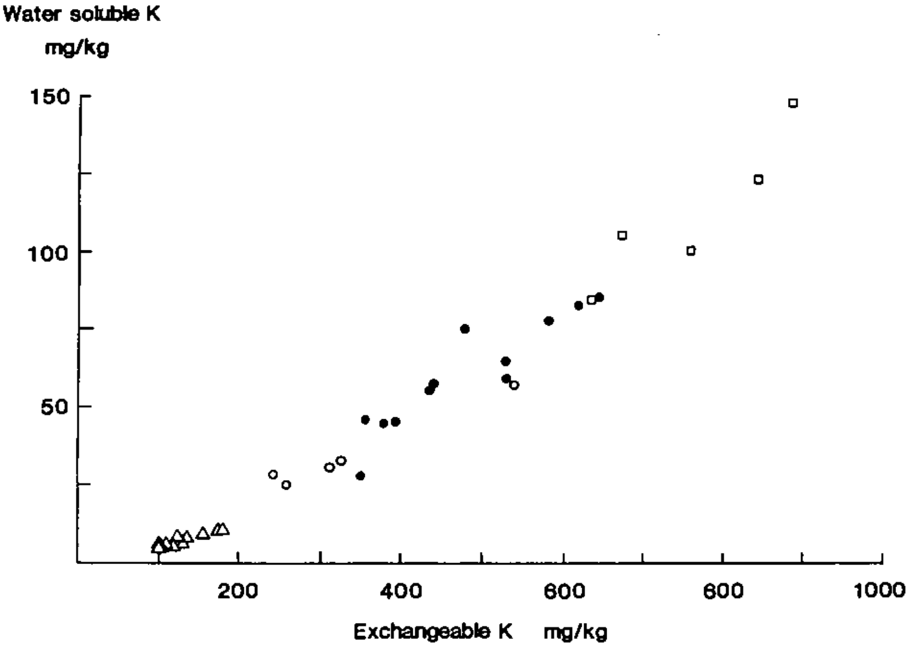


Fig. 1 Relationship between water soluble and exchangeable K in 1958, in the 0-23 cm depth of soils given K as fertilizer, ●; farmyard manure, ○; fertilizers plus farmyard manure, □; or no K, Δ; since 1856.

the exchangeable K that is water soluble. *Warren* and *Johnston [29]* found a good relationship between water soluble K and exchangeable K that ranged from 100 to 900 mg/kg, on a Rothamsted soil where K had been added both in fertilisers and FYM, singly and in combination, for many years (Figure 1). Above 170 mg K/kg about 15% of the exchangeable K was water soluble, below this value the proportion was smaller. Whether similar proportions of water soluble to exchangeable K would be found on other soils is not known.

4. Factors influencing exchangeable K in soil

4.1 Effect of pH

Warren and *Johnston [30]* described a laboratory technique in which water soluble K, at rates up to 200 mg K/kg, was added to soils and changes in exchangeable K were

Table 4 Effect of soil texture, pH and past K manuring on the percentage of added K which remained exchangeable after 12 weeks in soils kept continuously moist or alternately wet and dry in the laboratory

Past manuring** and soil pH	Soil number*	Exchangeable K, mg/kg, in unamended soil	Percentage K remaining exchangeable after 12 weeks	
			Continuously moist	Alternately wet and dry
No K	1	80	95	75
Soil pH 5-6	2	80	95	75
	3	80	100	65
No K	4	80	80	40
Soil pH 7-8	5	120	85	45
	6	110	80	40
	7	160	65	30
Fertilizer K	8	120	100	80
Soil pH 5-6	9	290	100	100
Fertilizer K	10	110	80	50
Soil pH 7-8	11	200	85	55
	12	460	100	75
	13	340	90	60
	14	690	60	55
K in FYM	15	100	70	50
Soil pH 7-8	16	480	100	95
	17	480	100	100
	18	420	95	60
	19	940	100	85

* All soils silty clay loams except 2 and 8 which were sandy loams
** Manuring had been unchanged since at least 1876, except soil no. 15 where FYM was applied 1876-1901 only

estimated over a 12-week period when the soils were kept continuously moist, dry after initial wetting, and alternately wet and dry. The proportion of the added K which remained exchangeable was independent of the amount added and only average values for the three rates tested are given here. Of the 19 soils used, 17 were silty clay loams and two were sandy loams, pH varied from 5 to 8 and all soils came from long-term experiments in which plots received either no K or where K had been applied as fertilizer or FYM. The results (Table 4) showed that:

1. more K remained exchangeable in continuously moist soils than in soils which were alternately wet and dry.
2. more K remained exchangeable in acid (pH 5 to 6) than in neutral or calcareous soils (pH 7 to 8).
3. less K remained exchangeable in neutral or calcareous soils when the initial exchangeable K values were small, less than about 150 mg/kg.
4. for neutral or calcareous soils with more than 200 mg K/kg the percentage of the K which remained exchangeable varied from 100 to 50% and was not related to initial exchangeable K values. Two soils (16 and 17 in Table 4) appeared to be K-saturated.

4.2 Effect of leaching

Long-term experiments on the silty clay loam at Rothamsted and sandy loam at Woburn provide examples of the effect of clay content, in both the surface and subsoil, on the retention of K within the soil. The Rothamsted Classical experiment on Barnfield *(Warren* and *Johnston [29])* tested the effects of N, P, K, FYM and rape cake singly and in combination on root crops grown almost continuously from 1843 to 1959. From 1942 to 1961 the Market Garden experiment at Woburn compared the effects on vegetable crops of two rates of FYM, sewage sludge and two composts and any additional benefit from these organic manures when a combined N P K fertilizer was applied to all plots. One compost was made from FYM and vegetable material, vegetable compost, and the other from sewage sludge and straw, sludge-straw compost *(Johnston* and *Wedderburn [22])*.

In both experiments the amounts of added K are known with more accuracy than the K balance and these are given in Table 5. This Table also shows the average exchangeable K in the 0-23, 23-30, 30-46 and 46-61 cm (46-54 cm at Rothamsted) soil depths of the unmanured and P only plots on Barnfield in 1958 and in the fertilizer only plots of the Woburn Market Garden experiment in 1961. Although the Barnfield soil had received no K since 1843 it still contained more K at all depths below 23 cm than the sandy loam at Woburn which had received 950 kg K/ha in the last 20 years.

The extra exchangeable K at each depth (also in Table 5) in plots receiving K shows that subsoil enrichment can be qualitatively related to the amount of K applied. At Rothamsted each horizon contained more exchangeable K than the one below it but at Woburn the three top horizons, down to 46 cm, all had the same amount and there was only a little less in the next 15 cm.

The most interesting feature of these results is that at Rothamsted each horizon has not become «saturated» with exchangeable K before enrichment of the deeper horizons commenced. This is not so immediately obvious at Woburn except that, where the single rate of FYM or vegetable compost was applied, exchangeable K contents have not increased as much as where the double rate was given. This is so for all horizons and not only the surface 23 cm where the double rate of FYM and compost had increased soil organic matter more than with the single rate. This phenomenon must be related to the amount and water solubility of K in the topsoil, the volume of drainage water and its contact time in each horizon and the speed of the reaction between water soluble and exchangeable K.

Table 5 Amount of K added, kg/ha, and exchangeable K, mg/kg, at four depths down the profile on a silty clay loam and a sandy loam soil

	Silty clay loam				Sandy loam				
Treatment	No K	FYM	PK	FYM &PK	NPK	FYM Rate 1	FYM Rate 2	Vegetable compost 1	Vegetable compost 2
K added	none	16700	20500	28800	950	6400	11800	4900	8800
Depth cm	Exch K	Gain in exchangeable K			Exch K	Gain in exchangeable K			
0-23	119	174	380	641	111	163	266	144	205
23-30	129	104	179	386	101	169	265	137	213
30-46	139	23	102	225	93	174	268	134	226
46-61*	152	- 2	79	152	83	143	226	91	186

* 46-54 cm on the silty clay loam

4.3 Effect of soil texture

Average annual K balances have been calculated for four long-term experiments and related to the exchangeable K content of the topsoil, 0-23 cm. The experiments and the years when they were sampled were:

1. Broadbalk, Rothamsted, continuous wheat since 1843, sampled 1966, silty clay loam.
2. Agdell, Rothamsted, four-course rotation of arable crops since 1848, sampled 1958, silty clay loam.
3. Continuous Wheat and Barley experiments, Woburn, continuous cereals since 1876, sampled 1956, sandy loam.
4. Rotation I, Saxmundham, four-course rotation of arable crops since 1899, sampled 1969, sandy clay loam.

Figure 2 shows that the relationship for each soil is different, especially when that for the sandy loam is compared with those for the heavier-textured soils. Such relationships provide important information on how K balances are likely to affect exchangeable K in different soils but they give no clear indication of the size of any non-exchangeable reserves. For example, of the estimated K balance for Broadbalk only about 10% remained exchangeable but 20% was recovered when the soils were exhaustively cropped with ryegrass in the glasshouse *(Addiscott* and *Johnston [1])*. It is tempting to extrapolate such relationships to zero exchangeable K and assume that this is the total amount of K which could be released from the soil. However, even in the exhaustive cropping experiment in the glasshouse mentioned above, exchangeable K never declined to zero. Equally it is tempting to assume that the intercept on the exchangeable K axis at K balance equals zero, has some significance but *Johnston [13]* showed that, for Broadbalk at least, this value changed with time suggesting that this is not a fundamental soil property but is likely to be influenced not only by the period of cropping but also by the release, fixation, or leaching of K.

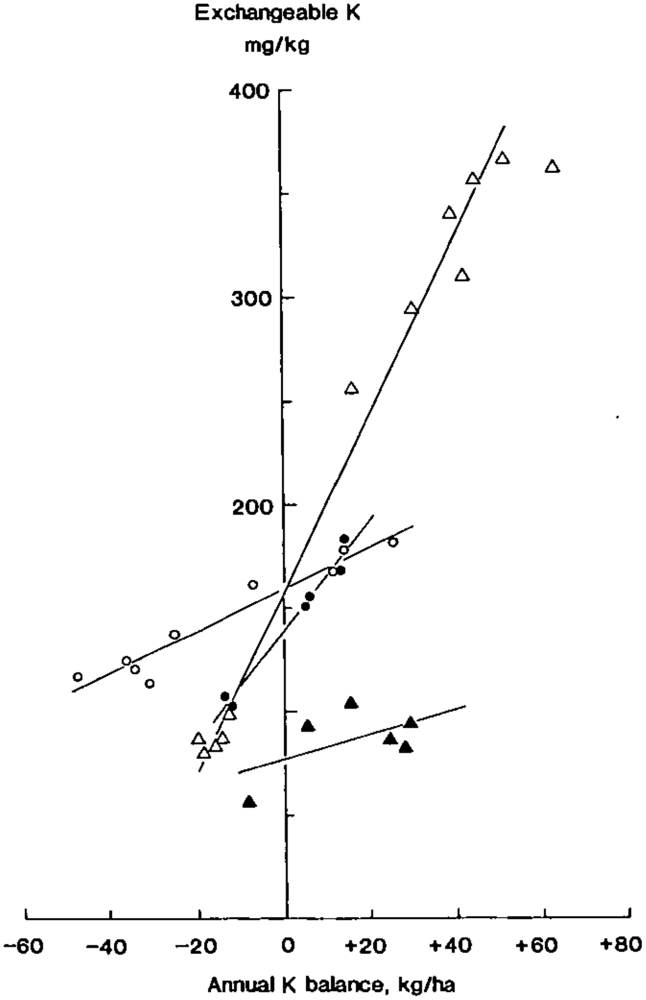


Fig. 2 Relationship between annual gains and losses of K, and exchangeable K in soils (0-23 cm) from: Saxmundham Rotation I, sampled in 1969, ○; Agdell Rotation Rothamsted, sampled in 1958, ●; Broadbalk, Rothamsted, sampled in 1966, Δ; Continuous Wheat and Barley, Woburn, sampled in 1956 ▲.

4.4 Effect of organic matter

4.4.1 Effect of farmyard manure

The Woburn Reference Experiment, started in 1960, compares the effect of N, P and K in all combinations with those of FYM and FYM plus P K fertilizers, the last at two rates of extra inorganic N, on the yields of five arable crops grown in rotation *(Widdowson et al. [33])*. By 1979 there had been four five-year cycles. In the first five years total K applied in fertilizers and FYM was 730 and 706 kg/ha, respectively. In each of the remaining three cycles fertilizer K was increased to 1042 kg/ha and K in FYM averaged 1045 kg/ha. Therefore K applied in the two FYM plus PK treatments was 1436 kg/ha in the first cycle and averaged 2087 kg/ha in the next three cycles. For this experiment a complete K balance can be prepared and the cumulative K balance at the end of each five-year cycle related to the exchangeable K in the cultivated soil layer (Figure 3). The same relationship, which accounts for 90% of the variance, holds for both FYM- and PK-treated soils. This supports the evidence in Figure 1 that there is no fundemental difference between FYM and fertilizers in their effects on exchangeable K, see also below.

4.4.2 Effect of other forms of organic matter

The close similarity in the relationship between K balance, when K was applied either as fertilizer or FYM, and exchangeable K will not necessarily apply where organic matter is derived from other sources. *Addiscott* and *Johnston [1]* in their exhaustive cropping experiment included soils from fertilizer- and FYM-treated plots from the Rothamsted Classical experiments and from arable and continuous grass plots from the long-term Ley-Arable experiments. They calculated a K balance for each plot from which soil had been taken and measured exchangeable K (K_e) and uptake of K (K_p) by ryegrass grown for 608 days in pots in the glasshouse.

They did single and multiple regressions of both K_e and K_p on K balance; K balance plus percentage organic C; K balance plus total cation exchange capacity (CEC): K balance plus organic CEC. For the Classical Experiments multiple regressions on K balance plus total CEC accounted for significantly the most variation in K_e and K_p suggesting that extra organic matter from FYM had simply increased CEC. This agrees with the conclusions in the previous section. In the Ley-Arable experiments, organic matter had been increased by growing grass continuously, and then the multiple regression on K balance plus organic CEC accounted for significantly more variation in K_e and K_p than that of K balance plus total CEC. It was suggested that K retention was improved because of the differing selectivities of clay and organic matter for K relative to Ca, divalent cations being very much more strongly adsorbed by exchange sites in organic matter than in clay. As Ca^{2+} was adsorbed from solution by the organic matter more would have come into solution thus freeing exchange sites for K^+ on the clay, which were assumed to be non-limiting in these soils.

The difference between the two sets of results probably arises from differences in both the origins of the K and the organic matter. In the Ley-Arable experiments soluble K fertilizers were applied, the CEC of the clay was dominated by Ca^{+2}, and the K balance was at risk to leaching. However, freshly accumulating organic matter under continuous grass was an ideal sink for Ca^{2+}, removing Ca^{2+} from solution would have encouraged more to come into solution thus releasing exchange sites on the clay for K^+. In the Classical Experiments, FYM supplied organic matter with K probably already occupying many exchange sites. Even if this K was displaced by Ca^{2+}, it should have been absorbed on sites on the clay vacated by the Ca^{2+}.

4.4.3 Effect of farmyard manure plus fertilizers

In very long-term experiments with very contrasted treatments relationships between K balance and exchangeable K may not always be as precise as those in Figure 3.

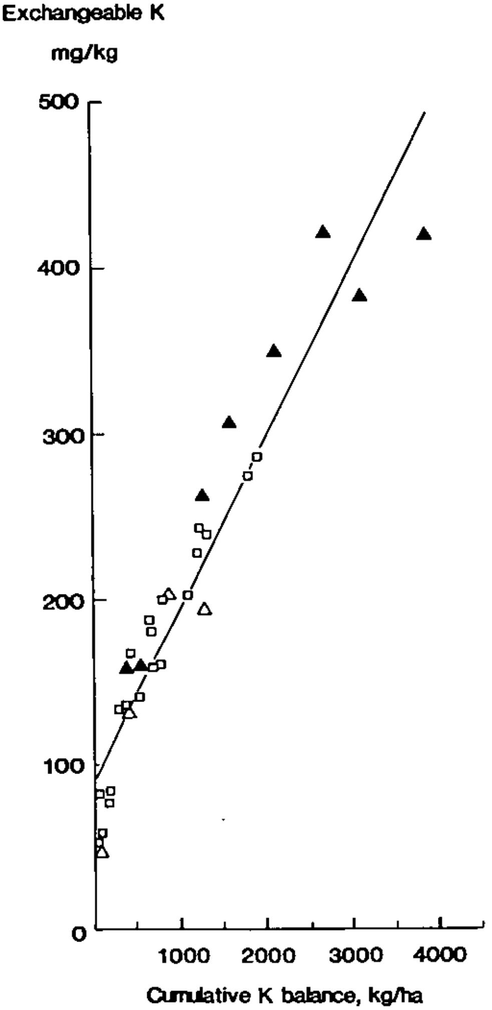


Fig. 3 Relationship between cumulative K balance and exchangeable K in soils treated with fertilizers, □; and farmyard manure, Δ; fertilizers plus farmyard manure, ▲; for 20 years at Woburn.

Figure 4 relates extra K in roots of mangolds grown in recent years on Barnfield (Section 4.2) to extra exchangeable K in soil using the comparisons, PK – P, PKNaMg-PNaMg, FYM-P and FYM+PK-FYM each at four levels of applied nitrogen, 0, 96, 110 and 206 kg/ha. Extra K was that in the 0-54 cm horizon, and, whilst the relationship was acceptable for the majority of the data, there were some outliers. These were mainly for the comparison FYM+PK-FYM; yields had not been increased by the extra PK, and so extra K in roots was small. Because the FYM+PK treatment had supplied excessive amounts of K for many years much K had leached below 54 cm (Table 5) and therefore the extra exchangeable K in the 0-54 cm layer was less than it should have been to fit the relationship in Figure 4 satisfactorily.

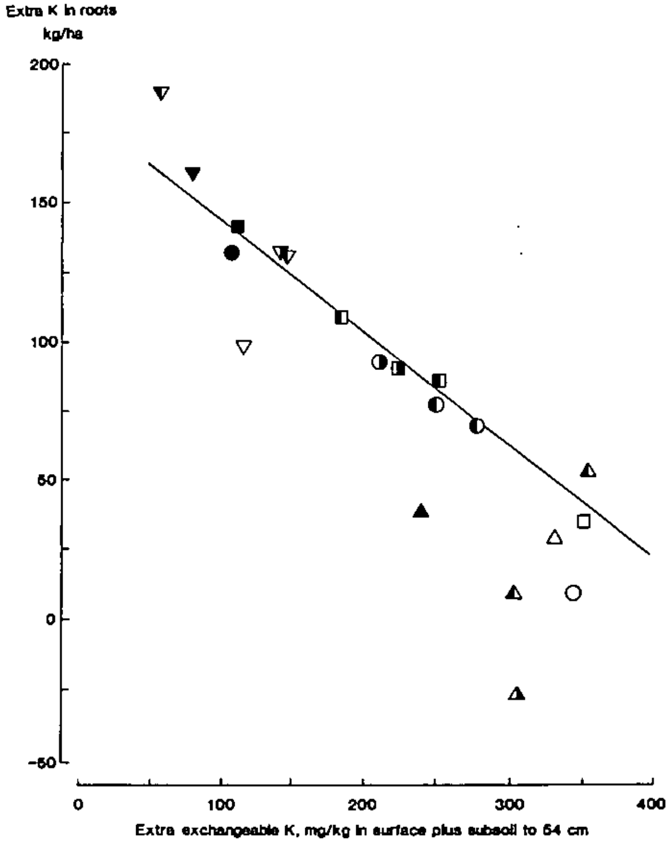


Fig. 4 Relationship between extra K in mangold roots and extra exchangeable K in soil to 54 cm for treatments: PK minus P, ○; PKNaMg minus PNaMg, □; FYM minus unmanured, ▽ and FYM + PK minus FYM, △ each at 4 rates of N, kg/ha, ●, 206; ◑; 110; ◐, 96; ○, none.

5. Release of matrix and residual soil K

5.1 Release of matrix K

The average amounts of K removed annually in crops harvested from soils not given K in long-term experiments on silty clay loam soils at Rothamsted, a sandy loam at Woburn and a sandy clay loam at Saxmundham are in Table 6 which shows that the rate of K release remained relatively constant with time. Offtake of K has been less from the sandy loam than from the silty clay loam and most K was removed from the sandy clay loam soil at Saxmundham. The amounts are dependent on other factors controlling yield and should not necessarily be considered as «base-line» values. Such values, even if accurate, are probably of little practical consequence because most cultivated soils have received dressings of K in fertilizers or manures at some

Table 6 Average amount of K, kg/ha removed annually in harvested crops in long-term experiments at Rothamsted, Woburn and Saxmundham

Experiment	Period	Years	Fertilizer applied			
			None	N	P	NP
Rothamsted						
Broadbalk	1843-1893	50	14	21	—	22
Winter wheat	1894-1944	51	8	10	—	9
each year	1945-1967	23	16	18	—	16
	1970-1975	6	15	25	—	25
Agdell	1848-1851	4	43	—	—	—
Turnips, barley,	1852-1883	32	14	—	—	—
clover, wheat	1884-1951	68	9	—	—	—
in rotation	1952-1957	6	12	—	—	—
Park Grass	1856-1873	18	—	—	43	40
Permanent	1891-1895	5	—	—	27	30
grassland	1920-1923	4	—	—	26	21
	1940-1943	4	—	—	24	20
	1956-1959	4	—	—	39	26
Woburn						
Continuous						
Wheat	1877-1926	50	6	10	7	9
wheat	1929-1942	14	4	3	7	3
	1943-1961*	15	9	6	11	9
Continuous						
Barley	1877-1926	50	9	13	10	12
barley	1929-1942	14	5	5	6	6
	1943-1961*	15	8	6	8	8
Saxmundham						
4-course rotation	1899-1969	71	22	30	—	47

* For 4 years the experiment was fallowed

time and reserves of exchangeable and non-exchangeable K, rather than matrix K, dominate the amounts of K available to crops. This is discussed below; Table 7 shows the amounts of K removed by grass grown on six different soils during periods of between 11 and 13 years following contrasted previous cropping and manuring.

Table 7 K, kg/ha, removed by grass grown on silty clay loams at Rothamsted and a sandy clay loam at Saxmundham where the soils had different manurial and cropping histories

	Rothamsted						Saxmundham	
	Park Grass*				Agdell*		Rotation I*	
	no K since 1856		PK 1898-1964		no K since 1848	PK 1848-1957	no K since 1899	FYM 1899-1969
Exchangeable K, mg/kg	80		670		115	166	126	242
N, kg/ha, per cut	34	68	34	68	100	100	100	100
Year** 1	86	106	286	407	127	182	0	0
2	55	59	306	411	76	179	348	450
3	43	109	218	414	27	129	161	275
4	52	37	206	379	65	157	124	228
5	31	30	161	264	44	105	98	170
6	31	23	106	197	3	8	119	212
7	32	21	105	167	5	9	76	131
8	17	35	175	323	150	208	150	234
9	32	21	226	248	75	122	119	208
10	25	27	161	242	49	52	66	87
11	24	21	114	241	93	129	88	115
12	20	15	113	172	74	106	—	—
13	—	—	—	—	22	33	—	—
Total K removed, kg/ha	448	504	2177	3465	810	1419	1349	2110
Average annual K offtake, kg/ha	37	42	181	289	62	109	123	192

* K applied per ha: Park Grass annually, 225 kg 1898-1964; Agdell every 4th year, 130 kg 1848-95, 220 kg 1896-1951; Rotation I, 15 t/ha FYM, average K content 68 kg. For further details of past cropping and manuring see *Warren and Johnston [31]* for Park Grass; *Johnston and Penny [18]* for Agdell and *Williams and Cooke [34]* for Rotation I, Saxmundham

** Year 1: Park Grass, 1965; Agdell, 1958; Rotation I, 1970

5.2 Release of matrix and residual K on permanent grassland

The site of the Park Grass experiment had been in permanent grassland for at least 200 years when *Lawes* and *Gilbert* started their experiment in 1856 *(Warren* and *Johnston [31])*. Each year the grass was cut for hay in June and the subsequent growth removed in September. One plot was fertilized with N only from 1856 to 1897. In 1898 it was halved, one half was unmanured, the other received PK and these treatments continued until 1964. In 1965 both plots were divided into 40 microplots to test four levels each of P and K at two levels of N, 34 and 68 kg/ha per cut of grass, usually four cuts each year. This change in management put more «stress» on both soils. From that which had been without K since 1856, annual offtake ranged from 37 to 109 kg K/ha during the first four years (Table 7) *(cf.* the 20 to 40 kg K/ha per year removed from the NP plot in Table 6). However, during the next eight years only 24 kg K/ha, was removed each year, about the long-term mean, irrespective of the amount of N applied. The lack of response to N was probably because the species dominating the sward on this plot had adapted to the impoverished soil conditions during the previous hundred years. Much more K was taken up from the soil which had annually received 225 kg K/ha from 1898 to 1964. Average annual offtake in the first four years was 254 and 403 kg/ha with the single and double rate of N respectively. During the next eight years offtake remained reasonably constant, 145 and 232 kg K/ha each year with the single and double rate of N, respectively.

From 1965 the maximum amount of K tested on these microplots was 450 kg/ha each year. On the impoverished soil K offtake was increased from 24 to 213 and 341 kg/ha with the single and double rate of nitrogen. On the enriched soils, K offtake was increased only from 181 to 210 kg/ha with the single rate of N and from 289 to 396 kg/ha with the double rate. This suggests that soil reserves in the enriched soil were able to supply much of the K required by grass, especially at the lower N rate for a period of at least 12 years.

5.3 Release of matrix and residual K following arable cropping

Cropping in the Agdell experiment was a four-course rotation of arable crops from 1848 to 1951 and arable cropping continued until 1957. Dressings of K were given only once in four years, 130 kg/ha between 1848 and 1895 and 220 kg/ha between 1896 and 1951 *(cf.* 225 kg/ha each year on Park Grass). Compared to the exchangeable K contents of Park Grass soils, those in Agdell soils in 1958 were much smaller on the K residue plot but slightly larger on the no K plot (Table 7). The Agdell no K plot had also been without nitrogen and the estimated amount of K removed between 1848 and 1957 was only 1325 kg/ha *(Johnston* and *Penny [18]).* During the next 13 years grass grown on this plot and given nitrogen, 100 kg/ha per cut, removed, on average, 62 kg K/ha each year, about twice that removed from the unmanured Park Grass soil although both had been unmanured with K for the same length of time, both had much the same amount of clay and both are classified as belonging to the same soil series. More K, 109 kg/ha on average, was taken up from the plot with K residues. For a number of reasons the grass was ploughed and resown three times. For example, the Cocksfoot was largely killed in the severe winter of the fifth year, it grew little in the sixth year and Timothy was sown the following year. K offtakes were small in both the sixth and seventh years but in the next year they were much larger, presumably K released and not taken up in the first two of the three years was removed in the third year. Such data emphasize the need for experiments to be continued over a number of years if reliable estimates of K release are to be obtained.

A four-course rotation of arable crops had also been grown at Saxmundham – Rotation I – from 1899 to 1969. The experiment was then sown half to grass and half to lucerne in spring 1970. K taken off in the grass from plots given either P but no K or with residues of 70 dressings of 15 t/ha FYM, each of which supplied, on average, 68 kg K/ha are in Table 7. In the first year the grass established slowly, no crop was harvested, and the following year offtakes were large. Unlike Agdell, the grass at Saxmundham did not need to be resown throughout the 11 years and K offtakes were much more uniform from year to year, average 123 and 192 kg/ha on plots without and with K residues. Thus this sandy clay loam soil, without K manuring since 1899, released twice as much K as did the silty clay loam on Agdell.

5.4 Offtake of residual K and its effect on exchangeable K

The negative K balances in these three experiments are related to decreases in exchangeable K in Table 8. Much of the K removed from the two Agdell soils and the soil without K manuring, no K soil, at Saxmundham came from non-exchangeable K reserves. The decline in exchangeable K accounted for only 20% of the K taken off the no K plot on Park Grass and the K residue plot at Saxmundham. The soil with K residues on Park Grass contained large amounts of exchangeable K. At the lower rate of N manuring the decrease in exchangeable K accounted for more than 60% of the K offtake whilst with the double rate of nitrogen, K uptake was greater and more non-exchangeable K was used.

Table 8 Effect of offtake of K in grass on the amounts of exchangeable K in the 0-23 cm soil layer at Rothamsted and Saxmundham

	Rothamsted						Saxmundham	
	Park Grass*				Agdell		Rotation I	
	no K since 1856		PK 1898-1964		no K since 1848	PK 1848-1957	no K since 1899	FYM 1899-1969
N, kg/ha per cut	34	68	34	68	100	100	100	100
Exchangeable K, kg/ha in:								
Year 1	205	205	1716	1716	303	437	425	816
Last year	113	120	333	243	282	337	342	391
Decrease in exchangeable K, kg/ha	92	85	1383	1473	21	100	83	425
K offtake in grass, kg/ha	448	504	2177	3465	810	1419	1349	2110
Decrease in exchangeable K as a % of K offtake	21	17	64	43	3	7	6	20

* For details see footnote to Table 7

Similar effects of negative K balances on exchangeable K were also observed by *Johnston* and *Poulton [19]* in an experiment at Rothamsted where barley was grown continuously (Table 9). Although the second period, 1951-74, was only about half as long as the first, 1903-51, much more K was removed in the second period because the barley was given N fertilizer. Even so the decline in exchangeable K in the second period accounted for a smaller proportion of the K removed, and much K must have come from non-exchangeable reserves.

Table 9 Changes in exchangeable K related to a negative K balance in two periods, 1903-51 and 1951-74, when barley was grown continuously on the Exhaustion Land at Rothamsted

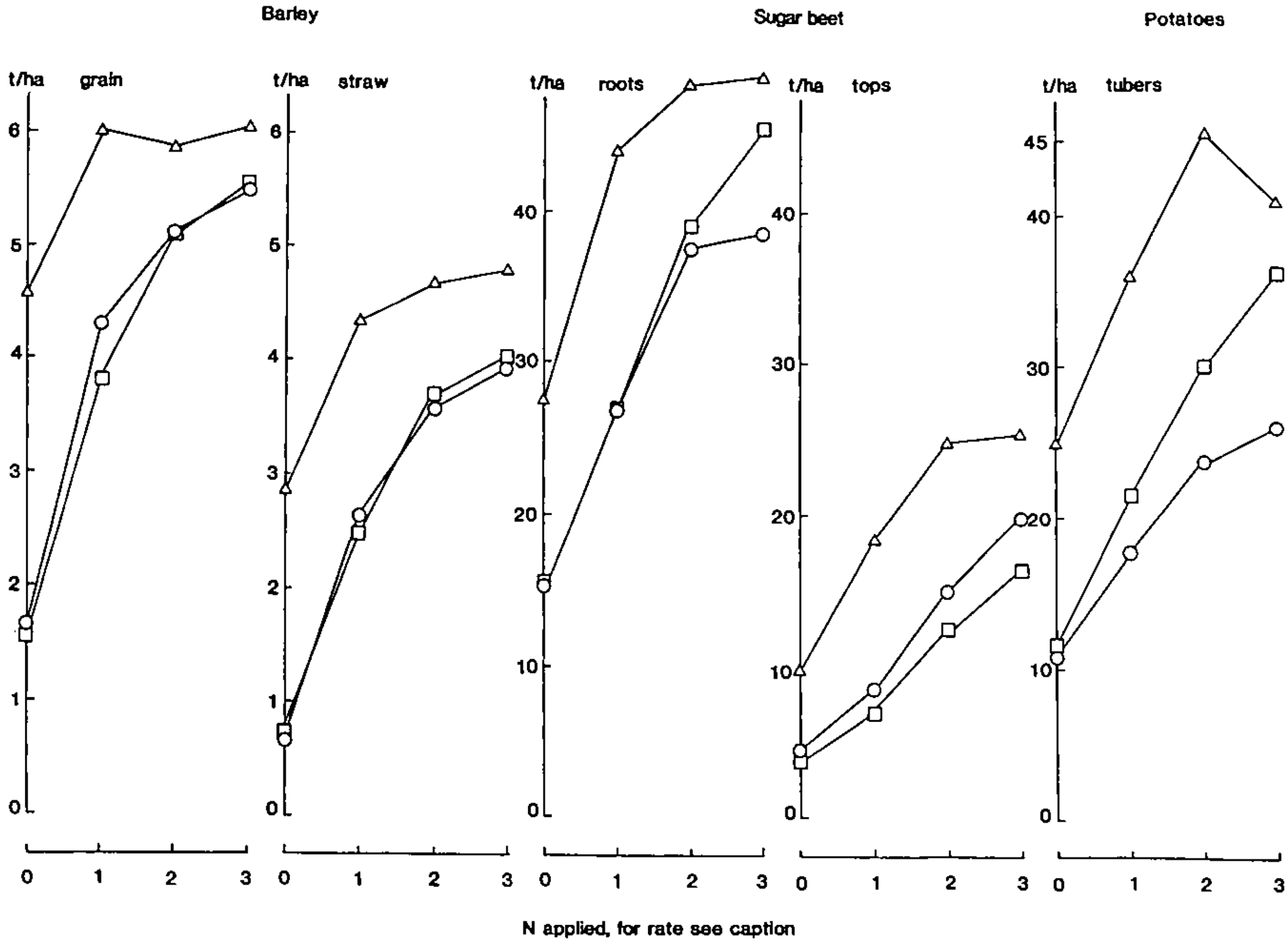
Period	Treatment prior to 1903	Exchangeable K in soil kg/ha			K balance kg/ha	Change in exchangeable K as a % of K balance
		At start of period	At end of period	Change		
1903-51	None	288	223	− 65	− 594	11
	FYM	801	321	−480	− 848	57
	P	442	255	−187	− 844	22
	PK	1376	455	−921	−1088	85
1952-74	none	223	208	− 15	− 317	5
	FYM	321	264	− 57	− 640	9
	P	255	230	− 25	− 481	5
	PK	455	339	−116	− 749	15

6. Factors influencing K balance and its effect on exchangeable K

6.1 Effect of nitrogen

From 1843 to 1959 the root crops grown on Barnfield (Section 4.2) were given only small amounts of nitrogen, 96 and 110 kg/ha as N fertilizer and rape cake respectively and 206 kg/ha as fertilizer plus rape cake. In 1969 the plots were divided to test four rates of fertilizer N (the amounts are in Table 10) on spring barley, spring wheat, sugar beet and potatoes. Treatment effects on the cereals were similar, yields of spring barley, sugar beet and potatoes for the P only, PK and FYM treatments are summarised in Figure 5; K in the crops at harvest are in Table 10. As yield increased, K in the crop at harvest increased, and the data clearly support previous findings that, for cereals, much of this K is in the straw and for sugar beet much is in the tops. The disposal of straw and tops at harvest will therefore have a large effect on the K balance.

Fig. 5 Relationship between yields of spring barley, sugar beet and potatoes in 1969-74 and fertilizer N applied, to soils treated with farmyard manure, Δ; PK fertilizers, □; P fertilizers only, ○; during 1856-1974. N applied: 0,1, 2,3: 0, 48, 96, 144 kg/ha to barley; 0,72, 144, 216 kg/ha to root crops. →



Barley
Sugar beet
Potatoes
t/ha grain
t/ha straw
t/ha roots
t/ha tops
t/ha tubers
N applied, for rate see caption

Table 10 Effect of nitrogen on potassium offtake, kg/ha, in spring barley, sugar beet and potatoes, Barnfield 1969-73, Rothamsted

Treatment** and crop	Nitrogen applied* 0		1		2		3	
Spring barley								
	grain	straw	grain	straw	grain	straw	grain	straw
FYM	22	43	29	66	28	78	29	106
PK	8	10	17	26	23	48	26	66
P	8	7	19	20	22	29	24	31
Sugar beet	roots	tops	roots	tops	roots	tops	roots	tops
FYM	57	90	91	150	102	182	111	190
PK	29	35	49	65	72	109	91	131
P	25	32	43	47	53	59	52	65
Potatoes	tubers		tubers		tubers		tubers	
FYM	150		220		274		243	
PK	65		125		158		205	
P	58		93		111		119	

* N applied: 0, 1, 2, 3: none, 48, 96, 144 kg/ha to barley grown in 1970 and 1972; none, 72, 144, 216 kg/ha to potatoes and sugar beet grown in 1969, 1971 and 1973; offtakes are averages for appropriate years

** Treatment applied each year: FYM, 35 t/ha; P, 35 kg/ha; K, 225 kg/ha

At each rate of nitrogen fertilizer, barley yields were as large on soils that had been unmanured with K for more than 100 years as they were where K had been applied each year. Extra yield on the FYM-treated soil, which contained more than twice as much organic matter as the fertilizer only soil, may have been because organic nitrogen was mineralized during the growing season, or the extra organic matter had improved soil physical properties to the benefit of the barley. Yields of both sugar beet roots and potatoes were increased by the accumulated K residues, especially at the highest rate of nitrogen tested. Yields of root crops, like those of barley, were even larger on FYM-treated soils, possibly for the same reasons. At each rate of N, the potato tubers and tops plus roots of sugar beet contained much the same amounts of K, especially on the P only treatment (Table 10). On this treatment, which had been without K since 1843, probably only matrix K was taken up but the root crops contained twice as much K as the barley. The average annual offtake of 38 kg K/ha was maintained for six years (no straw analyses were available for one crop of barley which has therefore been excluded). This amount is larger than the 25 kg K/ha which is now removed annually from Park Grass (Table 7). Whether this extra offtake on Barnfield is related to differences in the amounts of clay, clay mineralogy or to the arable crops getting some K from the subsoil is not known.

An additional interesting effect of testing two N rates on Barnfield between 1843 and 1959, and the effect this had on K balance, is that the soils fertilized with the lower rate of N now have more exchangeable K (Table 11). Because manuring has continued over such a long period, extra exchangeable K is found at all depths sampled down to 54 cm, except for two comparisons in the lower horizons.

Table 11 Effect of extra nitrogen fertilizer on exchangeable K, mg/kg, in soils with K manuring each year since 1843

	Soil depth cm			
Treatment*	0-23	23-30	30-46	46-54
PK plus 110 kg N	530	293	220	215
PK plus 206 kg N	375	212	186	156
FYM plus 110 kg N	308	294	178	190
FYM plus 206 kg N	261	204	192	146
FYM plus PK and 110 kg N	846	494	324	212
FYM plus PK and 206 kg N	638	460	300	216

* K, 225 kg/ha in potassium sulphate, 165 kg K in 35 t/ha FYM
FYM supplied 220 kg total N

6.2 Effect of removing constraints on yield

The Garden Clover experiment at Rothamsted has grown clover continuously since 1854 *(McEwen et al. [26])*. It was sited on an enriched garden soil, no fertilizers were applied before 1896, and only very small amounts were given between then and 1956. Initially the soil contained much exchangeable K, 593 mg/kg, and the amount gradually declined, to 216 and 163 mg/kg in 1879 and 1896, respectively, and by 1956 it was only 85 mg/kg and K deficiency was considered to be limiting yield. A test of extra K between 1956 and 1966 did not increase yield dramatically, average yields of dry matter without and with K were 2.2 and 4.6 t/ha respectively. K offtake was small, there was a small negative K balance where no K was applied but exchangeable K changed little, there was a large positive K balance where K was given and this did affect exchangeable K (Table 12).

Table 12 Effect of K balance on exchangeable K in soil in the Garden Clover experiment, Rothamsted, 1956-83

	Average annual K dressing kg/ha	K balance kg/ha	Exchangeable K, kg/ha during each period: At start	At end	Difference	Change in exchangeable K as percentage of K balance
1956-66	None	− 246	171	194	+ 23	—
	136	+ 617	171	431	+260	+42
1967	Balancing*	+ 437	194	338	+144	+33
1968-78	250	+1667	375	1065	+690	+41
1979-83	125	−1494	1065	502	−563	−38

* Balancing dressing, 437 kg K/ha applied once only to plot which received no K during 1956-66

In 1967 the K test was stopped and a balancing dressing of K was applied to the plot without K to unify exchangeable K on the two plots so that other factors could be tested. From 1968-78 a generous dressing of K was applied each year but yields remained small, not more than 5 t/ha dry matter, and again the K balance was positive and large. In 1979 the K dressing was decreased. In 1979 the cultivar was changed and adequate disease control resulted in large yields over the next four years, up to 18 t/ha dry matter. Offtakes of K exceeded K dressings and the K balance was negative. The effects of these changes in manuring and K balance on exchangeable K are summarized in Table 12, which shows that changes in exchangeable K, as a percentage of K balance, varied from − 38 to + 42%.

A similar change in K balance from positive to negative for arable crops was observed on Broadbalk when a change of cultivar, improved disease and pest control and a change of crop rotation, all resulted in an increase in crop yield and K offtake *(Dyke et al. [8])*.

6.3 Changes with time

The proportion of the K balance which can be accounted for by a change in exchangeable K can vary with time. In the Reference Experiment at Woburn (Section 4.4.1) where K was applied, the K balance was positive in each of the four cycles of the five-course rotation. However, the proportion of the K balance which remained exchangeable changed with time (Table 13). In the last two cycles, only about 25% of the K balance remained exchangeable on the fertilizer plots even though the amounts of exchangeable K were not as large as those on FYM-treated soils. This may have been because the extra organic matter provided additional exchange sites. The phenomenon is presumably related to the relative risks of K being leached or held on suitable sites.

Table 13 Change with time in the proportion of the K balance which remained exchangeable, Reference Experiment, Woburn, 1960-79

Year*	Plots receiving Fertilizer K			Plots receiving FYM		
	Exchangeable K mg/kg	K balance kg/ha	Change in exchangeable K as a % of K balance	Exchangeable K mg/kg	K balance kg/ha	Change in exchangeable K as a % of K balance
1964	70	154	50	125	505	79
1969	160	372	86	236	743	58
1974	195	410	26	324	805	41
1979	230	510	27	332	865	10

* Last year of 5-year rotation, exchangeable K value in that year

7. Effects of negative K balances on succeeding crops

Positive K balances, that build up soil K reserves, may or may not benefit following crops depending on the requirements of the crop for K and the amounts of K released from the soil. However, of perhaps greater importance are the effects of negative K balances on yields of succeeding crops. There were large negative K balances on Agdell and Rotation I as a result of growing grass (Section 5.3) and these experiments were modified to test the effect of these negative balances.

7.1 On a silty clay loam soil

On Agdell only half of each plot grew grass for 12 years; the other half grew arable crops for three years and was then fallowed for the remaining period so that K offtake on the «arable» half plot was small. Spring barley, potatoes and sugar beet were grown in rotation during 1973-76 and K offtakes and responses to fresh K dressings are in Table 14. Although the grass removed much K from soils without and with residues, barley following grass on either soil took up only a little less K than when following arable crops. However, grain yields following grass, but not arable crops, were increased by giving extra K. This response by barley to fresh K was much larger than on Barnfield (Figure 5). K offtakes by potatoes were much less following grass than following arable crops; the potatoes after grass took up less K than did barley. Pota-

Table 14 Effect of removing much K from soils by growing grass on the annual K offtake, and response to fresh K, by arable crops which followed, Agdell, Rothamsted

Period and cropping								
1848-1957 arable rotation	No K since 1848				PK 1848-1957*			
1958-1972 grass or arable	Grass**		Arable		Grass		Arable	
1973-76 arable crops testing fresh K	K offtake kg/ha	Response t/ha	K offtake kg/ha	Response t/ha	K offtake kg/ha	Response t/ha	K offtake kg/ha	Response t/ha
Spring barley, grain fresh K 50 kg/ha	31	0.89	40	−0.23	42	0.66	56	−0.26
Potatoes, tubers fresh K 205 kg/ha	18	15.5	92	6.2	38	16.2	184	2.1
Sugar beet, roots fresh K 257 kg/ha	105	3.4	160	−0.2	118	6.6	196	0.4

* For details see text and footnote to Table 7
** Average annual K offtake by grass: 62 kg/ha on no K plot, 109 kg/ha on PK plot

toes responded to fresh K on all soils and the response on the soil with most K residues was about equal to that on Barnfield; K offtakes were similar also *(cf.* Tables 14 and 10). Sugar beet following grass removed more K than the grass had, especially from the soil without K residues but possibly some of this K came from the subsoil. Root yields were much increased by fresh K on soils following grass, but there was hardly any response following arable crops. K offtakes and responses were similar to those on Barnfield (Figure 5 and Table 10).

7.2 On a sandy clay loam soil

Lucerne sown at Saxmundham in 1970, at the same time as the grass (Section 5.3), failed in 1974-75 because of crown wart of lucerne *(Urophlyctis alfalfae).* The amount of K removed in the lucerne was less than in the grass, 520 and 926 kg/ha respectively on soils without K since 1899 and 1000 and 1466 kg/ha on soils with FYM each year from 1899-1969. The lucerne was ploughed in 1976 and cereals, beans and potatoes were grown during the next four years. The principle comparisons were between plots which had received 1. FYM 1899-1969; 2. K fertilizer 1899-1976; 3. no K since 1899. For each of these three treatments, the K balance during 1970-76, when lucerne was grown, was -1000. -220 and -520 kg K/ha, respectively. Average yields of winter wheat (3 years), winter barley (2 years), spring barley (1 year), beans (3 years) and potatoes (3 years) are in Table 15 together with yields given by fresh K, 52 kg/ha for cereals and beans and 208 kg/ha for potatoes. Yields of winter and spring cereals were as large on soils without K manuring since 1899 as they were on soils which had received K each year, 104 kg/ha since 1966 and 53 kg/ha before that. The FYM-treated soils yielded more, although FYM had not been applied since 1969, perhaps because the soils contained more organic matter rather than more K residues. Neither crop responded to fresh K on any soil (the yield of spring barley on FYM-treated soil without fresh K was anomalous). Yields of beans and potatoes increased in the order expected, namely soils without K < soils with the FYM residues < soils with K each year. Both crops responded to fresh K, except beans on the most enriched soil, However, fresh K did not increase yields on the most impoverished soils to those obtained on soils which had received K each year; again evidence for the maintenance of soil K reserves for K responsive crops (see also Section 2).

During the 11 years when grass was grown at Saxmundham much K was removed (Table 7) and even on plots receiving K each year the balance was negative. To measure the effect of this large K offtake on the yields of arable crops the grass plots were divided and sufficient grass was ploughed each year to grow first beans (1982-84) and then winter wheat during 1983-85. Four amounts of nitrogen were tested on the wheat; the crops grown following lucerne had received only a single rate of N. Grain yields were large, ranging from 7 to 12 t/ha, and are averaged over years and appropriate treatments in Table 16. The shape of the N response curve suggests that maximum yields were probably achieved. Even after more than 80 years without K manuring yields were 9.16 t/ha with most nitrogen. This yield was less than the best yield obtained either on the soil with FYM residues, 10.07 t/ha, or where K was applied each year, 10.48 t/ha. So after 80 years without K manuring, and the removal of much K in grass grown in the last 13 of those years, winter wheat yields were increased by 1.32 t/ha where extra fertilizer K was given.

Table 15 Effect of K balance after seven years of growing lucerne on the yields of the arable crops which followed, Saxmundham 1977-80

	Annual treatment* 1899-1980					
	FYM		no K		K	
K balance after lucerne 1970-76 kg/ha	−1000		−520		−220	
Exchangeable K in 1976, mg/kg	132		113		166	
Crop and treatment** 1977-80	−K	+K	−K	+K	−K	+K
Winter wheat grain, t/ha	9.04	9.08	8.49	8.54	8.50	8.60
Winter barley grain, t/ha	8.48	8.32	7.58	7.74	7.69	7.71
Spring barley grain, t/ha	5.27	6.08	5.68	5.68	5.71	5.86
Beans grain, t/ha	3.73	4.15	2.52	3.60	4.42	4.38
Potatoes tubers, t/ha	41.3	46.2	28.8	39.6	43.1	44.0

* FYM, 15 t/ha supplying 68 kg K, not applied after 1969; K, 53 kg/ha 1899-1965, 104 kg/ha 1966-80

** Fresh K, 52 kg/ha for cereals and beans, 208 kg/ha for potatoes

Table 16 Yields of winter wheat, given four amounts of nitrogen and following grass at Saxmundham, 1983-85

	Annual treatment* 1899-1985		
	FYM	no K	K
K balance** after grass 1970-84, kg/ha	−2230	−1500	−1210
Exchangeable K mg/kg, in 1984	115	106	136
N applied, kg/ha		Yields of grain, t/ha	
120	8.67	8.90	9.87
160	10.07	8.72	10.48
200	9.61	8.70	10.22
240	8.90	9.16	9.68

* For details see text, FYM not applied after 1969, K applied each year

** The amounts of K given here are averages for the sub-plots which were ploughed for wheat from 1983, they are larger than the offtakes during 1970-80 given in Table 7

8. Conclusions and future research needs

Evidence presented here shows that various factors interact to control K balance. Fertilizer and manure dressings should be adjusted to allow for the release of soil K reserves and should not be so large as to risk excess K being leached to depths from which roots cannot recover it. There is no simple relationship between either positive or negative K balances and exchangeable and non-exchangeable K in soil. Both forms of K are related more to past cropping and manuring than to any fundamental property of the soil. Therefore any estimate of either form of soil K obtained by field, glasshouse or laboratory experiments is specific to each soil. Results of exhaustive cropping of many soils with different histories from one experiment *(Johnston* and *Mitchell [17]* did give an estimate of non-exchangeable K but such experiments are time consuming, a laboratory method would be preferable. Some laboratory methods have been proposed, they include the use of strong acids but invariably these extract too much K. For example nearly all the K in micaceous minerals in Rothamsted soil is extracted; whilst this K may be potentially available such methods give no indication of the likely time scale for its release in the field. Recently, *Goulding [9]* has summarized work done at Rothamsted on the release of potassium to a calcium-saturated cation-exchange resin and *Goulding* and *Loveland [10]* have described an application of the method. Whilst the amount and rate of K release towards the end of the exchange period probably reflects release of matrix K, and may relate to different soil types, much larger amounts of K, with much faster rates of release, are exchanged initially and these relate more to past cropping and manuring than soil type. Like exhaustive cropping in the glasshouse, the method is time consuming and because of this and the reasons given above, is unlikely to be used for routine advisory purposes. Recently attempts have been made to find extractants capable of giving similar data to that by calcium exchange but more quickly. So far, the extractants tested have only removed amounts of K equal to those exchangeable to ammonium ions. We still need a reliable, quick method to determine soil K reserves which are available over a period of a few years. In addition, a good method for categorizing soils for the likely response by annual arable crops to fresh K dressings is needed. As suggested earlier in this paper a reassessement of water soluble K for this purpose might well be worthwhile.

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Nutrient Cycling in Different Pasture Systems

W.E. Murphy, An Foras Taluntais, Johnstown Castle Research Centre, Wexford/ Ireland*

Summary

Most of the nutrients in grassland systems pass through the animal. The amounts retained are relatively small. When nutrients are lost from the cycle they are replaced from the soil, fertilisers, the atmosphere or imported feed. Nutrients are lost by leaching, runoff and in animal products. The influences of the factors that make up grassland systems are discussed.

1. Introduction

The essential nutrients for plant growth follow many pathways in grassland. They are transformed several times in the soil and then taken up by plants. When the plants are harvested they may be consumed directly by animals or may be stored and consumed later. Most of the nutrients in the plants are not retained by the animal but are excreted to be returned again to the soil to be the subject of another cycle of activity.

The supply of nutrients in the cycle may be increased or decreased by additions and removals. The main activities are represented in Figure 1.

There is considerable variation in the source and in the long term fate of nutrients and depending on the nutrient and on the method of utilization of the sward.

2. Sources of nutrients

In intensive grassland systems the balance of nutrients is maintained by supplies of nutrients from different sources such as weathering of soil minerals, deposition from the atmosphere, imported feeds fed to the animals and fertilisers supplied by the farmer. The farmer's problem is to know how much fertiliser to use to optimise production. Of the major nutrients, the soil minerals supply considerable amounts of potassium and much lower amounts of phosphorus. The atmosphere supplies nitrogen and sulphur. Forage crops and grain brought into the system together with fertilisers supply all the major elements.

* Dr. *W. E. Murphy,* The Agricultural Institute, Johnston Castle Research Centre, Wexford/ Ireland

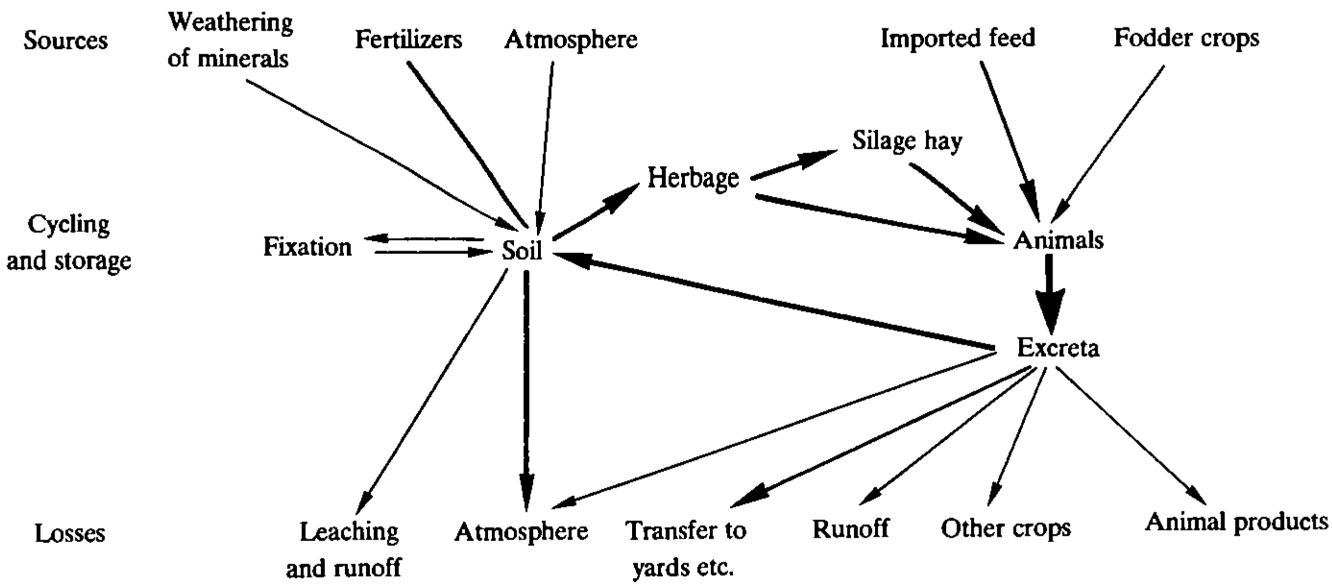

Fig. 1 Nutrient pathways in pasture systems

3. Loss of nutrients

Losses may occur to the subsoil, drainage system, the atmosphere or as animal products. Losses from the system occur as a result of surface runoff and leaching. Leaching is not an important source of loss of P or K but nitrogen is freely leached as nitrate. Runoff of applied nutrients either in the organic or inorganic form is very important immediately after application and is dependent on weather and soil conditions. Large quantities of applied nutrients may be lost in this manner.

The influence of adverse weather conditions near the time of application of slurry was shown by *Sherwood [1983]* where she measured the concentration of nutrients in runoff water when rainstorms occured at different intervals after slurry application (Table 1).

Atmospheric losses apply mainly to nitrogen; ammonia may be volatilized or there may be denitrification. Another source of loss to the system is transfer of excreta to roads and yards in the movement of stock. This may be as high as 30 per cent in intensive dairy systems *(Karlovsky [1981]*.

Animal products are a source of loss of nutrients to the nutrient cycling system. The actual amounts removed are determined by the type of animal, the yield of animal product and the stocking rate. There is considerable variation in the amounts of nutrients removed by the livestock unit equivalent of different types of animals. The amounts involved for different animals were estimated by the *Agricultural Research Council [1965]*. Table 2 shows these amounts on a livestock unit basis.

Table 1. Composition of runoff water from storms which occured at different intervals after application of pig slurry at 3.6 t DM/ha.

Intervals between spreading slurry and rainstorm (days)	N	P in mg/l water	K
1	300	39	168
7	41	4	52
14	10	11	16
21	8	7	13

Table 2. Amounts of nutrients removed in one year by a livestock unit.

	Nutrient removed (kg/LU)			
Animal Types	Ca	P	K	Mg
Young cattle	11.0	7.0	1.2	0.4
Mature cattle	3.9	1.6	0.6	0.2
Cow 4500 kg milk	6.2	4.6	7.3	0.6
Sheep	8.9	5.0	1.6	0.4

Thus, removals of potassium in animal products are very small but significant amounts pf P are extracted from the system. In contrast, where excreta are transferred out of the system the removal of K is high because of the relatively high concentration of K in the herbage.

The cycling of nutrients is also affected by the fixation or storage of elements in the soil or in the organic matter. In conditions of low fertility the fixation of nitrogen, phosphorus and potassium prevent rapid release to the growing plants and therefore reduce the productivity and rate of cycling.

4. Stocking rate

The rate at which nutrients are recycled to grazing land is greatly influenced by the stocking rate. To have an effective stocking rate of 2.5 livestock units (LU) per ha on a full year basis the grazing area supplies 912 cow grazing days durning the grazing season and all the excreta are returned to that area. The areas influenced by dung and urine are approximately equal at about 4 square meters per cow per day *(Mac Lusky [1960])*. Since the urine contains most of the N and K and the dung contains all the P it is necessary for an area to be affected by both dung and urine before there is a complete cycling of the nutrients. There will always be some overlap of areas from year to year so that complete cycling is delayed by this process. Figure 2 shows the number of

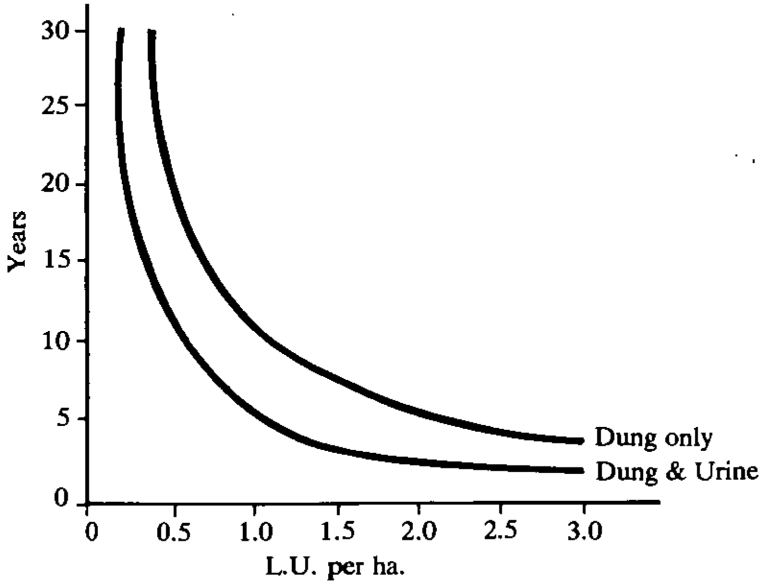

Fig. 2. Return of nutrients to grazing land and effect of stocking rate on time required to affect 80% of area

years required to have recycling of nutrients to 80 per cent of the grazing areas at different annual stocking rates. It requires 9 years at 1 LU per ha and 5 years at 2.5 LU per ha. The significance of this is that large areas of fields must have sufficient reserves of nutrients to grow grass under what is virtually a cutting regime for severeal years before the reserve is replenished by the large amounts of nutrients deposited in dung and urine. In areas that are cut for silage the number of grazing days and hence the effective stocking rates are reduced and the period required for recycling is at least doubled.

5. Sward utilization

The method of utilization of the grassland has a large effect on the nutrients in the cycle. The sward may be grazed or cut once or more times for silage and then grazed for the remainder of the year. When the sward is cut for silage large quantities of N, P and K are removed and may be returned as a uniform dressing of slurry about a year later. Thus, to maintain plant growth in the meantime the total amount of nutrients in the system must be increased. Further increases are necessary if there are losses from storage.

6. Sward type

Grassland systems may be based on permanent swards or on swards that are part of a crop rotation system. Under permanent swards there is a build up of soil organic matter and a large store of nutrients in the organic form. The relatively slow breakdown of this organic matter provides a supply of nutrients each year, when the soil temperature rises and biological activity increases. In swards in a crop rotation system there is a large release of nutrients on ploughing up the sward. Nitrogen as nitrate is often in excess of the crop needs and is lost to groundwater or denitrified in winter. When the land is resown to grass, nitrogen is in short supply until there is a build up of organic matter.

In the course of the tillage rotation nutrients are removed from the system in the crops. In a large scale rotation experiment at Johnston Castle the amount of potassium removed in an arable rotation was 164 kg/ha/year compared with less than 10 kg/ha removed by grazing animals.

7. Factors affecting supply of nutrients

There is a wide diversity of grassland systems. They contain factors that seriously affect the supply of nutrients in the nutrient cycle. Table 3 shows the main factors.

Table 3. Factors that influence the nutrient cycle.

Factor	No. of levels	
Sward type	2	Permanent or temporary
Utilization method	2	Grazing or silage
Type of animal	4	Young and old cattle, cows, sheep
Stocking rate	3	Low medium high
Use of concentrates	3	Zero medium high

All combinations of the factors in Table 3 are possible.

The number of subdivisions could be increased by allowing for more diversity in sward types, methods of utilization of the sward, stocking rates and levels of supplement feeding. It is obvious that the nutrient cycle can contain large or small amounts of nutrients and there can be a rapid recycling (2-3 years) or very slow recycling over 20 years depending on the system used an the intensity of the farming.

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Evaluation of Potassium from Plant Residues in Arable Cropping Systems

R. Gutser, Institute for Plant Nutrition, Technical University Munich, Freising – Weihenstephan/Federal Republic of Germany

Summary

In one model experiment and four long-term field trials the effects of straw, beet tops and stable manure on removals of K by plants and on K contents of soils were examined. In principle, K supplied by crop residues is adequately determined by conventional extraction methods (model trial). Utilization by plants varied according to K supply of the soil and amount of fertilizer K application between 10 and 90%. Positive balances of K (fertilizer added – removed) after organic manuring were expressed in an increase of the K pool in the soil (partly CAL-K, but especially HCl-K); on soils with a good buffer capacity for K, CAL-extraction did not indicate positive K balances sufficiently.

Crop residues, as is known, contain much potassium *(e.g.* straw 45-55 kg K, 40 t beet leaves 200-250 kg K). Consequently, the actual amount of K removed by a crop depends largely on whether or not the residues are removed from the field.
In summary, K fertilizer policy in the Federal Republic of Germany is related to soil tests as under.

K supply according to soil test:	K application:	
low	removal + addition	optimally
medium – high	removal	distributed
very high	removal – reduction	within a crop sequence

Potassium contained in crop residues or supplied by farm manure is equivalent to that in fertilizer.

Pot trials have shown that potassium in plant residues has the same good effect as mineral potassium *(e.g. Kuhlmann [1983]; Amberger et al. [1984]* for slurry manure). *Von Braunschweig [1985]* however found fertilizer K to be more efficient in field trials than potassium in straw or beet tops.

* Dr. *R. Gutser*, Institute for Plant Nutrition, Technical University Munich, D-8050 Freising-Weihenstephan, Federal Republic of Germany

Practical experience shows that a positive K balance (application – removal), especially as a consequence of organic manuring, is often not reflected in measurements of available potassium in the soil. This is partly explained by the fact that especially in well buffered soils potassium measured by conventional methods (DL, CAL, $CaCl_2$ etc.) is not an adequate value for balance accounting (*Amberger* and *Gutser [1976]*). In the work described we have tried to elucidate the potassium effect of crop residues. However, as these experiments were concerned with various problems and as potassium supplied by crop residues was only an addition to, but did not substitute, fertilizer K, optimal supply to plants was in most cases already guaranteed by fertilizers, and the potassium in crop residues could not effect any yield increases and at most led to higher removals of K by the plants.

1. Pot experiment on the evaluation of potassium from crop residues in the soil

In a model trial we tried to clarify how far potassium supplied by crop residues and slurry can be estimated by conventional soil testing methods.

Experimental outline

soils: a) loamy sand (12% clay, 19% silt), pH 6.0, CAL-K: 30 mg/100 g soil
b) silty loam (22% clay, 65% silt), pH 6.2 CAL-K: 26 mg/100 g soil)
500 g/pot

incubation: 2, 8 and 18 weeks (18 °C, 60% of max. water capacity)
organic manure (mixed with soil):

		K supply (mg total K 100 g soil)	CAL soluble portion %
1. control		—	—
2. wheat straw	2 g DM/pot	8.4	73
3. beet leaves	0.5-1 cm chopped	12.9	73
4. green rape	— fresh material —	12.2	73
5. cattle slurry (10g/pot)		7.6	96
6. KCl (in solution)		8.3	100

From73 up to almost 100% (slurry) of the potassium contained in organic manure was CAL soluble.

Results

Potassium in crop residues and slurry was recorded properly by CAL – and $CaCl_2$ – extraction independent of soil or incubation time; it did not differ essentially from potassium applied in mineral form (Table 1).

Table 1 Recovery of K added in form of plant residues (% of total K applied – minus control)

Manuring	Loamy sand 2	8	18 Wo	Silty loam 2	8	18 Wo
			CAL-extraction			
straw	73	82	87	73	68	67
beet tops	83	104	99	88	88	84
green rape	92	102	104	97	99	83
slurry (cattle)	79	93	99	84	80	85
KCl	112	84	80	55	65	71
			$CaCl_2$-extraction			
straw	60	60	58	47	46	43
beet tops	73	85	71	57	60	53
green rape	66	82	83	72	66	65
slurry (cattle)	70	74	80	68	53	51
KCl	67	71	74	57	49	43
			Changes in control (mg K/100 g soil)			
extraction						
CAL:	31	31	29	26	28	26
$CaCl_2$:	19	19	17	14	14	13

Potassium from beet leaves and green rape (higher amounts of applied K) as well as slurry K appeared faster and more complete in the soil extract than potassium contained in straw. CAL dissolved more K than $CaCl_2$ (higher exchange capacity). In most cases on the loess soil the recovery of added potassium decreased in most cases with increasing incubation time ($CaCl_2$), in some cases it did not change (CAL) with the exception of CAL-extraction after KCl – application.

2. Field trials with straw and stable manure

In several long-term field trials (fertilizer tests with various P and K forms or increasing N application), the nutrient and special additional effects of organic manure were studied on plots receiving straw and stable manure *(Amberger* and *Gutser [1976]; Gutser* and *Amberger [1985]; Bosch* and *Gutser [1985]).*

Site conditions:

Weihenstephan — 810 mm precipitation
7.7 °C mean annual temperature
brown earth from loess loam

22% clay	C_t = 1. 1%
60% silt	N_t = 0.12%
Total K: 1.5%	CEC = 14 me/100 g

Experiment 1: **Increasing N at uniform K fertilizer application with and without straw**

duration: 1968-1981

improved three-year rotation: In 2 years out of 3 there was straw application with compensating N dressing and a mean K supply of 28 kg K/ha yr
mineral K application: 135 kg K/ha yr
initial soil K: 7 mg DL-K/100 g soil.

Results

Straw manuring had no effect on crop yields and only slightly increased K removals (Table 2). The resulting K balance was raised by straw application from +35 to +60 kg/ha as mean of all years. Utilization of potassium supplied with straw (additional removal as percent of added amount) was 11%.
Corresponding with positive K balance, DL-soluble potassium was raised by fertilizer application from 7 to 13 mg/100 g soil; additional straw manuring gave only a further slight increase of K content of the topsoil. Somewhat more distinct was an increase of K extractable by HCl even though this increase did not nearly reflect the positive balance of altogether 350 kg/ha caused by straw.

Table 2 Manuring of straw in combination with fertilizer NPK application (1968-81)

Straw	Yield t DM/ha yr	Removal kg K/ha yr	Balance of K (kg/ha yr) fert. applied-removal	Utilization of straw-K (%)
–	7.5	100	+ 35	–
+	7.5	103	+ 60	11

Soil analysis (mg K/100 g soil)

	topsoil				subsoil	
		DL		HCl	DL	HCl
straw	1963	1976	1984	1984	1985	1985
–	7	10	13	67	5	51
+	7	12	14	71	5	51

Experiment 2: **Effect of straw manuring with and without additional mineral fertilizer application (NK) – test with various P fertilizers**

duration: 1959-1984

crop rotation, every second year straw manure with an average K supply of 18 kg/ha yr

mineral K application: 0 and 120 kg K/ha yr
initial K supply of the soil: 9 resp. 17 mg DL-K/100 g soil

Results

Straw manuring resulted in a distinct increase of yields and K removals by the crops especially in plots without mineral fertilizers (Table 3).

Table 3 Effect of manuring with straw with and without mineral fertilizer (1959-84)

		without mineral fert.		NK fertilizing	
		–	+ straw	–	+
yield (t DM/ha yr)		3.3	4.5	8.2	9.0
removal of K (kg/ha yr)		39	55	103	112
balance of K (kg/ha yr)		– 39	– 37	+ 17	+ 26
fert. applied-removal					
utilization of straw-K (%)		–	89	–	50
Soil analysis (mg K/100 g soil)					
DL	1954	9	9	17	17
	1971	8	8	14	15
	1981	8	8	13	16
	1984	8	10	17	20
	subsoil:				
	1974	7	7	7	7
	1985	7	7	7	7
HCl	1981	59	60	68	75
	1984	60	62	75	79
	subsoil				
	1974	52	49	55	55
	1985	55	51	55	55

For potassium supplied by straw, the calculated utilization is 89 (no fertilizer applied) and 50% (with K fertilizer).

In spite of a negative K balance on plots without mineral fertilizers, DL-soluble K (8 mg/100 g soil) remained practically on the initial level; straw caused a small increase especially of non-exchangeable potassium. Likewise, a positive K balance on plots with PK-application did not essentially change the DL-soluble K. Straw manuring is expressed in an increase of DL- as well as HCl-extractable K of the soil. In this long-term trial, an agreement between the amount of K supplied by straw and the additional removal by plants as well as the amount of K left in the soil was found at least by way of calculation. The low sensivity of the CAL-extraction to positive or negative balances indicates a high buffering capacity for K in this loess soil.

Experiment 3: **With the same site conditions, the K-effect of stable manure was calculated**

duration: 1942-1973

improved three year-rotation: normally every third year 30 t stable manure/ha to leaf crops equivalent to 51 kg K/ha yr

uniform NP-fertilizer
K-rates: 0 or 100 kg K/ha yr

Results

Stable manure with or without additional K fertilizer caused a marked increase in yields and K removals (Table 4). In plots with NPK, the K balance was always negative, with mineral K or stable manure, however, near to zero.

Table 4 K-effect of stable manure (1942-73)

		NPK_0		NPK_{100}	
			stable manure		
		–	+	–	+
yield (t DM/ha yr)		7.2	9.0	9.3	10.1
removal of K (kg/ha yr)		69	95	127	144
balance of K (kg/ha yr)		– 69	– 44	– 27	+ 7
fert. applied-removal					
utilization %:					
mineral K		–	–	58	49
K in manure		–	49	–	33
both		–	–	–	50
	1975:	Soil analysis (mg K/100 g soil)			
DL	(0-25 cm)	6	7	7	9
HCl	(0-15 cm)	31	33	36	40
	(30-45 cm)	31	31	28	34
K-fix.*	(0-15 cm)	22	21	4	1
	(30-45 cm)	23	24	20	22

* wet fixation

Utilization of manure-K was somewhat lower than of mineral K, especially when stable manure was applied in addition to mineral K fertilizer; overall utilization of applied K was 50%. The slightly positive K balance with stable manure when added to mineral K is demonstrated in somewhat higher values for DL-, and especially in HCl-soluble K (0-45 cm soil layer); the soil did not show any fixation of K.

No complete record of the fate of K from stable manure can be given from the crop results and soil analysis, but, considering the differing application times (periodic application of stable manure), it can be concluded that the two K forms had virtually identical effects.

3. Field trial with beet tops

Since 1976, an experiment has been run in Weihenstephan with varying levels of K-application to sugar beet as single crop on a humic limy gley soil (25 cm humic layer on top of a 50 cm river marl layer). Since 1978 this trial has been supplemented with plots receiving an additional application of beet tops.

soil: pH 7.3 — 20% clay — C_t = 3%
free $CaCO_3$ = 50 — 70% — 30% silt — N_t = 0.36%
wet fixation of K: 35 — 45 mg K/100 g soil — CEC = 25 me/100 g
duration: 1978-1985
optimized NP fertilizing
K application: 125, 250 and 375 kg K/ha yr
initial K supply of the soil: 1-3 mg K/100 g soil

Results

Increasing rates of K up to K_{250} increased yields significantly, K_{375} only raised K contents of plants, but resulted in a positive K balance (Table 5).

Table 5 Manuring with beet tops in single cropping of sugar beet (1978-85)

K-fertilizer		K_0	K_{125}		K_{250}		K_{375}	
beet leaves		—	—	+	—	+	—	+
yield (t DM/ha yr)		11.9	19.8	20.4	21.9	20.3	21.7	21.2
removal of K (kg/ha yr)		115	202	232	270	288	315	309
balance of K (kg/ha yr) fert. applied-removal		− 115	− 80	+ 12	− 26	+ 120	+ 51	+ 225
utilization (%):								
mineral K		—	70	—	62	—	53	—
K in leaves		—	—	25	—	11	—	0
both		—	—	47	—	42	—	36
soil analysis (topsoil)				(mg K/100 g soil)				
CAL	1977	1	1	1	1	2	3	4
	1982	1	2	3	3	6	4	8
	1985	3	3	3	3	8	5	11
$CaCl_2$	1985	0.6	0.7	0.9	1.2	3.2	2.1	5.5
K-fix.	1979	49	48	46	43	37	32	32
	1982	36	37	26	34	29	26	21
	1985	47	44	36	33	26	26	24

Beet leaves applied in addition to fertilizer gave only slightly increased yields on the level K_{125}, in combination with K_{250} only higher K removals of crops. K balances at the levels K_{250} and K_{375} were highly positive (+ 120 and 225 kg K/ha yr).

Utilization of fertilizer K attained high values (70% at K_{125} and 53% at K_{375}), at best only 25% K from beet tops applied in addition to fertilizer was utilized (K_{125}). When considering the amounts of K applied with beet tops, the calculated utilization of K for the combination K_{125} + tops (247 kg K/ha/yr added) was higher (47%), but still lower than for fertilizer K (62% at K_{250}). The positive K balance of the levels K_{250} and K_{375} plus beet leaves is expressed in a marked increase of CAL-K; correspondingly, K-fixation was generally lower after organic manuring. On the whole changes in the soil K are not sufficient to account for the positive K balance.

4. Discussion of results

From consideration of the results of these 4 long-term field trials, the conclusive evaluation of the effects of K in crop residues, is not possible since in some cases there were evident discrepancies between positive K balances in crop trials and increases of K contents in soils. In all trials where K need of crops was guaranteed by fertilizers alone, utilization of K from crop residues was only 10% or less.

Contrarily, in trials without additional fertilizer application, K in residues was utilized to the extent of 50 up to 90%; effects of K from straw were largely identical with stable manure.

In the trials with stable manure on loess brown earth soils and with beet tops on the humic limy gley soil, potassium supplied by the organic manure was not utilized quite as well as fertilizer potassium (see below). In general (except experiment 1: straw manuring on brown earth with optimized K application), low utilization of potassium in crop residues resulted in a distinct increase of K-contents in the soil, especially of less exchangeable forms (HCl-K) and in a decrease of wet fixation. Neither $CaCl_2$ – or CAL-extraction are suitable for K balance accounting on well buffered soils even though mineral and organic fertilizers are recorded equally well as is shown in the pot trial. This low sensitivity of the CAL or $CaCl_2$ method on soils with high buffer capacity consequently proves a great handicap to the evaluation of fertilizer demands (see introduction); the desired control function of soil analysis for proper fertilizing is questionable in such cases.

We cannot explain why in one of the long-term field trials K from straw manure was neither appreciably utilized nor did it increase the soil potassium; leaching or fixation is not possible on this site.

The results on limy gley soil have to be interpreted somewhat differently: the slightly smaller effect of K in beet tops as compared to fertilizers might be caused mainly by different application times (tops in autumn, fertilizer at sowing). The following explanation is suggested.

1. Leaching of K from tops during non-growing season (shallow humic soil with high lime saturation),
2. stronger fixation of beet leaf-K since it was applied about 6 months before needed by plants (soil with an intermediate fixation potential).

A heterogeneous mixing of organic manure and therefore uneven distribution in the soil should not have any effects on the efficiency of K in long-term trials.

Considering all results and making certain restrictions, the following assessment may be concluded:

1. Potassium from crop residues gives a similarly good effect as mineral potassium (utilization by plants, increase of K pool in the soil)
2. On strongly fixing soils as well as on sites with appreciable K leaching (sands and shallow humic soils, some with high lime content, K application directly at sowing often gives better effects than organic manure-K already applied in autumn.

These findings should be considered in the determination of fertilizer requirements for the respective sites.

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Evaluation and Utilisation of Potassium from Industrial Wastes

P. Dutil, Soil Science Station, I.N.R.A., Châlons-sur-Marne/France*.

Summary

The nutrient content of a range of aqueous effluents from various agro-industries is described and discussed and, based thereon, the appropriate rates of application to agricultural land are calculated. Rate of application is determined by the mineralisable N content of the effluent which dictates the maximum rate that can be applied without risk of pollution. In practice, the rates of potassium applied are very large. Fear of nutrient imbalance due to the high K applications (K-Mg antagonism) has not been realised.

1. Introduction

Potassium is taken up by crops in large quantities and this applies particularly to industrial crops: sugar beet, starch potatoes, lucerne for dehydration and extractions of protein. Their products: sugar, starch, alcohol and proteins are highly refined and almost all the potassium in the crop raw material ends up in the residues and especially in the waste water. Thus there is a problem in the recovery and utilisation of this major nutrient which is the dominant nutrient in most of the factory effluents.

The main industries concerned are:

- for *beet:* sugar extraction and distillation,
- for *potatoes:* starch production,
- for *lucerne:* drying with extraction of protein,
- for *cane sugar:* distilleries.

Of lesser importance are:

- brandy distillation,
- preservation of vegetables,
- dairy industry, cheese manufacture,
- cider manufacture and distillation.

* *Dr. P. Dutil*, Directeur de Recherches, INRA, chemin du Mas d'Ayran, F-30700 St. Quentin-la-Poterre/France

2. Evaluation of potassium in factory wastes

This is based on mean values for samples taken over the period over which the factory operates. These operations, except in the dairy industry and cheese manufacture, are necessarily seasonal. There is no great problem with the solid wastes, but there are problems in sampling the liquid effluents. The general practice is to sample every 4 hours over 24 hrs every fortnight over the campaign. So that analysis will give a true picture of the agronomic value of residues applied in the field, the samples are taken from the material applied, even if there is sometimes addition of other materials before spreading.

2.1 Potassium in aqueous waste from beet factories

The content varies greatly with season and the technique adopted by the factory. The effluent is a mixture of:

- washing water,
- the sap of the beet,
- some organic materials.

The chief variations are:

a) Weather at the time of lifting which affects the amount of soil brought into the factory (tare varies between 20 and 50% of washed beet).

b) Factory policy; some store the effluent in tanks before spreading, others not.

The result is that the content of suspended matter can vary from 50 to 250 g/l, of which soil makes up about 90%. In these conditions it is necessary to analyse the liquid (filtered) and solid (suspended matter) separately. Where the suspended matter (S.M.) content is high, exchangeable K content is determined as for soil. The total available K content of the effluent is the sum of the dissolved K and exchangeable K in the solid matter.

For reasons of economy in water consumption, the factories now recover the water contained in the roots and the quantities of water used are reduced; these vary between 0.25 and 0.40 m^3 per ton of beet treated. Thus the effluents are now more concentrated.

Obviously it is difficult to cite mean values for a number of factories but a rough indication of K content is 1000 mg/l (liquid + solid phases) (see Tables 1 and 2). As an example, a factory producing annually 500 000 m^3 liquid effluent with 1g/l K has an output of 500 t K (600 t K_2O)

Table 1 Average* K content of beet factory effluent (mg/l K)

	Solids (g/l)	K in filtered water mg/l	K in solids mg/l	Total K in water mg/l
With decantation:	30 à 60	800 à 1500	—	800 à 1500
Without decantation	150 à 250	350 à 750	80 à 250	600 à 1000

* Average of 5 factories over 4 years

Table 2 Average composition of effluents (1976 and 1977 campaigns in Champagne)

Détermination	Beet factory	Distillery (beet)	Starch (potato)	Protein (lucerne)
Solids (g/l)	120	5.5	8,8	2,7
pH	7.0	4,6	6,2	5,5
Oxygen chemical demand (mg/l O_2)	10350	16950	10450	11850
N (mg/l)	705	865	815	535
P_2O_5 (mg/l)	15*	225	245	80
S (mg/l)	202	650	60	135
Cl^- (mg/l)	1450	200	30	40
Ca^{++} (mg/l)	1990	585	1630	795
Mg^{++} (mg/l)	140	135	45	30
K^+ (mg/l)	1095	1565	1150	445
Na^+ (mg/l)	470	69	7	15

* Liquid phase only: content is very variable (50-400 mg/l), depending on content of suspended matter *(Dutil et Muller,* INRA Châlons-sur-Marne)

2.2. Potassium in water effluent from beet-sugar distillation

These effluents are mainly washing water plus organic wastes from dead yeasts used in fermentation which are rich in nitrogen which is easily mineralised. It is also rich in potassium (about 1500 mg/l). The sulphuric acid used to correct the pH for fermentation to 3.5 contributes significant amounts of sulphur.
Towards the end of the campaign, the distilleries are working on molasses and then the residues («vinasses») are more concentrated in all elements, the K content varying from 12000 to 15000 mg/l (Table 3).

Table 3 Average composition of beet distillery effluent (molasses residues)

	Unit	Average in crude effluent
Total N	N mg/l	5145
Ammonium N	N (NH_4) mg/l	435
Nitrate N	N (NO_3) mg/l	215
Potassium	K^+ mg/l	13460
Sodium	Na^+ mg/l	1485
Magnesium	Mg^{++} mg/l	31
Phosphate	P_2O_5 mg/l	258

2.3. Potato starch

The aqueous residues are not very high in suspended organic matter, but this is rich in protein-N which is easily mineralised. The protein content is very much reduced if steps are taken to recover the protein. Potassium content is high (1000 to 1200 mg/l) as all the K in the tubers diffuses out (Table 2).

2.4. Lucerne drying

To conserve energy, the water content of the lucerne is no longer discharged to the atmosphere and its energy content is recovered. The condensation water contains sulphur from the fuel. When the process includes extraction of protein there are also residues of ammonia from partial hydrolysis of the lucerne tissues. The resulting effluent is not as strong as those from the preceding processes though it does contain appreciable amounts of N, K and S. Suspended matter content is low (1 to 3 g/l with K at 400-500 mg/l) (Table 2).

2.5. Wine distilleries

The effluents vary greatly with the product under treatment. They may be dilute wine residues, marc juice (pressed or not), and lies residues (very concentrated) containing 1 to 6 g/l N and 2-10 g/l K.

These various wastes contain mainly: potassium, nitrogen, phosphates and sulphur (Table 4), but there are problems in agricultural utilisation (as with residues from beet sugar distillation) necessitating application at low rates or dilution with inferior residues (vinasses of wine).

2.6. Vegetable preservation

These are mainly French beans and petits pois processed only during June to September. The residues are low in concentration and very variable. The K content varies between 15 and 150 mg/l (Table 5).

2.7. Dairies and creameries

The residues from dairies comprise essentially washing water; thus they are low in concentration. In cheese making (more usually combined with the creamery) the aqueous residues are somewhat concentrated and contain mainly chloride and sodium from whey, straining of the cheese and renewal of the brine.

Usually when the water is decanted there is a muddy residue rich in P and N but small in quantity. Dilution is large with production of 3 to 5 l water per litre of milk treated. Thus, concentration in the residues is low (Table 6). The K content varies from 40 to 80 mg/l at the creamery and 150-200 mg/l in cheese making.

Table 4 Average composition of various effluents from wine distillery*

	Formules and Units	Lies residues	Juice from pressed marc	Outflow juice	Residuary liquor of wine
Solids	mg/l	115490	12170	9286	3463
pH	pH	4.3	4.9	5.0	4.0
Oxygen chemical demand	O_2 mg/l	164930	69200	68930	29780
Organic C	C mg/l	33625	4816	3711	1263
Total N	N mg/l	6392	2113	2396	976
$NO_3 + NO_2$	N mg/l	2.6	2.9	2.9	2.3
NH_4^+	N mg/l	662	1340	1385	291
Sulphur	S mg/l	764	228	245	96
Phosphate	P_2O_5 mg/l	1889	1517	1656	259
Calcium	Ca^{++} mg/l	2018	476	400	276
Magnesium	Mg^{++} mg/l	130	205	222	96
Potassium	K^+ mg/l	10720	6356	6408	1913
Sodium	Na^+ mg/l	156	68	38	55

* Ay factory (Champagne)

Table 5 Composition of effluent from vegetable preservation

	Content
pH	4. 5 — 6.5
Solids	0.10 — 1.50
Total N (mg/l)	10 — 100
P_2O_5 (mg/l)	2 — 50
K^+ (mg/l)	15 — 150
Mg^{++} (mg/l)	10 — 100
Ca^{++} (mg/l)	100 — 300
Na^+ (mg/l)	50 — 300

Table 6 Average composition of effluent from dairy stations and cheese manufacture

	Dairy station	Dairy station and dairy-cheese station
Solids	0.5 — 2	2 — 15
pH	4,5 — 5.5	7 — 9
Total N (mg/l)	100 — 200	200 — 300
NH_4^+ (mg/l)	10 — 20	20 — 30
P_2O_5 (mg/l)	100 — 200	100 — 200
K^+ (mg/l)	40 — 80	150 — 200
Mg^{++} (mg/l)	10 — 15	10 — 20
Ca^{++} (mg/l)	40 — 80	300 — 600
Cl^- (mg/l)	100 — 200	300 — 2000
Na^+ (mg/l)	150 — 300	500 — 1000

2.8. Cider and Calvados

The crude effluents from manufacture of apple juice, cider or calvados contain little 2-3 g/l) and there is very little suspended material after decantation (300-400 mg/l). Fertilizer nutrient content is very low. On the other hand, distillery residues are much richer, especially in potassium (100 mg/l and nitrogen 500 mg/l (Table 7).

2.9. Other agro-industry wastes

There are a number of other less important wastes which have not merited examination: very acid effluents from rum distilleries in the tropics which require liming: residues from distillation of fruits rich in potassium and nitrogen but very acid; effluent from knacker's yards.

Table 7 Average composition of effluent from cider making and distillation

	Crude effluent	Decanted effluent	Residues from distillation
pH	4.2	4.5	3.4
Solids (mg/l)	2500	250	3000
Total N (mg/l)	100	25	500
P_2O_5 (mg/l)	50	10	200
K^+ (mg/l)	60	100	1000
Ca^{++} (mg/l)	70	200	170
Mg^{++} (mg/l)	10	10	60

3. Agricultural use of potassium in industrial wastes

Analysis shows that most of these wastes are rich in potassium and nitrogen, sometimes rich in sulphur with lower contents of other nutrients like P and Mg. Their composition reflects that of soils and crops.

The products of the factories are highly refined (sugar. alcohol, starch ....) and the residues contain most of the mineral elements brought into the factories. Thus, there is justification for the use of these residues in agriculture.

3.1. Application of aqueous residues – calculation of rates

Aqueous residues are the major waste products of agro-industry. They contain:

- solid matter; both mineral (soil) and organic (soil and plant).
- the water which contains various soluble minerals.

To achieve rational use, it is necessary to know the actual availability in the soil of the elements applied. This problem is easily solved as almost the whole of the mineral elements is found in the liquid phase; hence they are rapidly available though affected by fixation (K, Mg, PO_4) or leaching (SO_4). On the other hand, most of the N is in the organic form and its availability depends on:

- the rate of mineralisation in the soil,
- leaching of nitrate, in particular by winter rainfall.

It is important that the mineral nitrogen in the soil resulting from the application should correspond with the actual crop requirement, since nitrates formed and not taken up by the crop are a potential source of pollution of the subsoil water. Studies of this problem have included:

- Laboratory investigation of nitric mineralisation of the organic matter in the residues as affected by temperature (simulation of autumn, winter and spring climatic conditions).
- Rate of leaching of nitrate in the soil in field and lysimeter studies, with measurement of winter losses.
- Finally, field experiments to determine the effect on crop yield.

The dual purpose of the agricultural use of these effluents is to meet the needs of crops and to avoid risk of pollution of the aquifer. It can be stated that the proportions of N available over the year following application of the wastes are:

Sugar beet factory 24.5% of total N in effluent)
Beet sugar distillery 37.0%
Starch manufacture 52.5%

From such data, the rate of application can be calculated by the following equation:

Mineral N produced by effluent
+ Mineral N produced by soil — Total crop uptake = 0.
— Winter leaching losses

(See example in Figure 1)

Phase	no. 1	no. 2	no.3
Leaching	conditions before leaching	during winter leaching	after leaching
Duration	2 months 15/10–15/12	4 months 15/12 — 15/04	6 months 15/04 — 15/10
Mineralisation (in % of total N applied)	7.5%	3.3%	14.8%
Losses	0	15% of N mineralized before start of leaching	uptake by the crop
Production migration and availability (% of total N applied)	7.5%	3.3% 6.4% 1.1%	14.8% 9.7%

Dutil. I.N.R.A. Châlons-sur-Marne

Fig. 1 Disposal of effluent from beet factory. Behaviour of mineral nitrogen in the soil after an autumn application

If X_{Nt} is the total N content of the effluent, with 70 kg/ha N supplied by the soil, the total amount of N which one should apply for a beet crop taking up 250 kg/ha N is:

- for beet factory effluent: $(0.245 \cdot X_{Nt} + 70) - 250 = 0$, *i.e.* $X_{Nt} = 734$ kg/ha.
- for distillery: $(0.370 \cdot X_{Nt} + 70) - 250 = 0$, *i.e.* $X_{Nt} = 486$ kg/ha.
- for starch factory: $(0.525 \cdot X_{Nt} + 70) - 250 = 0$, *i.e.* $X_{Nt} = 342$ kg/ha.

The volumes of liquor to apply can then be calculated from data in Table 2 as follows:

- beet factory: 734:7.05 = 104 mm
- distillery: 486:8.65 = 56 mm
- starch: 340:8.15 = 42 mm

These values are indicative and should be adjusted for each factory and for the season.

3.2. The role of applied potassium

The rates of effluent application are determined by consideration of the mineralisable N in effluent and of the crop following the application; the rates of P, K, Mg and S applied as a result are calculated from the available analytical data. Potassium is usually the dominant element in the effluent and dictates the frequency with which application should be made to the field in accordance with the needs of the rotation. Potash demanding crops play an important role as they determine not only the frequency of application but also the total area which the factory can serve. The following indicate the size of potash application which may occur:

Type of factory	Total application mm	K content mg/l	K_2O applied kg/ha
Beet	2×40	1000	960
Starch	50	1100	726
Distillery (beet)	50	1500	900
Distillery (vine)	10	6000	720
Lucerne (protein)	2×40	400	384
Dairy industry	4×40	150	288

In many cases there is a high application of potassium. After 15 years experience it can be said that this method of disposal of factory effluent is practical and has carried no risk for agriculture. One might have expected, in some cases, some disequilibrium in the K/Mg ratio especially in soils low in Mg; in fact potassium induced Mg deficiency is rare.

4. Conclusion

Analysis of factory effluents from agro-industry shows that they are usually rich in nitrogen and potassium. Hence there is an interest in their use in agriculture, but this has to satisfy two conditions:

- suitability to the farming system,
- avoidance of pollution of the aquifer by nitrates.

Our research has resulted in a practical policy for the use of these effluents. Rate of application is governed by the mineralisable N content of the effluent with the object of avoiding the risk of pollution by nitrates. Potassium fixed in the soil, considered along with crop removal of K, dictates how often effluent should be applied and thus the area of land necessary to cater for the needs of the factory. In practice K applications are large and more generous than the rates used in traditional practice.

Fifteen years experience in the agricultural exploitation of N and K in the effluents has thrown up virtually no agronomic problem wherever soil conditions are suitable. However, there are circumstances under which effluents cannot be used in agriculture because the effluent is produced at times when the land is under crops and not available for spreading as is the case with wine distilleries which operate until the spring, with the dairy industry which operates throughout the year; the first cut of lucerne is also handled by the driers before any land is free of crop. In such cases, temporary storage is required.

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Types of K-Fertilizers in the K-Replacement Strategy

L. C. von Braunschweig, Advisory Service, Kali und Salz A.G., Kassel/Federal Republic of Germany*

Summary

Choice of the type of potassium fertilizer depends on the form of chemical combination (chloride, sulphate, nitrate) and content of other nutrients (sodium and magnesium). The accompanying anion does not affect the availability of K except that nitrate increases K concentration in the plant.

Chloride influences the plant's water relations and has no effect on metabolism. However, very high concentrations can be toxic. Plants can be classified according to chloride tolerance. The sulphur in potassium sulphate is an essential plant nutrient, especially important where industrial emissions of SO_2 are lacking. K_2SO_4 has a much lower salt index than KCl making it especially useful in arid regions. The form of K fertilizer has no effect on soil pH.

Auxiliary nutrients are important as indicated by the German practice of using 40% chloride with 8-15% Na_2O and 5% MgO for sugar beet. They are also important in livestock farming as they increase herbage contents of Na and Mg.
Economic aspects of the different choices are also discussed.

The need for potash fertilizers and their use in agriculture were thoroughly discussed during this Congress. At the end we are faced with the question: «What criteria determine the choice of potash fertilizer material?» This paper considers in turn: the composition of the different materials; their effects on potassium availability; the properties of the anions accompanying K; the salt index; effects on soil pH; the auxiliary substances (Na_2O and MgO); economic factors.

1. Composition of the main potash fertilizers

The following potash-containing materials are used in world agriculture (Table 1):

Other salts of potassium have little use in agriculture; only potassium nitrate (KNO_3) which is mainly used in intensive horticulture outside and under glass, needs to be mentioned. KNO_3 is a relatively expensive fertilizer.

Dr. *L. C. von Braunschweig,* Leiter der Landw. Abteilung Inland, Kali und Salz AG, Friedrich-Ebert-Str. 160, D-3500 Kassel/Federal Republic of Germany

Table 1 Average composition of the most widely used potash fertilizers

	Kainit	Potassium chloride 40% K_2O	50% K_2O	60% K_2O	Potassium sulphate 50% K_2O	Sulphate of potash/ magnesia 30% K_2O/ 10% MgO
K_2O	12-15	38-42	48-52	58-62	47-52	22-30
MgO	6-10	0- 5	2	1	2	8-12
Na_2O	25-30	10-18	5- 8	1- 4	—	—
Cl	40-43	40-50	42-50	47-59	0.5- 2	0.5- 6
S	3-10	5	2	1	18	16-22

Generally speaking, the potassium in raw materials is combined in the form of chloride at concentrations of 10 to 30%.

Depending on the source, the raw materials contain various other plant nutrients such as magnesium in $MgSO_4$ or $MgCl_2$ or sodium as NaCl. Potash is used in agriculture mostly in the form of sulphate or chloride. KCl is obtained from the raw material by straightforward concentration. The sulphate occurs but rarely as a natural mineral Langbeinite – $K_2SO_4 \cdot 2MgSO_4$) and is usually obtained by reacting KCl with $MgSO_4$:

$$2\,KCl + MgSO_4 \rightarrow K_2SO_4 + Mg\,Cl_2$$

or with sulphuric acid:

$$2\,KCl + H_2SO_4 \rightarrow K_2SO_4 + HCl$$

2. Effect on potassium availability

From the crop's point of view, the way in which the potassium is combined is of no importance. As both materials, chloride and sulphate, are water soluble, the K is immediately and completely available. The chloride and sulphate anions have little effect on potassium uptake by crops, only nitrate favours the uptake of K. Criteria for the choice of potash material are therefore not the form of the chemical compound but the properties conferred by the anion and auxiliary nutrients.

3. The chloride (Cl^-) and sulphate (SO_4^{--}) anions

Chloride is very widely distributed in nature. Most plants take up more chloride than is physiologically required *(Röber [1968])* and plant chloride contents are of the order 2-20 mg/g DM. Chloride can be taken up not only by the roots but also by the leaves as chloride or gaseous Cl_2 in the atmosphere *(Johnson et al. [1957])*. Chloride

is mobile in the plant in acro- and basipetale directions *(Rinne et al [1960])*.
How far chloride has any essential function in plant metabolism is not clear. Its most important effect is upon the water economy of the plant. As the chloride content increases so does the cell osmotic pressure and in this Cl^- can take over some colloid-chemical functions of NO_3^- . Recent work by *Hähndel et al. [1984]* has shown that the nitrate content of spinach can be reduced by applying chloride. This might have significance for the production of quality vegetables (reduced NO_3^- content) but there are practical difficulties and other reasons, which are not discussed here, why chloride should not be used in intensive horticulture.

Von Uexküll [1984] states that chloride has positive effects on the yield and quality of oilpalm and coconut. This is explained by effects on stomatal regulation and thereby the water economy of the plant.

3.1. Sulphate in plant physiology

In contrast to chloride, sulphate, or more specifically sulphur, is an important plant nutrient. Following uptake, sulphate must be reduced in the plant which takes place in the course of ATP metabolism *(Schiff et al. [1973])*. Sulphur is an important protein constituent. Sulphur deficiency, by disturbance of protein metabolism brings about an increase in soluble amino-acid and nitrate contents *(Linser et al. [1964]; Friedrich et al. [1978])*.

Sulphate is not the only source of sulphur to the plant, it can also be taken up as SO_2 from the atmosphere *(Faller [1978])*. In non-industrial areas, sulphur deficiency may occur as a result of the lack of SO_2 emissions. Such symptoms have been described by a number of authors: *Storey et al. [1933]; McLachlan et al [1968]; Agble [1974]; Walker et al. [1958]*. Under such conditions, sulphur application increases crop yield.

3.2. Plant tolerance to chloride

Chloride can build up in the plant. In considering chloride damage one should distinguish between direct toxic effects of a surplus of chloride and salt damage which can result from increased concentrations of NaCl, $MgCl_2$, $CaCl_2$ or even KCl. Chloride excess leads to chlorosis through disturbance of cell metabolism. It occurs at concentrations of 0.2-2.0% in dry matter. However, tolerant species can cope with concentrations of up to 4% without signs of damage *(Bergmann [1983])*. Too high chloride concentration can also hinder transport of assimilates from leaves and stems to the storage organs *(Häder [1977])*. The most important chloride tolerant and chloride sensitive plants are listed in Table 2

Table 2 Chloride sensitivity of crops *(Bergmann [1973])*

Chloride tolerant	cereals, maize, beet, cabbage, mangold, chicory, lettuce, celery, asparagus, spinach.
Chloride sensitive	potatoes, tomato, tobacco, flax, cucumber, onion, fruit trees soft fruit, strawberries, pine, vine

4. Salt index of potash fertilizers

This is an important factor in the choice of fertilizer material. The salt indices of various potash fertilizers are given in Table 3.

Table 3 Salt index of potash fertilizers *(Zehler et al. [1981])*

	Salt index per fertilizer unit
$NaNO_3$	100.0
KCl (60% K_2O)	116.3
KNO_3 (47% K_2O, 14% N)	83.6
K_2SO_4 (50% K_2O)	46.1
K_2SO_4 + $MgSO_4$ (22% K_2O/10% MgO)	43.2

Sulphate of potash or sulphate of potash magnesia have about half the salt index of KCl as compared to $NaNO_3$ measured by the increase of osmotic pressure in the soil solution while KNO_3 occupies an intermediate position.

The salt index is important in the fertilization of saline soils which are found in arid and semi-arid regions as a result of low rainfall or improper irrigation. Large areas in China, India, Pakistan, the Near East, North and West Africa, Southwest Africa, North and Latin America are semi-arid and here the use of sulphate of potash is increasing strongly *(Loué [1978])*. This is due to the low salt index of K_2SO_4 and the fact that cations as well as anions are largely taken up by plants.

In contrast, when KCl is used most of the Cl^- remains in the soil. With low rainfall or too little irrigation, the excess Cl^- is not washed out from the surface soil and there is a further contribution to salinity through evapotranspiration bringing up salts from the subsoil. Similar effects can occur in intensive vegetable or glasshouse cropping, where there is little possibility of washing Cl^- into the subsoil. In addition salts accumulate in the surface soil because of the arid glasshouse climate.

In all such situations, fertilizers in which both anion and cation are nutrients (KNO_3 and K_2SO_4) and which have a low salt index are to be preferred.

The salt index of fertilizers is important from another point of view – that of the crop's salt tolerance. As discussed above, salt damage can rarely be distinguished from true chloride damage. However, one should distinguish between specific salt toxicity (caused through NaCl) and general salinity effects *(Schleiff et al. [1976])*. Here we shall deal only with the latter point. Resulting from the increased suction pressure of saline soil the plant suffers from water deficiency and wilts. As we have seen above, salt tolerance varies greatly between crop species and between varieties; age of plant is also important. A good example is sugar beet, which is both salt and chloride tolerant. However, the young seedling is extremely sensitive to salinity, and the potash dressing should be divided or applied along with the phosphate well in advance of sowing, *i.e.* in the autumn before planting. The winter rain washes the chloride into the deeper soil layers where it is available to the older plants when they have developed their full root system. Table 4 lists salt tolerant and salt sensitive crops.

Table 4 Examples of salt-tolerant and salt-sensitive crops *(Bergmann [1971])*

Tolerant	barley, wheat sugar beet (but not the seedlings)
Intermediate	tapeseed
Sensitive	Phaseolus beans, maize, onion

5. Effect on soil pH

Effects of fertilizers on pH should not be confused with the currently fashionable effects of «acid rain» and damage to forests. There is a great difference between SO_2 emissions and K_2SO_4 in their effects on soil pH. At certain concentrations SO_2 is toxic, entering the plant through stomata, hindering photosynthesis and causing leaching of nutrients. When mixed with water (acid rain) it penetrates into the soil, it takes the form of sulphuric acid and in this case the acidifying agent is the H^+ ion, SO_4 being taken up by the plant or leached from the soil. Sulphate in fertilizer behaves in the same way though there may be local shifts in pH near the sites of exchange processes on the clay minerals. These fertilizers have no permanent effect on soil pH as they do not release protons. Evidence for this is found in coastal soils where there is a yearly input of 30 kg/ha of sulphate (with Na, Mg, Ca and K). These soils do not show a lower pH than other comparable soils. *Budig [1972]* has tested the effect of K_2SO_4 on soil pH and confirms the above conclusion. *Sluismans [1970]* says the lime requirement to neutralise K_2SO_4 or KCl is zero.

6. Auxiliary nutrients NaCl and MgO

6.1. Sodium

Rocksalt (NaCl) is the major portion of raw potash minerals (50-80%). According to the degree of refining and concentration, NaCl content of the finished fertilizer varies (Table 1).

In the years following *Liebig's* discovery of the significance of potash it was used in the form of the ground raw mineral or fertilizer with 40% K_2O. The sodium content (8-25% Na_2O) was welcomed by beet growers. In this connection it should be mentioned that the main beet growing areas in Germany are in the Magdeburg and Hildesheim regions near to the potash mines; low transport costs from the mines have favoured a preference for low grade (40%) fertilizer by beet growers up to the present time. The same applies for the GDR. On light soils the sodium is given credit as a «water retainer».

6.2. Magnesium

Magnesium, as chloride or sulphate occurs in only some potash mines. $MgCl_2$ is an undesirable constituent of fertilizer, being very hygroscopic. Kieserite ($MgSO_4 \cdot H_2O$) and Epsom salts ($MgSO_4 \cdot 7H_2O$) are good Mg fertilizers, but most magnesium is applied to the land as magnesium limestone. Magnesium is the 5th major plant nutrient after N, P, K, Ca and plays a major role in photosynthesis (the central atom in chlorophyll) and other metabolic processes. Until recently, magnesium fertilization has not been given its due priority. Based on nutrient balance of most intensive farming systems, Mg is mobile in the soil and easily washed out (Table 5).

Table 5 Average magnesium balance in the German Federal Republic

	t MgO	kg MgO/ha
Additions		
Fertilizers	265000	22
Organic manures	112000	9
Total additions	377000	31
Removals		
Harvested crops	430000	36
Leaching	350000	30
Total removals	780000	66
Balance	− 403000	− 35

It is hardly surprising that large parts of the Federal Republic are not sufficiently supplied with magnesium (Figure 1) as a result of native deficiency or insufficient use of magnesium containing fertilizers.

6.3. Magnesium and sodium in animal nutrition

Both of these plant nutrients are also important in human and animal nutrition. Salt was in early days in short supply and much sought after. Now there is no shortage and worldwide human needs are covered. The requirements of domestic animals are large. Production of meat and milk requires a high salt input which is not always entirely covered by the provision of salt-licks and it is advisable to ensure a high salt content in the fodder to ensure good health and improve productivity *(Kemp et al. [1968])*. The same holds true for magnesium which is particularly important in early spring when the animals are transferred from winter rations to grazing young grass with a risk of magnesium deficiency. When dry matter and magnesium are low in fodder, resorption of Mg is insufficient and this can lead to tetany. The spring fodder should contain 0.2 g Na and 0.2 g Mg/kg DM, levels seldom achieved in practice. It has been shown, however, that by using MAGNESIA-KAINIT, a potash mineral with

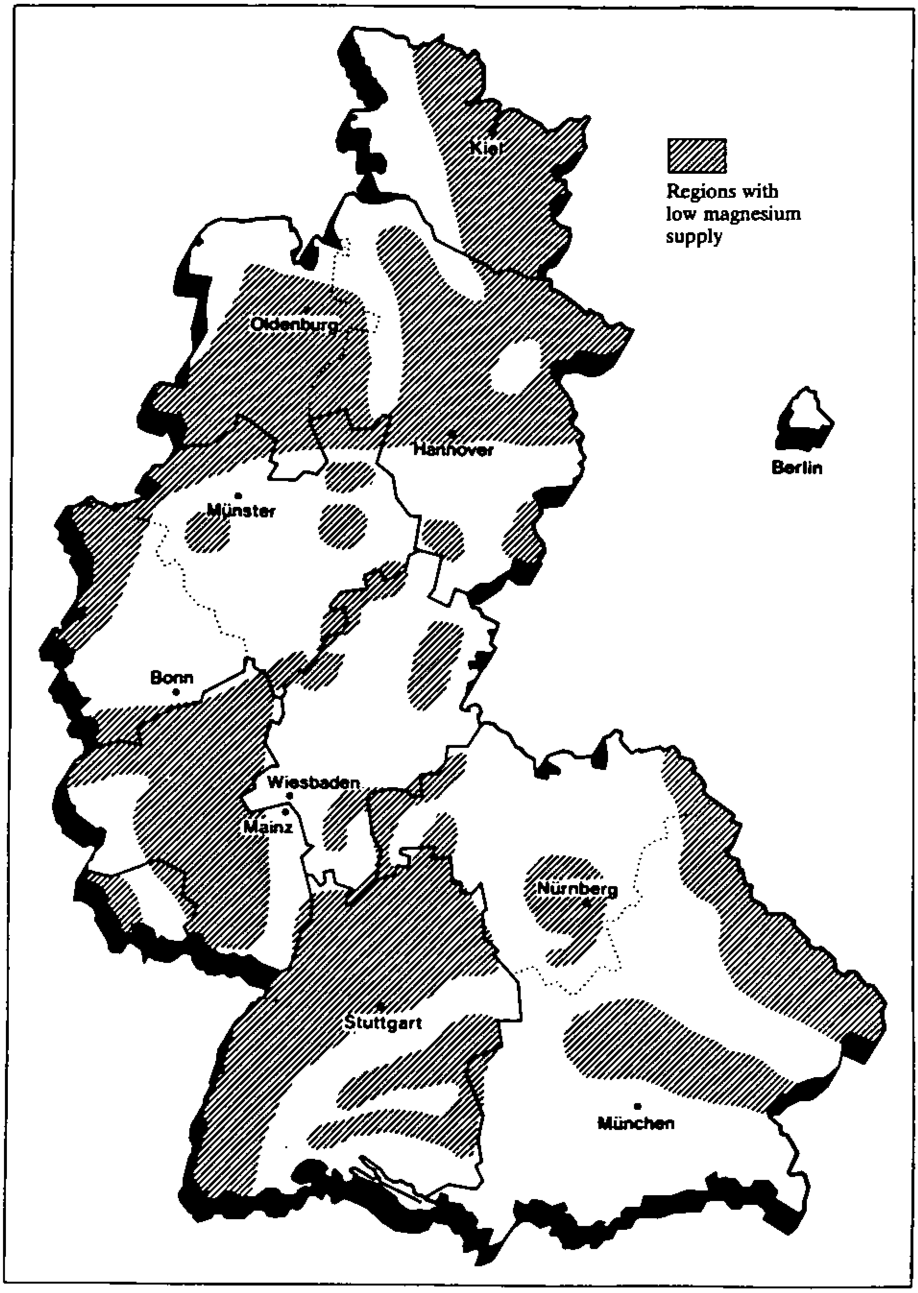

Fig. 1 Many areas in the Federal Republic of Germany show magnesium deficiency

12% K_2O, 6% MgO and 24% Na_2O, it is possible to raise herbage contents of magnesium and sodium, especially in herbage with a high proportion of meadow grass *(Finger et al. [1972]; Grass [1975]; Werk [1976])*. Such an enriched herbage is prefered by the grazing animal as experiments have shown *(Ernst [1978])*.

7. Economic factors

As well as plant and animal needs and the farming system, economic factors must be taken into account when selecting the potash fertilizer. These are for instance:

- cost of manufacture of the fertilizer,
- transportation cost
- content of auxiliary nutrients,
- facilities available to the user.

These considerations apply in the choice between straight and compound fertilizers. The high K content of compound fertilizers is only achieved in costly processes. On the other hand these compounds offer economical transportation and also labour economy in handling on the farm. Straight fertilizers are cheaper per unit and often contain free auxiliary nutrients but these have to be set against higher transportation costs on account of lower nutrient concentration. In any case, each factor must be considered when making the decision on what to purchase.

In conclusion, there are many factors to consider in choosing the appropriate fertilizer and these are summarized in Table 6.

Table 6 Factors to consider in the choice of K fertilizers

	Chloride/ Salt tolerance		High requirement for			Mineral to grassland	for NPK	Freight/Distance	
	high	low	MgO	Na_2O	S			high far	low near
Kainit (6, 12/24)	X		X	X		X			X
Chloride 40% K_2O	X		X	X		X			X
50% K_2O	X								
60% K_2O	X						X	X	
Sulphate (50% K_2O)		X			X		X	X	
Potash-magnesia (30/10)		X	X		X				

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Co-ordinator's Report on the 4th Session

A. Dam Kofoed, Askov Forsøgsstation, Vejen/Denmark; member of the Scientific Board of the International Potash Institute*.

Mr. *Johnston's* comprehensive opening paper, largely based on results from long-term experiments at Rothamsted and other experiments in the U.K., pointed out the value of nutrient balances at field or farm level. National balances are important for administrators but have their limitations.

He posed the question: «If the balance is positive, how large should it be? If the balance is negative, would the crop then respond to extra fertilizer K and would added K have diminished the amount released by weathering and if not would that K have been lost from the soil?

He presented results comparing the effects of old and new residues and of fresh K dressings on winter wheat yields and showed that K residues often persist for many years.

There had been some discussion in Session 2 of the merits of exchangeable K. Mr. *Johnston* found that exchangeable K ranked soils better than did other rapid analytical methods. More K remained exchangeable in acid than in neutral or calcareous soils.

He dealt with the effect of K in farmyard manure, concluding that there was no fundamental difference between FYM and fertilizer in their effects on exchangeable K.

The long-term experiments at Rothamsted indicated that the release of K was relatively constant with time but offtake of K was less from sandy soils than from clay-loams. The amounts depend on other factors controlling the yield.

He discussed the factors which influenced the K balance and the effect of the latter on exchangeable K and described the effects of negative balance on succeeding crops. As an example, barley following grass which had removed much K from the soil took up only a little less K than barley after arable crops.

In his concluding discussion, Mr. *Johnston* suggested that we still need a reliable and quick method to determine soil K reserves which are available over a period of a few years. The active discussion which followed the lecture showed that the problems raised had created much interest.

* *A. Dam Kofoed*, Director, Askov Forsøgsstation, DK-660 Vejen/Denmark

Dr. *Murphy* described nutrient pathways in pasture systems. He stressed the importance of run-off and discussed the removal of nutrients by livestock, illustrating this with a figure. It was shown that at a stocking rate of 2.5 livestock units per hectare, it took 5 years to recycle nutrients to 80% of the grazing area.

Dr. *Gutser* dealt with the evaluation in pot and field experiments of potassium from plant residues in arable cropping systems. Pot trials showed that potassium in plant residues had the same good effect as fertilizer K though some have found in field experiments that fertilizer K is more efficient.

In trials where no fertilizer K was applied, K in residues was utilised to the extent of 50 to 90% and straw K was roughly equivalent to FYM K. In the case of beet tops there may be leaching or fixation of K in the long interval between ploughing-in and planting. Dr. *Dutil* discussed the utilisation of potassium in industrial wastes. The disposal of all wastes, including those from industry, is an increasingly important problem, and it was interesting that the problem should be taken up in this conference, since large amounts of potassium were concerned — 500 000 m^3 factory effluent per year contained 500 t K.

The properties of effluents from various agro-industries were described; they are usually rich in N and K. A practical policy for the use of these effluents had been evolved and no problems had arisen over the past 15 years when effluents were applied in accordance with advice.

Dr. *von Braunschweig* discussed the composition of different potash fertilizers, their effects on potassium availability, the properties of the anions accompanying K, the salt index, effects on pH, other substances (Na, Mg) and economic factors. From the crop's point of view, the way in which K is combined is of no importance. Chloride and sulphate are water soluble and the K is immediately and completely available. The chloride and sulphate ions have little effect on K uptake, which is favoured only by nitrate.

It was interesting that Dr. *von Braunschweig* quoted work *(Händel [1984])* showing that the nitrate content of spinach can be reduced by applying chloride but, on the other hand, some crops are sensitive to chloride.

In conclusion, it was stated that economic factors must be taken into account in selecting potash fertilizers. The trend in many countries is to use compounds.

On the whole, the papers presented dealt in an interesting manner with the important subjects included in the session.

13th Congress of the International Potash Institute
August 1986 in Reims/France

5th Session

Investing in soil fertility to insure the future

Co-ordinator: *Dr. L. Gachon,* Directeur de Recherches, I.N.R.A., Clermont-Ferrand/France; Chairman of the 13th IPI-Congress; member of the Scientific Board of the International Potash Institute

The Intercontinental Transfer of Plant Nutrients

*G. W. Cooke, Rothamsted Experimental Station, Harpenden, Herts/United Kingdom; member of the Scientific Board of the International Potash Institute**

Summary

Intercontinental trade results in the loss of nutrients from the agricultural systems which produced the products exported. The use made of imported products determines whether the nutrients they contain will contribute to agricultural productivity in the receiving country. A considerable proportion of the nutrients in livestock foodstuffs will appear in excreta which should be applied to soil. Some of the N and P in human food will be retrieved in sewage sludge which may be applied to agricultural land, but most of the K will be lost in effluents which are discharged into rivers. No nutrients in products used by industry, such as rubber, jute or tobacco will be recovered to benefit agriculture.

The gains of nutrients from imports, and the losses by exports in developed and developing regions are summarised here:

	All developed countries			All developing countries		
	N	P	K	N	P	K
	kilotonnes of nutrients					
Gains from imports	1105.6	133.6	450.8	963.8	182.8	269.6
Losses by exports	987.8	187.1	274.9	1074.6	130.9	456.3

In developed countries the gains of N and K resulting from imports are greater than the losses by exports. In developing countries the reverse is true, losses of N and K through exports being much greater than gains from imports. These average data for regions are not representative of the situation in individual countries; thus in Thailand exports remove four times as much K as is supplied by fertilizers in the whole country. Exports of jute and bast fibres from Nepal and Bangladesh remove about 1½ times as much K as is provided by fertilizers used in the whole of each country.

Some continents, notably North Central and South America, export products containing much more nutrients than are received in imports. The reverse is true in other continents, notably in Europe where imports provide much more nutrients than are contained in the exports from the continent and much of these imported nutrients are in products used for livestock foods. Many products exported from tropical countries contain much K and countries engaged in such trade should make careful studies of the nutrient balance in the agricultural systems. All countries need to construct a national nutrient balance for the whole of the agricultural system, taking account of the fate of the products which leave farms. These balances should then be used to determine national policies on fertilizer imports and manufacture, and advice to farmers. Only then will it be possible to maintain soil fertility, and therefore crop productivity and national prosperity in countries which have large export trades.

* Dr. *G. W. Cooke*, Rothamsted Experimental Station, Harpenden, Herts. AL5 2JQ/United Kingdom

1. Introduction

The transfer of plant nutrients from one region of the world to another has two forms. The first is the movement of raw materials from countries where they are mined to other countries which manufacture fertilizers, and the movement of prepared fertilizers to other regions where they are applied to the land. *FAO [1985a]* publishes full records for all regions of the production of fertilizers, of imports and exports, and of the amounts used in each country; this subject is not pursued in detail here.

The second form of transfer, which is the subject of this paper, is concerned with the transport of nutrients in agricultural products that are exported from one region and are received and used as food for man or animals, or for industrial purposes, in another distant region. This movement of nutrients has important consequences for the fertility of soils, and the productivity of agricultural systems, in both the exporting and the importing regions.

The nutrients in products that are exported are completely lost from the agricultural system of the country which produces the exports. The use which is made of imported products influences the fate of these nutrients and determines the extent to which they may enter soils of the importing country and so enhance fertility. The nutrients in products which are used by industries other than the food industry will not reach agricultural systems, examples are rubber, tobacco, and fibres such as jute or kenaf. The fate of nutrients in human foodstuffs, and in beverages (tea, coffee and cocoa) will vary with social living conditions and with methods of waste disposal. Relatively little of the N and P, and practically none of the K, is retained in the human body. In rural areas where wastes are collected as «night soil» which is applied to land most of the nutrients in the food will enter the soil. In urban areas the fate of nutrients in excreta will depend on the nature of the sewage system. Much of the N, and some of the P, and almost all of the K in sewage will appear in liquid effluent and will be discharged to rivers. Only where this river water is used for irrigation will these nutrients benefit agriculture. The solid sewage sludge will contain some of the N and P that originated in food and in many countries the sludge is applied to agricultural land so the nutrients will benefit crops. It is estimated by the *Royal Society [1983]* that 12% of the N which enters sewage becomes incorporated in the sludge, but some of this N may volatilise as ammonia from the sludge before it is incorporated in the soil (no parallel estimates of the proportions of P and K entering sewage sludge are available).

By contrast most of the nutrients in animal feeding-stuffs will remain in the agricultural system and will enhance soil fertility because animal wastes are generally applied to soil. The wastes need careful handling and application techniques to ensure that nutrients are not lost by leaching and that N is not lost by volatilisation. *Balch and Cooke [1982]* provided examples of the recovery of nutrients present in livestock foods. Where barley was used to feed a steer 75% of the N ingested was excreted, together with 50% of the P and 80% of the K. Where a cow grazes grass about 75% of the N, 67% of the P, and 90% of the K in the grass eaten will be in excreta. The *Royal Society [1983]* estimated that while human sewage contributes 26 kilotonnes

The amounts of nutrients in agricultural products, and in fertilizers, stated in this paper are all in terms of the elements: N, P, and K (where quantities have been stated in other publications in terms of the oxides P_2O_5 and K_2O they have been converted to P and K).

of N to agricultural land in U.K. livestock excreta provide 1020 kilotonnes of N. These differences of course reflect differences in numbers of people and of livestock, differences in types of food, and also differences in ways of disposing of excreta.

1.1 Transfer of nutrients into the U.K. in the Nineteenth Century

The importance of studying nutrient cycles was recognised in the U.K. a century ago. *Johnston and Cameron [1877]* stated that the nutrient losses which occur when produce is removed from the farm can be replaced by the nutrients in imported foods and manures. They reported that in the 1870s immense quantities of food were imported into Britain and other parts of Europe: «When consumed the effete matters into which they are converted are chiefly discharged into sewers and rivers, still a portion is deposited in British soils. An enormous amount of oil-cakes and other feeding stuffs is consumed on the farms, as only a small portion of their weight becomes permanently reorganised into animal substances their nitrogen, phosphoric acid and potash, for the most part go into the soil». Losses of nutrients from farms were also largely compensated by imports of guano, nitrate of soda, and phosphate and potash from foreign countries. The imports into the U.K. in 1874 are shown in Table 1.

Johnston and Cameron considered that all the N, P and K contained in the agricultural seeds, oil cakes, guano, and «artificial manures» would ultimately reach the cultivated land in U.K. They calculated for the cropping and stocking stystems of the time, and the use made of the crops, the amounts of N, P and K removed each year from this cultivated area; they showed that although the soils of U.K. received more P than was removed in agricultural produce, they received no more than one-fourth of the N, and only one-tenth of the K removed by the crops that were sold away from the farms.

Table 1. Plant nutrients in imports into U.K., and in exports from the country in 1874 (from *Johnston and Cameron [1877]*).

	N	P tonnes	K
Imports			
Meat, cheese, eggs and fish	9658	1487	778
Grain and flour	42545	8488	10089
Rice	3507	265	1782
Potatoes	953	299	1583
Agricultural seeds	3795	538	883
Oil cakes	7211	1049	1596
Guano	9715	7482	1897
Sodium nitrate	16143	–	–
Artifical manures*	5080	33254	843
Total Exports+	2716	913	345

* Some of these «artificial manures» were fertilizers manufactured from British materials, some were imported – for example phosphates from Africa and potash salts from Germany.
+ Exports were of cheese, fish, animals, grains and seeds, and guano.

Although it was prepared more than 100 years ago this plant nutrient balance sheet for the U.K. in 1874 remains a good example of a national nutrient balance. The results must influence policies on importing fertilizers, or the materials needed to manufacture them. They also influence the nature of the advice given to farmers on the use of fertilizers needed to maintain nutrient balances in the farming system that is used.

Table 1 emphasises that in maintaining a satisfactory nutrient balance the imports containing nutrients that are used on farms have an important role, notable examples are the oil-cakes used as animal feeds, and the seeds. In this example the oil cakes used in 1874 supplied more N and K (but much less P) than was contained in the «artificial manures» that were available. It is considered that the nutrients in the large amounts of imported animal foods used in U.K. in the second half of last century, and the early years of this century, had an important role in building up and maintaining reserves of nutrients in soils and allowing cropping to be intensified.

Table 1 shows that exports from U.K. in 1874 removed very much less nutrients than were contained in the imports into the country; the situation at present (in 1986) is similar. This is very different from the position in other countries which have a large export trade in agricultural products; in such situations there is a risk the amounts of nutrients exported may exceed the amounts in imported products that reach the farms plus the fertilizers used; if this occurs reserves of nutrients in the soils will be depleted and productivity will fall leading to damage to the export trade that is so important for the prosperity of many countries. Such a situation is explored in the next Section.

1.2 Exports from Thailand

Thailand has a very important industry which exports food and other agricultural produce. In my Introduction to the IPI-Bangkok Colloquium *(Cooke [1986])*. I showed that the fertilizers used in Thailand supplied much more N and P than was contained in the products exported in 1982, but the amount of K supplied by fertilizer was less than one-quarter of the amount exported. This subject is discussed in greater detail in this Section using information kindly supplied by the Commercial Counsellor of the Royal Thai Embassy in London. This example of an examination of one country's export position indicated the kind of treatment needed for investigating transfers of plant nutrients between different regions of the world.

1.2.1 The destinations of exports from Thailand.

Table 2 shows the quantities of rice, maize and rubber exported from Thailand in 1983, and of tapioca exported in 1982, to various destinations. The surprising feature of Table 2 is that large amounts of the products were exported to other countries in Asia, they received 45% of the rice, 85% of the maize, 80% of the rubber, but only 4% of the tapioca exported.

This indicates that in considering the effects of exports on nutrient balances in regions we must take account of both imports and exports of each commodity in the whole of each region; simply to examine the totals of the amounts exported by each country could be misleading because an unknown proportion of the total will be involved in internal trade and will not have left the region. *FAO [1985b]* does not record the destinations of the commodities exported from each country.

Table 2. Quantities of products exported to various regions from Thailand

Product exported Year of export	Rice 1983	Maize 1983	Rubber 1983	Tapioca 1982
Destination	kilotonnes of product exported			
Asian countries	1569	2282	446.8	306.1
Europe	–	–	16.6	7318.9
USA	–	–	69.1	25.2
USSR	0.2	172	–	54.4
African countries	910	–	–	–
South America	106	–	–	–
Others*	892	205	22.6	110.8
Totals exported	3477.2	2659	555.1	7815.4

* the countries in «other» destinations are not specified

1.2.2 Exports of tapioca

Tapioca products are very important exports from Thailand. Table 2 shows that 94% of the total was exported to Europe in 1982; this was distributed between 5 countries of Western Europe:

Receiving country	*kilotonnes of tapioca*
Belgium	369.5
France	166.1
West Germany	279.7
Italy	124.1
Netherlands	6379.6

Of the total of 7319 kilotones of tapioca exported to Europe 87% was received in Netherlands, and this also amounted to 82% of the total amount exported from Thailand. The total exports of tapioca in 1982 would have removed:

46893 tonnes of N
14 537 tonnes of P
129 737 tonnes of K

The amounts of nutrients in the fertilizers used in Thailand as a whole in two relevant years, as recorded by *FAO [1985a]* were:

	1981-82 tonnes	1983-84 tonnes
N	162000	255000
P	55074	59132
K	29548	61088

While fertilizers supplied much more N and P than was exported in tapioca in 1982, the exports removed 2.1 times as much K as was used in the whole country in the following year (1983-84) and 4.4 times as much as was used in the year when the tapioca was produced (1981-82).

We should now consider the importing country: the Netherlands received in tapioca imported from Thailand:

38 278 tonnes of N
11 866 tonnes of P
105 901 tonnes of K.

FAO [1985a] records that the Netherlands used these quantities of nutrients in fertilizers:

	1981-82 tonnes	1983-84 tonnes
N	477 273	478 309
P	35 156	37 773
K	87 931	97 463

Therefore the Netherlands received in the tapioca imported from Thailand more potash than was supplied by fertilizers in the whole country in either 1981-82 or 1983-84 (but fertilizers supplied more N and P than was contained in the tapioca). Whether all the tapioca products were fed to livestock in the Netherlands, or whether some was exported or used as human food, is not known, so we cannot say whether these large quantities of potassium all reached the Netherlands soils through the application of animal manures.

1.2.3 Other exports

In addition to the four crops noted in Table 2 considerable quantities of other crops were exported from Thailand in 1982 and these were included in the calculations leading to the total quantities of nutrients exported which were reported in the Introduction to the IPI-Bangkok Colloquium *(Cooke [1986])*. In addition large quantities of wood have been exported from the forests of Thailand. For example a total of 39 373 cubic metres of teak was exported in 1977; nearly half of this went to USA, with smaller amounts going to Australia, Canada and to six European countries. These quantities of wood must have removed further amounts of nutrients from Thailand.

2. Nutrient transfers between developing and developed countries

A main concern in studying nutrient transfers must be to assess the movement of nutrients from developing countries to developed regions (and the reverse where it occurs). These transfers have been examined in this Section by using selections of the data on imports and exports published by FAO in their *Trade Yearbook FAO [1985b]*. Because there is so much local trade in a region, products being exported to neighboring countries (as in the example given above for Thailand), groups of countries classed by *FAO [1985b]* as «developed» or «developing» were treated as regions.

Similarly the Continent classifications established by *FAO [1985b]* were used in the later sections of this paper. A few examples of countries which exported specific products were also investigated (in Section 4).

2.1 Quantities of some agricultural products featuring in international trade.

The total amounts of imports into, and exports from, developed and developing countries were abstracted. Subtracting exports from imports gave the «gains» (for positive results) or the «losses» (for negative results) which are stated in the Tables of this Section. Table 3 shows the gains and losses in developed and developing countries for a wide range of products which feature in world trade. Comment is made on these data in the following paragraphs; nutrient transfers are discussed in Section 2.2.

2.1.1 Cereals

Wheat, maize, barley, oats, and rice are grown in developed countries and amounts exported greatly exceed imports for all these crops. Developing countries gain through imports of the first four of these cereals, but more rice is exported than is imported into these countries. The nett result is that losses of cereals from developed countries total 78.6 million tonnes and developing countries gain 77.5 million tonnes of cereals.

2.1.2 Grain legumes

The developed countries import more pulses (the species are not specified), ground nuts, and soybeans, than they export; the total gain of these crops amounted to 732 kilotonnes. Developing countries export more of each crop than they import and the total loss is 1.6 million tonnes.

2.1.3 Products for industrial processing

A wide range of crops grown in tropical countries which are processed in various ways are shown in Table 3. Developed countries gain, and the developing countries lose nutrients by trade in coconuts, copra, palm nut kernels, linseed, castor beans, and seeds of cotton and sesame. Crops grown in more temperate climates to provide rape and mustard and sunflower seeds which are exported from developed countries provide gains for the developing countries. Natural rubber, jute and bast fibres, and tobacco, are all exported from developing countries and the losses recorded for these products are similar to the gains from these crops reported for the developed countries.

2.1.4 Fruit and vegetables

A wide range of fruits are exported from developing countries and they represent gains to developed countries; the quantities of citrus fruits, bananas and pineapples are notable. Tomatoes and onions are also gained by the developed countries. Potatoes are an exception, exports from developed countries are 379 kilotonnes greater than imports and the developing countries gain by a similar amount.

Table 3. Movement of agricultural products in 1984, balances of imports and exports in developed and developing countries (from *FAO [1985b]*).

	Developed countries		*Developing countries*	
	Gain	Loss	Gain	Loss
	tonnes of agricultural products			
Cereals, total	–	78603650	77505010	–
Wheat and flour	–	57077490	56551600	–
Rice	–	736286	–	31963
Maize	–	11026823	10682996	–
Barley	–	10064159	10126233	–
Oats	–	214807	67113	–
Grain legumes				
Pulses	81245	–	–	28911
Groundnuts	334897	–	–	317633
Soybeans	315826	–	–	1279502
Totals	731968	–	–	1626046
Agricultural products for processing				
Coconuts	39021	–	–	44132
Dried coconuts	103948	–	–	109735
Copra	207816	–	–	186186
Palm nut kernels	93491	–	–	117297
Linseed	12421	–	–	9828
Rape & mustard seed	–	53306	40599	–
Castor beans	92112	–	–	93840
Cotton seed	61599	–	–	81497
Sunflower seed	–	810855	440023	–
Sesame seed	157757	–	–	181892
Products for industry				
Natural rubber	2724418	–	–	2690740
Jute & bast	147135	–	–	157704
Tobacco	552056	–	–	542538
Fruit				
Oranges	843100	–	–	968114
Lemons & limes	186354	–	–	183418
Other citrus	253405	–	–	259532
Bananas	5739936	–	–	5971988
Fresh pineapples	329504	–	–	351839
Canned pinneapples	398241	–	–	452524
Apples	22041	–	–	35823
Pears	20748	–	–	26801
Peaches	27123	–	–	15216
Grapes	151521	–	–	168807
Raisins	119517	–	–	144505
Dates	47861	–	–	51220

Table cont'd. Movement of agricultural products in 1984, balances of imports and exports in developed and developing countries (from *FAO [1985b]*).

	Developed countries		*Developing countries*	
	Gain	Loss	Gain	Loss
		tonnes of agricultural	products	
Vegetables				
Tomatoes	532191	–	–	591084
Onions	86233	–	–	60543
Potatoes	–	379091	372906	–
Beverages				
Tea, leaves	508111	–	–	555304
Coffee, green & roast	3485469	–	–	3662464
Cocoa, beans	1154324	–	–	1122188
Oilseed by-products used as animal feeds				
Oilseed cakes and meals, total	14061414	–	–	12658511
Soybean cake	8947502	–	–	7637289
Groundnut cake	490744	–	–	500096
Cottonseed cake	731930	–	–	798110
Linseed cake	434861	–	–	459170
Sunflower cake	783871	–	–	769545
Rapeseed cake	300636	–	–	299129
Copra cake	653331	–	–	616903
Palmkernel cake	602392	–	–	662219

2.1.5 Beverages

Tea, coffee and cocao are all tropical crops which are exported from developing countries which have a total loss of these products of over 5 million tonnes, and the developed countries register a similar total gain.

2.1.6 Oilseed cakes for animal feed

These by-products from the processing of oil-seeds are very important in transferring nutrients, as was indicated in Section 1.1. *FAO [1985b]* records that developed countries received 14 million tonnes more of these products than they exported, developing countries lost 12.66 million tonnes of these products. Table 3 shows gains and losses for cakes made from soybeans, groundnuts, cottonseed, linseed, sunflower, rapeseed, copra, and palm kernels; the cake from soybeans clearly dominates this trade and it accounts for nearly two-thirds of the total gains and losses.

2.1.7 Other products

Many other products of agricultural systems which feature in the trade as recorded by *FAO [1985b]* have not been included in the present study. The oils resulting from seed processing, and sugar and honey, are much involved in trade, but they contain little or no plant nutrients. Other products, such as cocoa preparations, pepper, vanilla, and silk and other fibres, may contain some N, P and K, but they have not been included in this study. Meat and other products made from animal processing, milk and milk products, and eggs, have all been ignored although they do contain some plant nutrients.

2.2 Nutrient balances resulting from trade between developed and developing countries

Tables 4 records summaries of the gains and losses of nutrients through a selection of the commodities in the trade balances noted in Table 3. The crop analyses used to prepare these and other nutrient balances are those published by *Cooke [1986]*, *Sanchez [1976]*. and *ILACO B. V. [1981]*. Analyses of animal feedingstuffs published by the *Agricultural Research Council [1976]* were used.

The losses of N, P and K from developed countries only occur through exports of cereals and potatoes; exports of wheat account for about two-thirds of the total. Corresponding gains by developing countries importing these commodities involve similar total quantities of N, P and K.

Table 4. Nutrient balances in developed and developing countries resulting from trade in agricultural products in 1984

	Developed countries				Developing countries			
	Gain or Loss	N	P (kilotonnes)	K	Gain or Loss	N	P (kilotonnes)	K
All cereals	LOSS	1171.8	223.9	319.6	GAIN	1145.7	219.2	313.7
Potatoes	LOSS	1.2	0.2	1.7	GAIN	1.2	0.2	1.7
Total	LOSS	1173.0	224.1	321.3	Total GAIN	1146.9	219.4	315.4
Groundnuts	GAIN	16.4	1.7	9.0	LOSS	15.6	1.6	8.6
Soybeans	GAIN	15.5	2.3	6.6	LOSS	62.7	9.2	26.9
Bananas	GAIN	9.8	2.9	28.7	LOSS	10.2	3.0	29.9
Fresh pineapples	GAIN	0.3	–	0.7	LOSS	0.3	–	0.7
Tomatoes	GAIN	1.4	0.2	1.6	LOSS	1.5	0.2	1.8
Tea	GAIN	26.4	1.9	12.7	LOSS	28.9	2.1	13.9
Coffee	GAIN	87.1	5.9	55.8	LOSS	91.6	6.2	58.6
Cocoa beans	GAIN	23.1	5.1	11.5	LOSS	22.4	4.9	11.2
Natural rubber	GAIN	17.2	2.4	9.8	LOSS	16.9	2.4	9.7
Jute and bast fibres	GAIN	7.4	2.6	19.6	LOSS	7.9	2.8	20.9
Tobacco	GAIN	64.0	7.7	111.5	LOSS	62.9	7.6	109.6
Oilseed cakes and meals	GAIN	951.2	86.1	183.9	LOSS	849.2	79.0	165.0
Total	GAIN	1219.8	118.9	451.4	Total LOSS	1170.2	119.2	456.8

Total losses from developing countries and corresponding total gains in developed countries also involve similar total amounts of N, P and K; outstanding contributions to these totals were made by the group of beverages (tea, coffee and cocoa), the industrial materials (rubber, jute and tobacco), and the oilseed cakes and meals.

In assessing data such as those in Table 4 it must be recognised that all «losses» by exports are the quantities of nutrients removed from the agricultural systems of the exporting country. «Gains» of nutrients by imports are not of certain value to agriculture in the importing country. Whether they enhance soil fertility, and the extent to which they do so, depends on the nature of the imports, the use made of them, and on the methods of disposing of human and animal wastes. These questions are discussed in Section 1.

3. Gains and losses of nutrients by trade between Continents

Although the balance of nutrients, as affected by imports and exports, is important for comparison between developed and developing countries such as was made in the previous Section, we must take account of the balances in different regions of the world. This has been done in this Section by using the classification of Continents used by *FAO [1985b]:* Africa, North-Central America, South America, Asia, Europe, Oceania, and USSR. It should be recognised that some regions contain both developed and developing countries. The balance in each Continent has been assessed for a series of 15 important products: wheat, rice, maize, potatoes, bananas, soybean, groundnut, tobacco, jute, rubber, coffee, cocoa, tea, oilseed cakes (as a whole group) and copra.

Table 5 gives two examples of the assessment of gains and losses by regions for particular crops; both are produced in tropical regions. Rice is taken as an example of a human food which is required all over the world. The oilseed cakes and meals (which are grouped together by *FAO [1985b])* are mostly the by-products from processing tropical oil-producing crops and they have a long history of being imported to feed livestock in regions where animal production is being intensified. Large quantities of rice are exported from North-Central and South America, and from Asia and Oceania, while Africa, Europe, and USSR benefit from their imports. Oilseed cakes and meals are exported in large quantities from Africa, North-Central and South America, Asia and Oceania. The beneficiaries are the developed regions, notably Europe and USSR.

For each region the balance between imports annd exports of the 15 crops listed above was calculated and the amounts of N, P and K involved in the transfer were then calculated. The detailed results for Asia are given in Table 6 as an example of this treatment. The results for all regions are summarised in Table 7. The total of gains of N, P and K for the seven regions are similar to the total losses. Comments on the results of the study in each region are made in the following Sections. It must, however, be realised that in most regions more species of crops are grown than the 15 species studied here, so total losses will usually exceed the amounts shown in the Summary in Table 7. As there will be some interest in comparisons of nutrient transfer by trade with amounts of nutrients applied by fertilizers in particular regions, the amounts of fertilizers consumed, as recorded by *FAO [1985a]*, are given in Table 8.

Table 5. The balance of nutrients in Continents resulting from exports and imports of rice and of oilseed cakes and meals in 1984

	Quantity of produce (imports minus exports)	Nutrients in the quantity of produce		
		N	P	K
	tonnes		tonnes	
Rice				
Africa	+3032005 (gain)	45480	7883	7883 (gain)
North Central America	−1545551 (loss)	23183	4018	4018 (loss)
South America	−214716 (loss)	3221	558	558 (loss)
Asia	−3173640 (loss)	47605	8251	8251 (loss)
Europe	+1076594 (gain)	16149	2799	2799 (gain)
Oceania	−70924 (loss)	1064	184	184 (loss)
USSR	+127983 (gain)	1920	333	333 (gain)
All developed countries	−736286 (loss)	11044	1914	1914 (loss)
All developing countries	−31963 (loss)	479	83	83 (loss)
Oilseed cakes and meals				
Africa	−88711 (loss)	5233	621	1118 (loss)
North Central America	−4239473 (loss)	250129	29676	53417 (loss)
South America	−11370563 (loss)	670865	79594	143270 (loss)
Asia	−1778645 (loss)	104937	12450	22410 (loss)
Europe	+17940798 (gain)	1058519	125586	226054 (gain)
Oceania	−6503 (loss)	384	46	82 (loss)
USSR	+946000 (gain)	55814	6622	11920 (gain)
All developed countries	+14061414 (gain)	829599	98427	177169 (gain)
All developing countries	−12658511 (loss)	746822	88606	159491 (loss)

3.1 Africa

The gains of N, P and K in Africa are all much larger than the losses. Considerable gains of N, P and K occurred through imports of jute and other fibres, soybeans, potatoes, and particularly the cereals – maize, rice and wheat. The nutrients in jute fibres are unlikely to benefit agriculture unless some of the material is wasted and made into compost. The other products noted are human foods; whether much of the nutrients they contain will reach agricultural land must depend on methods of disposal of human wastes; sewage systems in cities will normally discharge much of the plant nutrients in excreta into rivers which flow to the sea but in some areas the enriched waters may be used for irrigation. The largest losses from Africa occur through exports of coffee, cocoa, tea, tobacco, groundnuts and oilseed residues. The gains of N, P and K in the Continent resulting from trade were greater than the losses by exports shown in Table 7; Table 8 shows that the amounts of nutrients applied as fertilizers in Africa were much larger than the gains through trade and very much larger than the losses by exporting produce.

Table6. Gains and losses of plant nutrients in the Continent of Asia resulting from imports and exports of agricultural products in 1984.

	Gains of nutrients			Losses of nutrients		
	N	P	K	N	P	K
	tonnes of nutrients			tonnes of nutrients		
Coffee	–	–	–	2192	149	1403
Cocoa	–	–	–	746	164	373
Tea	–	–	–	21982	1606	10568
Tobacco	–	–	–	12563	1516	21877
Jute and bast fibres	–	–	–	11060	3982	29420
Rubber	–	–	–	14022	2003	8013
Soybeans	339198	49841	145370	–	–	–
Groundnuts	–	–	–	4885	518	2692
Bananas	–	–	–	12	4	35
Oilseed cakes and meals	–	–	–	104937	12450	22410
Copra	4268	1164	3880	–	–	–
Potatoes	–	–	–	134	21	189
Maize	33502	5863	8166	–	–	–
Rice	–	–	–	47605	8251	8251
Wheat and wheat flour	539989	104141	154283	–	–	–
Total nutrients in the balance	916957	161009	311699	220138	30664	105231

Table7. Summary of the gains and losses of plant nutrients in the Regions of the world resulting from imports and exports of the standard list of 15 crops in 1984.

	Gains of nutrients			Losses of nutrients		
	N	P	K	N	P	K
	kilotonnes of nutrients			kilotonnes of nutrients		
Africa	435.0	81.4	123.3	57.7	7.4	42.5
North Central America	25.1	3.0	17.0	2286.1	375.5	770.7
South America	1.1	0.2	1.0	1076.0	138.3	353.6
Asia	916.9	161.0	311.7	220.1	30.7	105.2
Europe	2075.8	275.8	733.5	185.9	35.8	54.2
Oceania	6.0	0.8	5.9	156.2	30.8	50.3
USSR	660.5	116.9	203.3	–	–	–
Totals	4102.4	639.1	1395.7	3982.0	618.5	1376.5
All developed countries	1105.6	133.6	450.8	987.8	187.1	274.9
All developing countries	963.8	182.8	269.6	1074.6	130.9	456.3

Table 8. Amounts of plant nutrients provided by fertilizers in 1983/84 used in Regions of the world and in some countries (from *FAO [1985a]*).

	N	P	K
Regions of the world	kilotonnes of nutrients		
Africa	1874.3	496.8	340.7
North Central America	12842.6	2504.2	4971.7
South America	1072.9	564.3	727.3
Asia	25362.0	3770.8	2511.8
Europe	15155.3	3702.5	7168.4
Oceania	307.4	483.0	222.6
USSR	10292.0	2816.5	5146.0
All developed countries	38122.0	9773.3	17874.8
All developing countries	28784.5	4565.1	3213.7
Countries discussed in Section 4	metric tonnes of nutrients		
Ivory Coast	10000	3273	20750
Mexico	1010400	166251	44544
Brazil	564200	436269	603161
Indonesia	1049077	155215	89513
Ghana	11000	3055	2822
Malaysia	166000	50622	167660
India	4637300	594551	520244
China	13678900	1627292	672549
Sri Lanka	82600	13572	39840
Zimbabwe	81300	19071	24485
Bangladesh	343000	71133	31955
Nepal	22000	4320	830*
Vietnam	289000	18154	22244
Netherlands	478309	37773	97463

* *FAO [1985a]* does not give a figure for the potash used in Nepal in 1983/84; the amount quoted here is for use in the year 1982/83.

3.2 North Central America

This Region, although it contains some developing countries, is a considerable donor of nutrients to other Regions. The small total gains in nutrients result only from the import of tropical beverage crops and also jute and rubber. Losses of nutrients are very much greater than gains; large contributions to nutrient exports are made by tobacco, soybeans, groundnuts, bananas, and oilseed residues. In addition there are large exports of wheat and some export of maize and rice. When the total losses in Table 7 are compared with the amounts supplied by fertilizers (Table 8) it is seen that fertilizers supplied about 6 times as much nutrients as were lost by the export of the crops noted above.

3.3 South America

This Continent gains very small amounts by imports of only three commodities (jute, rubber, and potatoes). Losses by exports are very much greater than gains of nutrients. The largest contribution to export losses is made by oilseed cakes and meals but there are also considerable losses by export of coffee, cocoa, tea, tobacco, soybeans, groundnuts, bananas, maize, rice and wheat. The amount of N in the agricultural products exported in 1984 slightly exceeded the amount applied in fertilizers, the P exported was about a quarter of that supplied by fertilizers, but the K exported by this selection of crops worked over in this study is about half of the amount supplied by the fertilizers used in the Continent.

3.4 Asia

Table 6 shows that the gains of all three nutrients from imports into Asia were considerably greater than the losses through exports. Over half of the total gain came from imports of wheat and wheat flour; soybean imports also made considerable contributions and smaller amounts came with copra and maize imports into the Region. Most of these commodities are human foods; as in other areas the amounts of the nutrients they contain which reach agricultural land will depend on the sewage disposal systems.

The largest losses of N and P are from exports of the residues of oilseed processing; jute, tobacco and tea export large amounts of K. Other contributions to the export of N, P and K were made by coffee, cocoa, rubber, groundnuts and rice. Comparison of data in Tables 7 and 8 show that the total amounts of nutrients exported by this selection of crops are very small fractions of the N, P, and K supplied by fertilizers in the Region.

3.5 Europe

Europe is the recipient of large amounts of nutrients contained in products exported from the tropics. The largest contribution is made by oilseed cakes and meals which provide about half of the total amounts of N and P, and a third of the K, that is received. All of these materials, and proportions of other imports such as soybeans and maize, are used as animal feeds; much of the N and P, and most of the K, that they contain will become available in animal manure which is applied to land. Some of the N and P in human foodstuffs (such as soybeans, groundnuts, bananas, and rice) and the beverage products may also become available to agriculture through sewage sludge, but the K is likely to be lost in the sewage effluent which is usually discharged into rivers that flow direct to the sea. The large amounts of nutrients in imports of tobacco, jute, and rubber, are unlikely to enter agricultural systems at any time.
Losses of nutrients from Europe are very much less than gains, and most of the total loss is due to the export of wheat and wheat products together with small amounts of barley and oats; small amounts of N, P and K are exported in potatoes. Comparisons of data in Tables 7 and 8 show that the gains in nutrients which come in imports are only small fractions of the amounts of N, P and K which are supplied by fertilizers.

3.6 Oceania

This Region contains developed temperate countries (Australia and New Zealand) and some developing tropical countries. Losses of nutrients by exports from the Region greatly exceed gains from imports. The loss totals are dominated by the nutrients in exports of wheat and wheat products from Australia which account for 80-90% of the totals; there are smaller exports of nutrients in tropical products such as coffee and cocoa, oilseed residues, copra and rice. The only sizeable gains in nutrients are from imports of tea, tobacco, jute, rubber, soybeans, and groundnuts, none of these are likely to benefit agriculture in the Region by providing nutrients. The total losses (shown in Table 7) are equivalent to about half of the N used as fertilizer, but only 6% of the P and 22% of the K applied by fertilizers (Table 8).

3.7 USSR

The USSR imported in 1984 quantities of all the products included in this study except copra and potatoes. Large amounts of nutrients were contained in imports of wheat, rice, maize, oilseed by-products, groundnuts, soybeans, rubber, tobacco and the beverages. The only exports noted were small amounts of potatoes. The total amounts of nutrients imported in 1984 were equivalent to very small percentages of the total amounts of N, P and K used as fertilizers in 1983/84 (Table 8).

3.8 Summary

Table 7 also shows a summary for developed and developing countries of gains versus losses of nutrients in this study of 15 standard crops. Developed countries gain more N and K by their imports than they lose by exports, but they gain less P. The reverse is true for the developing countries; they lose larger amounts of N and K by exports than they gain through imports, but they lose less P than they gain. In both developed and developing countries the gains and losses of N, P and K involved in the trade in the commodities included in this study were very much less than the total amounts of N, P and K applied as fertilizers in each of the class of countries.

When considering the implications of losses and gains of nutrients through exports and imports the points discussed in Section 1 must be considered. All losses through exports are losses to the agricultural systems of the Region or country. Whether imported nutrients benefit agriculture depends on the use made of the products which contain them. If they are processed by non-food industries the nutrients will be lost; if used as food for man or animals the fate of nutrients depends on the methods by which human wastes are disposed of, and the use made of animal wastes.

4. Specific problems arising from nutrient transfer by exports

The foregoing Sections have given a general account of nutrient transfers between the regions of the world; it is clear that some regions may benefit by increased supplies of nutrients while other regions may be depleting soil productivity by the export of nutrients. In most regions considered as a whole the fertilizers used are sufficient to replace nutrient losses caused by exports, but this may not be so in all individual countries of the region. In any case fertilizers are required to build up the fertility of soils deficient in nutrients and to produce the yield required as well as to replace the nutrients lost by removing products from farms. It must also be recognised that this present study does not always give a complete assessment of nutrient balance and needs as most countries grow other crops which have not been included in the 15 standard crops in the list that I chose; these other crops will need fertilizers to produce economic yields, and some of the products they provide may be exported.

Therefore all countries which trade in agricultural products should assess the effects of exports and imports on the nutrient cycle in their territory so that balance may be maintained by adjustments to the use of fertilizers. A full examination of all countries in the Continental regions studied, and of all the crops involved, is beyond the scope of this paper. A few examples are therefore given in this Section of specific crops which are exported from the tropics, and notes on some of the countries involved. The amounts of nutrients provided by fertilizers in the countries studied are stated in Table 8.

4.1 Tea, coffee and cocoa

These crops are grown in the tropics to provide beverages, they are responsible for the transfer of considerable amounts of nutrients.

4.1.1 Tea

Asia exports large quantities of tea, lesser quantities are exported from South America and Africa. Large amounts of N are involved in these transfers, the weight of K transferred is about half the weight of N, the weights of P transferred are much less. Date are given in Table 9 for three important exporting countries in Asia. Exports of tea from India and from China removed only about 1% and 0.5% respectively of the amounts of K used as fertilizers in these countries, but exports from Sri Lanka removed about 13% of the amount of K that was supplied by the fertilizers used in the whole country.

4.1.2 Coffee

There are large exports of coffee from countries in Africa, South America, and Asia, and small exports from Oceania. Data for the losses of nutrients in coffee exported in 1984 by four major exporting countries are given in Table 9. The quantities of N, P and K exported are only small percentages of the amounts of nutrients which are given in Table 8 to show how much fertilizers supply to the whole of these countries; it appears that no problems are likely to arise through the export of nutrients in coffee.

4.1.3 Cocoa beans

There are very large exports of cocoa beans from Africa, smaller quantities are exported from countries in South America, Asia and Oceania. Details of the transfer of nutrients by four exporting countries are given for 1984 in Table 9.

Table9. Examples of the transfer of nutrients in exports of produce from tropical countries in 1984

	Quantity of produce (exports minus imports)	Nutrients in produce exported		
		N	P	K
	tonnes		tonnes	
Tea				
India	215000	11180	817	5375
China	151146	7860	574	3779
Sri Lanka	204471	10632	777	5112
Coffee				
Ivory Coast	210200	5255	357	3363
Mexico	174028	4350	296	2784
Brazil	1031931	25798	1754	16510
Indonesia	294433	7360	500	4710
Cocoa				
Ghana	142000	2840	625	1420
Ivory Coast	390000	7800	1716	3900
Brazil	107289	2146	472	1073
Malaysia	83880	1678	369	839
Tobacco				
Zimbabwe	89460	10382	1253	18079
Brazil	186788	21669	2615	37734
India	80687	9361	1130	16301
Jute & bast fibres				
Bangladesh	358830	17940	6458	47720
Nepal	8961	448	161	1192
Viet Nam	2500	125	45	322

In Ghana cocoa exports removed the equivalent of 25% of the N, 20% of the P, but 50% of the K, supplied by fertilizer in the whole country. Exports of cocoa from the Ivory Coast removed the equivalent of 78% of the N, 52% of the P, but only 19% of the K, applied in the fertilizers used in the whole country. In both these countries exports of cocoa may result in serious depletion of soil fertility unless adequate fertilizer is directed to the areas which grow this crop; if this is done there may then be too little fertilizer available for other crops in the countries and these crops will then give low yields.

In Brazil and Malaysia the exports of cocoa removed only very small percentages of the amounts of N, P and K supplied by the fertilizers used in the whole of each country.

This assessment of losses by cocoa exports refers only to exports of «cocoa beans, raw or roasted»; in preparing a full nutrient balance for such crops account must be taken of the export of products prepared by processing the crop. For example *FAO [1985b]* records that in 1984 Brazil exported 107 289 tonnes of cocoa beans, but in the same year Brazil also exported 37 088 tonnes of cocoa powder and cake, 67 358 tonnes of cocoa paste, 35 843 tonnes of cocoa butter, and 33 819 tonnes of chocolate products. These materials must add to the amounts of N, P and K exported in the beans (but analyses of these products are not at present available so a numerical assessment cannot be made here).

4.2 Tobacco

Table 9 shows the losses of nutrients in tobacco leaves exported by three countries selected from the major exporting regions of South America, Africa, and Asia. The amounts of fertilizers used in these countries are given in Table 8.

Tobacco exported from Zimbabwe removed nutrients equivalent to 13% of the N, 7% of the P, but 74% of the K applied as fertilizer in the whole country. This removal of K could become an important cause of lessened productivity of other crops if most of the K-fertilizer available is diverted to land which grows tobacco to maintain reserves of soil-K.

The tobacco exported from both India and Brazil removed nutrients which were equivalent to very small percentages of the N, P and K used as fertilizers in the whole country. Exports of tobacco are unlikely to cause serious problems of nutrient deficiencies in these two countries.

4.3 Jute and bast fibres

These crops remove large amounts of N and K, but smaller amounts of P. Most of the crop is grown in, and exported from, countries in Asia. Table 9 gives the amounts of nutrients exported in 1984 from three Asian countries with large trades in these commodities; the amounts of fertilizers applied in the whole of each of the three countries are given in Table 8.

Exports of fibre from Bangladesh removed nutrients equivalent to 5% of the N, and 9% of the P, but 1½ times as much K, as was applied in the fertilizers used in the whole country. In Nepal the exports of these crops removed nutrients equivalent to only 2% of the N and 4% of the P, but 1.4 times as much K as was applied in the fertilizers used in the whole of Nepal. In Viet Nam the smaller exports removed amounts of N, P and K that were negligible in relation to the amounts supplied by the fertilizers used in the country.

4.4 Further activity

Three of the countries listed in Table 9 exported two of the crops that were studied. In India tea and tobacco together removed very small fractions of the amounts of nutrients applied as fertilizers in the whole country. The same was true for coffee and cocoa exported from Brazil, fertilizers supplied many times more N, P and K than exports of these two crops removed. The situation was different in the Ivory Coast where coffee and cocoa together removed much more N in exports than fertilizers supplied to the whole country; the exports also removed P equivalent to 63% of that applied in the country and K equivalent to 35% of that in the fertilizers used.

In all countries the total amount of fertilizer applied will be distributed between most or all of the crops that are grown and will not be reserved for the crops that are studied here as sources of export materials. Therefore the risk of nutrient deficiencies being caused by the export of agricultural products is more serious than the assessment in this Section suggests.

These examples emphasise again the need for countries involved in an export trade to have national nutrient balance sheets prepared. These are essential for avoiding disastrous falls in crop productivity due to nutrient deficiencies developing as a result of growing crops for export. The balances will indicate the kinds and amounts of nutrients which must be applied as fertilizers to maintain soil productivity.

4.5 The transfer of potassium by inter-Continental trade

Several references have been made above to the transfer of potassium in exports of agricultural products. The amounts transferred depend, of course, on the type of produce; some examples are given in Table 10.

The cereal grains contain small percentages of K, which are very much less than the percentages of N, (most of the K taken up by these crops resides in the straw or stover at harvest). Products such as coffee and cocoa beans, and the grain legumes, contain larger proportions of K relative to N than the cereal grains do. The largest losses of K occur when the parts of the plants exported are those which are rich in K; examples are tobacco leaves, and the fibres from jute stems, these contain percentages of K that may be twice as great as the percentages of N. Some fruits are rich in K, bananas and copra are examples.

Table 10. Amounts of plant nutrients that are removed by agricultural produce that is exported

	N	P	K
	kilogrammes of nutrient per tonne of product		
Product exported			
Maize grain	16	2.8	3.9
Rice grain	15	2.6	2.6
Wheat grain	14	2.7	4.0
Coffee beans	25	1.7	16
Cocoa beans	20	4.4	10
Soybeans	49	7.2	21
Groundnuts	49	5.2	27
Tea, dried leaves	52	3.8	25
Tobacco, dried leaves	116	14	202
Jute, fibre material	50	18	133
Bananas, fruit	1.7	0.5	5.0
Copra	44	12	40
Oilseed cakes and meals (average values)	59	7.0	13
Rubber, dried	6.3	0.9	3.6
Potatoes, tubers	3.2	0.5	4.5
Tapioca, dried products	6.0	1.9	17

Large amounts of potassium are taken up by root crops and are transferred to the tubers which are harvested and removed from the farm. Potatoes provide a good example of large removals of K. The amounts of K removed by cassava are even more striking; this K remains in the tapioca products that are prepared from cassava. Some tapioca is consumed as human food but in recent years a large trade in exports of cassava products from the tropics for use as livestock food in Europe has been built up. The place of Thailand in this trade has been discussed in Section 1.2. The quantities of potassium involved are so large that countries with a big export trade should be aware of the need to replace the K removed if crops which follow the cassava are not to suffer from K-deficiency. The countries which import cassava products for animal feed should also be aware of the large amounts of K which they contain which will be present in the animal wastes which will be applied to agricultural land.

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The Social and Environmental Implications of Large-scale Translocations of Plant Nutrients

A. van Diest, Department of Soil Science and Plant Nutrition, Agricultural University, Wageningen/Netherlands; member of the Scientific Board of the International Potash Institute*

Summary

In spite of large variations in natural fertility among soils, it must be realized that few soils are capable of supplying crops with the necessary nutrients over an extended period of time without extraneous supplementations. The necessary influx of nutrients can be brought about by natural mechanisms such as translocation with *e.g.* water or wind.

In many instances, however, man took it upon himself to concentrate the fertility of soils in large areas onto small areas. Through such actions relatively intensive types of agriculture could be established and maintained in a pre-fertilizer era. The remnants of several such types of soil management can still be observed in N.W. Europe.

The introduction of fertilizers created opportunities for revitalization of large tracts of earlier depleted soils. Recently, however, the necessity of farming intensification induced many former peasants in the Netherlands to introduce into their agro-ecosystems large quantities of nutrients, not in the form of fertilizers, but in the form of enriched feedstuffs. The influx of nutrients into these eco-systems is no longer determined by the demands of the soils but by the demands of animals raised in meat factories. The soils in these ecosystems are presently used mainly as dumping grounds for nutrients.

The consequences of a vast discrepancy between nutrients entering and nutrients leaving soils are discussed. The conclusion can be drawn that in the Netherlands large-scale measures must be taken to either export nutrients or to drastically curtail the present system of intensive livestock production.

The ability of soils to provide crops with nutrients over any extended period of time without extraneous supplementation is usually limited. This is most clearly noticeable in shifting-cultivation agriculture where after a few years of crop production soils need a recovery period in which ongoing weathering of primary minerals provides for a renewed, but usually modest availability of mineral nutrients. Yet, we all know of soils whose inherent fertility is high enough to sustain crop production over an extended period of time. A textbook example of relatively successful long-time farming without any sizeable inputs of nutrients from outside the agro-ecosystems, is formed by the prairie soils of North America, now known under the new name of Mollisols.

The year in which farming started on these soils is usually exactly known and, consequently, it can be stated that the first signs of impending soil exhaustion became evident in the dust bowl period of the 1930's after about ninety years of farming. Follow-

* Prof. Dr. *A. van Diest,* Department of Soil Science and Plant Nutrition, Agricultural University Wageningen, de Dreyen 3, 6703 BC Wageningen/Netherlands

ing the implementation of the soil-protective measures designed by the so successful *U.S. Soil Conservation Service,* the same type of farming continued on these soils for another ten years before signs of soil acidification and P deficiency started to manifest themselves. Since that time the use of fertilizers and liming materials has contributed to steady increases in productivity of these soils.

In the history of agriculture, one hundred years of farming is but a short period. There are regions in which farming has continued over many thousands of years, largely in times prior to the discovery of the beneficial effects of fertilizers. In many instances, early civilizations have developed on the banks of great rivers. Their spectacular irrigation systems are often viewed as the basis of the sedentary life style that became customary in these societies. The constant availability of precious water enabled these societies to develop in such a way that a part of the population was no longer needed for the daily gathering of food or for the tending of livestock. Thus, among other professions, arts and sciences could emerge. The once strictly agrarian societies diversified into multi-faceted societies whose treasures are sometimes admired until the present day.

As said before, the permanent availability of water is often looked upon as the cornerstone of these early civilizations. It is often overlooked that in such situations we are not dealing with pure water, but with silt-containing water. The silt which settles when in the irrigation system the water comes to a standstill, is the bearer of the nutrients needed to ascertain the permanence of agriculture.

Not all early civilizations can be linked to a mighty river. The Inca civilization in the Andes highlands flourished without such a river, but again cleverly designed irrigation systems ensured the availability of water and probably also of nutrients supplied with the silt suspended in the water.

Reversely, it cannot be alleged that all great rivers on earth once served as the artery of a past civilization. Mighty streams, like the Congo and Amazone Rivers, never seem to have served as the core of a civilization or even of a dense population. Without being able to claim that lack of nutrients in the silt of these rivers was the limiting factor, I consider it worthwhile to pay attention to the large differences in nutrient content of the water in three large rivers, as listed in Table 1. Since the quantities of nutrients present in the suspended silt were not taken into account, the reported values will certainly have underestimated the real quantities of these nutrients in the river water, but can serve as a reflection of the relative richnesses of the waters of these rivers.

Table 1 Quantities of nutrients, in mg l^{-1}, present in dissolved form in the water of three great rivers

Nutrient	Nile (1870)	Amazone (1903)	Mississippi (1906)
K	3.9	1.4	2.9
Ca	15.8	6.4	34.0
Mg	8.8	1.4	8.9
NO_3	0.2	0.0	2.7
PO_4	4.7	—	—
SO_4	0.7	2.8	25.5

Clarke F. W.: Data of Geochemistry, 1924. The NO_3 value of the Amazone river was taken from data collected by *R. E. Oltman* and published in U.S. Geol. Survey Circular 552 (1968)

An interesting question is why never any agglomeration of people developed along the Mississippi River. Perhaps the very richness of the soils in this region can have been the decisive factor in discouraging people to settle. According to some sources of information, the herds of buffalo on the prairies were so plentiful that perhaps no American Indian has ever felt a desire to settle and practice arable farming in an area so richly endowed with meat.

Silt in irrigation water can enrich soils only as far as these soils are being irrigated with the water. Far larger areas, however, are enriched when periodically a river bed falls dry and the dried-out silt is blown out of the river bed by the action of wind. In this way, large sections of our European continent have been covered by this silt, which has resulted in a welcome rejuvenation of the underlying soils. On the North American continent, more clearly so than on the European continent, it can be seen that rivers are often the origin of this silt. On the lee side of large streams such as the Mississippi and the Missouri Rivers, large quantities of loess material were deposited and these loess deposits taper off in easterly direction.

Nowadays, heavy dust storms are still common in Eastern China when during the summer the Yellow River falls dry and large quantities of loess are lifted up to be subsequently deposited on a vast stretch of land.

This Yellow River is responsible for the translocation of fertile silt from North Central China to Eastern China. The former area is consequently badly eroded and impoverished, but thanks to the fertility in the aeolian material deposited in Eastern China, a sizeable portion of mankind can now make a living there on soil material translocated from Central China.

Closer by, in Northwestern Europe wind velocities during interglacial periods were apparently so high that not only silt but also fine sand was lifted and transported by wind action. Consequently, in N.W. Germany, the Netherlands and Belgium we find deposits of so-called cover sand overlying fluvio-glacial material. The relatively fine texture of this cover sand ensures the presence, next to quartz, of some other minerals which impart upon these soils a certain degree of native fertility. Yet, the fertility is considerably lower than that found on the neighbouring loess-covered soils of Central Germany.

In the Netherlands, the cover sands are found mainly in those areas where in former times the slightly elevated position of the land offered some natural protection against the hazards of frequent flooding by river- or seawater. Hence, there where people found protection against the combined forces of water and wind they had to take the low fertility of the soil for granted, whereas in areas with fertile riverine and marine soils the early settlers had to live with the ever returning discomforts associated with floods.

On both the slightly elevated cover sands and the low-lying riverine soils we now find the remnants of farming systems in which soil fertility was translocated from one site to another. As a consequence, the soils of relatively large areas were depleted to bolster the fertility of the soils in relatively small areas where the farming communities were located.

This translocation of nutrients probably started when swine and possibly also cattle found their food in the forest and were rounded up for the night into paddocks in which a large portion of the faeces was deposited. These faeces were never returned to the forest but were utilised on small patches of arable land for the nutrition of food crops.

In the long run, the soil under forest became so depleted of nutrients that the natural process of forest rejuvenation came to an end. The trees gave way to shrubs, mainly heather *(Calluna vulgaris)* and in livestock farming the emphasis switched from swine to sheep. In this stage, soil depletion not only continued but even intensified. The sheep spent the nights in sheepbarns, and in order to ensure a relatively dry litter for the animals, sod of the heather-covered soils was mixed with the manure. A few times or once per year the barns were emptied and the mixture of sand, sod and manure was again translocated to the arable soils around the villages. This process gave rise to the formation of the so-called «plaggen soils».

Translocation of nutrients from the heather-covered soils to the arable soils eventually resulted in situations in which even the heather failed to maintain itself. Soils fell bare and the sand started to shift. This shifting sand threatened to cover the man-made fertile plaggen soils and thus became a menace to the livelihood of the farming communities.

Research in the Netherlands has made it clear that over the centuries arable soils have sometimes been abandoned several times because of wind-blown sand deposition on the fertile plaggen soils.

I am inclined to compare this past process of concentrating nutrients from a relatively large area onto a relatively small area with the present-day situation in which in the Netherlands large quantities of nutrients are imported in feedstuffs and small quantities are exported in agricultural and horticultural commodities. Both systems have their limits, in terms of quantity and time, and in the long run societies have to come to realise that drastic changes are needed.

In the case of the plaggen soils, a solution was sought in the form of reforestation of the shifting-sand areas. Fertiliser application was either absent or remained limited to a basic-slag dressing into the planting hole. As a result, the trees are often in very poor condition and prove particularly vulnerable to the imbalance between ample availability of nitrogen on the one hand and low availability of minerals on the other hand. This imbalance is created by the large influxes of ammonium present in wet and dry deposition as a result of widespread ammonia volatilization from liquid manure in the Netherlands.

The practice of concentrating nutrients from a large area onto a small area is not confined to N.W. Europe. One can find it all over the world. On the savanna of Northern Ghana, several generations of a family live together in compounds. Immediately around the compounds, fruits and vegetables are grown and the nutrients needed by these crops are obtained from manure of cattle grazing in a wider ring around the compound and the inner ring of vegetable crops. This wider ring has a width of often less than a hundred meters and its outer boundary is set by the distance between compounds. The depletion of these pasture soils leads to severe soil degradation, with respect to both chemical and physical properties.

Peasants practicing mixed farming on the plaggen soils of the Netherlands usually farmed only a few hectares of arable land. Around 30 years ago, economic circumstances forced them to make far-reaching decisions concerning their future. They were forced to either enlarge their farms, to intensify their farming, to abandon farming, or to become part-time farmers. Unlike in Germany, where many of the peasants took jobs in industry and chose for part-time farming, in the Netherlands the peasants opted for intensification. With the aid of bank loans, they started to build sheds for housing pigs, calves or poultry, and thus these small farming enterprises were converted into meat factories.

The cereals, fodder beets and mangolds these peasants used to grow on their few hectares of arable land had to be supplemented with feedstuffs bought elsewhere. The quantities of feedstuffs imported from overseas countries grew with the increasing livestock populations (Table 2).

Table 2 The use of feedstuffs in the Netherlands for various animal species (in 10^3-ton units)

Animal species	1965/66	1970/71	1976/77	1980/81	1982/83
Cattle	1595	2066	4212	4697	5280
Pigs	2540	3833	5047	6219	6256
Poultry	1764	2188	2348	2972	3103
Total	5899	8087	11607	13888	14638

Source: *[8]*

The manure produced rose to volumes far too large to be utilised effectively on the farms themselves (Table 3). Besides, the manure had to be disposed of partially on the plaggen soils that over the centuries had already become enriched with large quantities of phosphate from the heather-covered soils.

The traditionally grown crops gave way to maize which crop became known as one that can be grown without serious yield reductions on soil heavily oversupplied with nutrients.

Table 3 The production of the various kinds of animal manure in the Netherlands in 1982

Type of manure	Quantity in 10^3-ton units	Percentage
Cattle slurry	66,973	78
Calf slurry	1,708	2
Sow slurry	6,051	7
Pig slurry	8,575	10
Chicken slurry	2,244	3
Dry poultry manure	187	0
Broiler manure	279	0
Total	86,016	100

Source: *[7]*

However, the previous build-up of a large pool of labile phosphate in these plaggen soils had resulted in a situation in which a sizeable portion of the P-sorption capacity of these soils had already become occupied. Consequently, after a few decades of excessive liquid-manure applications on these soils the moment approaches at which any further application of phosphate will lead to considerable phosphate leaching.

Through legislative action it was recently established that starting from 1987 the following limits for annual application of phosphate in animal manure per ha will have to be regarded:

Arable land, except for maize:	125 kg P_2O_5
Permanent pasture:	250 kg P_2O_5
Maize:	350 kg P_2O_5

Although in farmers' circles these measures met with strong opposition, one must come to the conclusion that, looked upon from an environmental standpoint, they were not rigorous enough. Especially annual applications of 350 kg P_2O_5 to maize that is generally grown on light-textured soils with little P-sorption capacity left is bound to result in P leaching to water reservoirs needed for drinking water supply.

Yet, the question can be raised whether it makes sense to use phosphate as the sole measuring stick for liquid manure application. In fact, the real problem is that a serious imbalance has developed between plant nutrients entering and plant nutrients leaving the country, and this problem is not confined to phosphate.

Table 4 supplies information on the quantities of N, P and K entering the Netherlands in feedstuffs, fertilizers and feedstuff additives, and leaving the country in the more important agricultural export products.

Table 4 Quantities of N, P and K in the major agricultural commodities, entering the soils of the Netherlands, through import, and leaving these soils, through export, for the year 1983.

	Influx in 10^3-ton units			Efflux in 10^3-ton units		
Commodities	N	P	K	N	P	K
Fertilizers	467	37	106			
Feedstuffs	341	77	152			
Feedstuff additives		20				
Meat products, except poultry				32	7.5	2.8
Dairy products				31	5.0	4.6
Poultry meat products				8.0	5.0	0.5
Eggs and egg products				6.7	0.7	0.3
Potatoes				5.0	1.0	7.8
Vegetables				3.6	0.7	5.0
Flowers, bulbs and plants				1.6	0.3	1.9
Total	808	134	258	87.9	20.2	22.9

Sources: *[1], [2], [3], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17]* It can be seen from these data that unacceptably high quantities of all these nutrients are remaining in the country. Phosphate is used as a yardstick because this nutrient is least mobile and therefore most persistent in soil, and is responsible for eutrophication of surface waters. There are limits set to the permissible concentration of phosphate in drinking water, but to my knowledge no data are available to show that phosphate in drinking water at any level can constitute a hazard to the health of humans and animals.

Nitrogen is more mobile and therefore escapes more readily to surface waters and deep water reservoirs, but also to the atmosphere. Escape to the atmosphere after denitrification is permanent and harmless. Escape to the atmosphere as NH_3 after volatilization is temporary. Its redeposition is harmful in oligotrophic nature reserves, but not necessarily so in agricultural and forest ecosystems. Its appearance in surface waters causes eutrophication, and in drinking water as NO_3 it can cause methemoglobinemia in babies. Any possible harm to the health of adults is, however, still debatable *[4]*.

Potassium as a pollutant certainly does not attract the attention given to phosphate and nitrogen. It is not a severe cause of eutrophication and does not constitute a hazard to the health of human beings. For livestock, the matter is different. In the recent past hypo-magnesemia has been a serious problem in the Netherlands. With the following data, it will be shown that the hazard could return if liquid manure would be applied annually to pastures in volumes containing the maximum permissible quantity of 250 kg P_2O_5 per ha, mentioned before:

- Nutrient contents in cattle slurry: 0.44% N, 0.18% P_2O_5, 0.55% K_2O.
- Maximum permissible quantities of cattle slurry on pastures: 250 kg P_2O_5 × 100%/0.18% P_2O_5 in slurry = 140 ton slurry per ha.

These 140 ton slurry contain 0.55/100 × 140000 kg = 770 kg K_2O which can be looked upon as an excessively large K application.

The 140 tons of cattle slurry contain 0.44/100 × 140000 kg = 616 kg N, which can also be seen as an excessive dose of nitrogen when applied annually over a number of years.

Nevertheless, the governmental decision to set limits to the permissible quantities of P applied in liquid manure is a first step into the direction of matching phosphate supply and withdrawal. The approximate quantities annually withdrawn are 70 kg P_2O_5 for arable crops and 85 kg P_2O_5 for grass. When it is assumed that arable farmers continue to give preference to the use of fertilizers instead of liquid manure, it can be calculated that at the present rate of liquid manure production approximately 50% of the P_2O_5 in animal manure and slightly more than 50% of the manure itself could no longer be applied inside the Netherlands.

The following consequences can be deduced from such a statement:

- Either the practice of intensive livestock production in the Netherlands must be reduced drastically,
- or the liquid manure surpluses must be exported from the country,
- or a combination of the two above measures must be sought.

The profitability of intensive livestock production and the importance of the commodities involved for the national economy are so high that nowadays in agricultural circles the idea of productivity reduction is viewed with great reluctance. On the other hand, one has not yet come to realise that maintenance of the present level of production will inevitably necessitate the export of nutrients in the form of the original liquid manure or in a concentrated form.

In the following I shall briefly discuss a number of possible ways to export from the Netherlands nutrients contained in liquid manure. A distinction can be made between

a) export of a residue after drying,
b) export of the liquid manure as such.

Ad a): Export of dried animal manure already takes place on a modest scale to a variety of countries. When it concerns products derived from liquid manure, separation of the liquid and solid phase can have taken place in a drying process. The energy needed for such a process can be obtained through production of biogas from the liquid manure itself. A serious drawback of this procedure is that during the drying a large percentage of the N volatilizes as NH_3 and thus aggravates an already existing problem of high NH_4 contents in dry and wet depositions.

Other means of separating liquid and solid components of the manure, *e.g.* through centrifugation, lead to large volumes of fluid containing so much N that disposal of it into surface water is prohibited.

Ad b): Export of liquid manure as such usually entails high expenditures for transportation. The nearest region that is sometimes mentioned as a possible recipient of liquid manure is Northern France where scarcity of livestock farming could create an interest in any form of organic material. Personally I believe that greater possibilities are to be found in developing countries. In such instances, however, the material would have to be made available to these countries at very low cost or at no cost at all, in other words, in the framework of our program of aid given to developing countries.

When observing the various forms of concern expressed in developed countries for the needs of developing countries I am constantly surprised about the discrepancy between concern for food shortages and concern for energy shortages. Forests disappear with a frightening speed and in a spectacular way because people think they can use the soil for the growth of food crops. However, in a much less spectacular way forests disappear because people need the wood as fuel in their households. In Africa the fuel needed to cook the daily meal is often more expensive than the ingredients of the meal. Women often walk several days to gather wood that lasts as fuel supply for only as many days as it took to collect it.

So far, little seems to have been accomplished in teaching Africans and Latin Americans the art of producing biogas like it is practiced in China. Liquid manure would be a material in Africa opening the way to producing biogas and to utilizing the residue as plant food. The basic material is available in large volumes in the Netherlands where many tankers unload their oil and return empty to Africa. It is indeed true that pipelines, storage facilities and distribution systems would have to be developed in the recipient countries and that this would require very large investments. At the same time, however, I maintain that such kind of aid would hold more possibilities in it for alleviating food and energy shortages in African countries than many of the present aid programs.

An even more controversial issue is the possibility of depositing liquid manure into the North Sea. In the recent past, this sea has been exposed to many types of pollution. Now that actions undertaken by environmentalists have resulted in various kinds of legislation barring the disposal of waste materials into surface waters, it is understandable that not much support can be found for a proposal to dump liquid manure into the North Sea, not even when it is announced as «fertilizing fishing grounds». Nevertheless, it is interesting to notice that in tropical countries increasing use is made of the possibility to raise pigs and poultry in constructions having slatted floors enabling the excreta to fall into ponds underneath, used for growing fish. Certain kinds of fish appear to thrive on organic waste materials, as long as proper care is taken that heavy metal contents do not exceed certain limits.

According to calculations by the *Dutch Institute of Agricultural Economics,* 11 percent of the cattle slurry and 60% of the pig slurry in the Netherlands can be seen as surplus materials. If these materials were dumped into the North Sea this practice would annually introduce into this sea a quantity of around 600 kg cadmium. This cadmium originates mainly from phosphates added to feedstuffs. For comparison, the rivers Rhine and Meuse together carry an annual load of 30 tons of Cd to the North Sea. This quantity is but a fraction of what was entering the North Sea 10 years ago. This cadmium is moving along the Dutch coast into Northerly direction towards the Wadden Sea, a lagoon-like stretch of water between the offshore islands and the Northern coast of the Netherlands. This Wadden Sea is one of the most important marine bird sanctuaries in Europe and 10 years ago was seriously threatened by unacceptably high levels of, among others, Hg, Pb and Cd in the food chains. It is therefore understandable that great care should be taken to avoid any further pollution of this sea.

The 600 kg of Cd in surplus slurry would add only 2 percent to the quantity of 30 tons annually entering the North Sea by way of the two rivers mentioned. Besides, if this slurry would be disposed of into the North Sea, it should be taken far enough offshore to minimise the risk of polluting coastal waters.

Finally, it is to be expected that in the near future both the Cd content of phosphate and the total quantity of phosphate used as addition to feedstuffs will decrease. In the light of these considerations, disposal of liquid manure into the North Sea should not longer be viewed as an outrageous conception. The greatest advantage of this means of disposal would be its cheapness.

Conclusions

When agricultural production depends on the native fertility of soils, the productivity level is either low or can be kept high over only a limited time period. Where productivity levels can be kept high over an extended period, this is usually accomplished through enrichment of the soils with nutrients introduced from outside the agro-ecosystem. Such enrichments can have taken place through natural processes, like is the case with aeolian and fluvial deposits.

Especially this latter process of fluvial deposition can be promoted by man. When this was done cleverly with the use of irrigation systems, agriculture could flourish and could open the way for the rise of early civilizations.

When populations grew in regions lacking any means of soil enrichment, man sometimes took it upon himself to concentrate the fertility of large soil bodies onto small areas in which relatively productive farming systems could be maintained over a long period. However, the implications of such types of agriculture for the environmental aspects of these ecosystems were often very negative.

During the last century, however, the use of fertilizers opened the possibility to restore the fertility of earlier depleted soils. The advantages of fertilizers in this respects are twofold:

1. The application of fertilizers can be regulated in such a way that only those nutrients that are needed are being supplied, and
2. Fertilizers allow the fertility of soils in a certain region or continent to be improved without any negative effects on the fertility of soils in other regions or continents.

In recent times, however, we have experienced that in the Netherlands the importation of nutrients has started to shift from the fertilizer form to the feedstuffs form. Both from an environmental and a social standpoint there are disadvantages associated with such a shift.

First, the quantity of feedstuffs bought by a livestock producer is not determined by the nutrient requirement of his soil but by the caloric requirement of his animals. When the relationship between number of animals raised and hectares farmed becomes lost, the soil will lose its function as supplier of nutrients to crops and will attain a function as dumping ground for nutrients nobody is interested in any more.

Since there are limits to the capacity of soils to retain nutrients, the chance exists that these nutrients will percolate through soils and will start to pollute surface water and deep groundwater which has seriously negative environmental effects and which in the long run will also affect the social wellbeing of a country or a continent.

Second, since the nutrients contained in imported feedstuffs are partly coming from developing countries, the hazard exists that soils in these countries become depleted of nutrients which are very much needed for the maintenance of soil fertility. In addition, when in these countries fertilizers are being used, the nutrients present in these fertilizers are often not applied to the soils whose nutrients were exported as constituents of feedstuffs.

Viewed from both a social and environmental standpoint, the solution to the problem is evident: A country like the Netherlands should either drastically reduce the import of nutrients contained in feedstuffs or should again export a large portion of these nutrients. As said before, the first alternative would have strong repercussions for the lucrative business of intensive livestock production. The second alternative would allow the continuation of livestock production on the present scale, but would require heavy investments in transportation and distribution systems needed to export liquid manure to developing countries.

It will be interesting to watch which future decisions are going to be taken by policymakers, who presently seem to be unaware of the graveness of the dilemma.

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