POTASH FACTS

INTERNATIONAL POTASH INSTITUTE

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Design: Mario Pellegrini, Bern
Printing: Lang Druck AG, Liebefeld-Bern

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1. Introduction

A farmer can only hope to use fertilizers sensibly and to the best advantage if he understands how they work. When fertilizers are first introduced they are frequently misused. Nitrogen fertilizer usually produces spectacular effects, people think they are on to an easy way of increasing yields and profits and it is only after some time that they find that things are not so simple and yields go down again. They may lose faith in the new miracle. Only too often it is not realised that there may be more than one obstacle to higher yield; another nutrient may be, or may become, limiting. The latter must also be given to back up or *balance* the first. This book, by stressing the need for balance, in which potash is so important, aims to put things right and no apology is offered for its concentrating on this oft-called «Cinderella» among the major plant nutrients.

The book starts with an explanation, in simple terms, of what plant nutrients do in the plant and how the plant obtains its food from the soil. Fertilizers are used both to make good any deficiencies there may be in the soil which make it impossible for crops to give good yields and to compensate for the nutrients removed when crops are harvested, in other words to increase and maintain fertility. The needs of individual crops should be considered in the light of the problem of keeping up fertility through a whole sequence of crops, apportioning the total requirement between crops in such a way as to give priority to those which are the most responsive.

Most of the book is taken up by discussion of the fertilizer treatment, especially the potash treatment, of the various crops, attempting to arrive at general practical recommendations. These cannot be exact since this book may be used in places differing greatly in soil and climatic conditions. Some crops are discussed in detail, some in more cursory fashion and it is hoped that, while some of the information given may not be strictly applicable to an individual case, the reader will obtain therefrom a sufficient basis upon which to make a decision as to how to approach his own particular problem. Recommendations are not to be taken as precise but to serve as a base from which, with the aid of experience, trial and experiment under local conditions, the reader will be able to use fertilizers with confidence.

The examples of fertilizer effects are intended to illustrate general requirements rather than to make exact fertilizer recommendations. Certain it is that they cannot deal fully with every crop or answer every question but we hope, by touching on examples from the main crop groups, to give some guide as to what should be done in a particular case. It has been as difficult to decide what to leave out as it has been to decide what to put in.

The treatment has been kept simple so that the book can be of assistance to those, farmers and others, whose acquaintance with fertilizers is very limited as well as to research and advisory workers and farmers who have a good knowledge of fertilizer use.

It may not be out of place to end this introduction with a note of caution. Fertilizers properly used will increase productivity, indeed it is only by bringing fertilizer onto the farm that soil fertility can be improved. However, while fertilizer is indeed a miracle of modern farming, it alone will not achieve the desired improvements unless the standard of farming is improved in other respects. For fertilizers to be fully effective it is necessary to apply the full package of improved practices – improved crop varieties of higher potential yield, improved water conservation, pest and disease control, generally high standards of cultivation.

Fertilizer is an essential part of the whole package of improved practices which aims at increased agricultural productivity.

If fertilizer is to be fully effective we must have balance. Each nutrient in the fertilizer "package" has its part to play but this part can only be played to the full if needs for other nutrients are also satisfied.

While this book concentrates on potassium it does so from the point of view of its place in the partnership with the other nutrients.

2. Potassium and plant growth

2.1 Essential elements

The elements known to be essential for plant growth are divided into two groups. The so-called major nutrients needed in large amount and the micro- or "trace" elements, required in only very small amounts:

Major	Micro
Nitrogen	Iron
Phosphorus	Copper
Potassium	Manganese
Sulphur	Zinc
Calcium	Molybdenum
Magnesium	Cobalt
	Boron

Sodium and silicon are not essential for all plants but where they are needed - sodium for maritime plants like beet and silicon for rice - they are needed in relatively large amounts. Chlorine is a major element for some coastal plants e.g. coconut.

The object of manuring or using fertilizers is to ensure that the crop has access to sufficient supplies of these essential elements. If one of the essential elements is missing from the soil, the plant cannot grow; if there is only a little of the element the plant may grow well but only until supplies are exhausted when yield will be poor. If the deficiency is made good the yield will increase until supplies of some other essential element are exhausted. If two nutrient elements are in short supply, adding only one of them will not increase yield, since this will be limited by lack of the other nutrient (case 2 in Fig. 1 - N added, P limiting). If the second element is added yield increases until supplies of a third element run out (case 3 Fig. 1 - N and P added, K limiting). Finally, (case 4 - N, P and K all added) when supplies of all three elements are adequate, yield increases still further. In this simple case, where it is assumed that nothing other than N, P and K is limiting yield, the yield in case 4 is the ultimate yield of which the plant is capable.

In fact, the diagram is something of an over-simplification; it frequently happens that adding the deficient element not only removes the barrier to further N response but also changes the manner in which the crop responds (see 2.8). In either case, the combined effect of two or more nutrients is greater than the sum of the separate effects. This is called interaction. This has wide significance; it applies not only between plant nutrients but also between other factors - water supply, disease control etc. and most importantly crop variety.

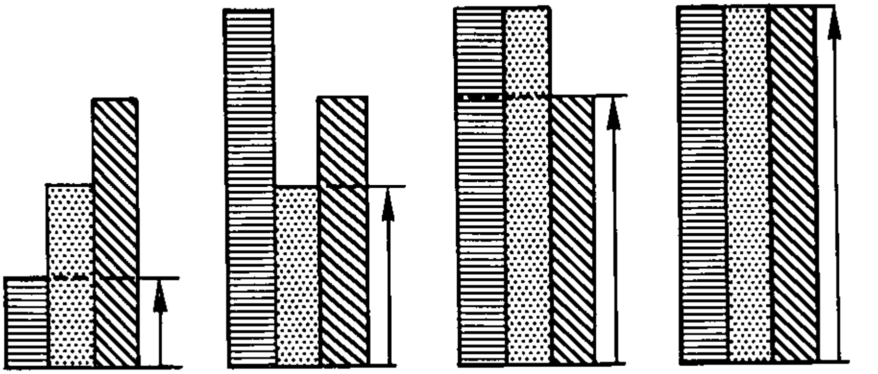

Figure 1. Illustration of the law of the minimum

Thus if rainfall should prove to be too little, fertilizer applied in expectation of a good growing season will not be fully utilised, while, in the contrary sense, improvement of the water supply through irrigation will result in greatly increased crop growth and yield and will also greatly improve the response to fertilizer. In the context of fertilizer use, the importance of removing or overcoming as far as is practically possible *all* limiting factors cannot be overemphasised. Fertilizer alone cannot solve every problem!

There is, of course, an ultimate limit to yield which is expressed in a second basic rule: Mitscherlich's "Law of Diminishing Returns". Assuming that supplies of all other nutrients are abundant, the yield increase produced by adding unit quantity of the nutrient which is in short supply falls off as more is added until, eventually, there is no further increase. The yield then obtained expresses the biological potential of the crop. The object of using fertilizers is to get as near as possible to the potential maximum yield, always with the proviso that the value of the crop increase shows a profit over the cost of the measures taken.

2.2 Fertilizers

Most of the effect of "natural" manures can be explained by their content of the essential mineral elements. Further, whatever the source of these elements, whether they come from the soil, from manures or from simple salts, the effect on the plant is the same. The necessary elements can be obtained from sources other than the soil and "natural" manures and used to add fertility to the soil. This is the job of the fertilizer industry: nitrogen from the air; potash and phosphate from natural deposits. The mined potash is just as natural as soil potash.

2.3 Potassium

It is easy to understand why carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur and some of the minor elements are essential for plant growth because they actually form part of the substances from which the plant is made up. Without them, these compounds would not exist. Potassium, on the other hand, though plentiful in all normal plants, does not actually enter into the composition of any organic compound in the plant, or in the animal for that matter. Yet it is all too easy to demonstrate that without a supply of potassium the plant will die. The total quantity in the plant is large; it occurs in all parts and easily moves from one part to another.

It can be demonstrated that potassium is concerned in the activation of a number of enzymes which bring about metabolic processes such as photosynthesis and protein formation. However, the amounts of K needed for this purpose are small and the effects of potassium deficiency, evident in poor growth and low yields, will be noticeable long before conditions reach such an extreme. Processes which involve large quantities of the element are from the practical point of view much more important. In these processes the effects of K are physical rather than biochemical. The potassium concentration is high wherever in the plant there is active metabolism.

2.4 Photosynthesis

Potassium is particularly important for the proper functioning of the stomata, tiny pores, through which carbon dioxide enters and oxygen leaves the plant. Detailed investigation has shown that potassium has a great influence on the opening and closing of the stomata; the K concentration in the so-called guard cells is many times higher when the stomata are open than when they are closed. Inefficient operation of the stomata, caused by a shortage of potassium, means that supplies of the raw materials essential for the formation of sugars are restricted and photosynthesis declines.

The rate of photosynthesis depends on the products of the process being removed from the scene of activity because if they accumulate, synthesis slows down. The soluble products of photosynthesis are moved from the leaves in the phloem and this transport is speeded up in the presence of adequate potassium, probably both by an effect on the loading of assimilates into the phloem sap and by an increase in the volume and, hence, the rate of movement of phloem sap. The other consequence of this speeding up is better filling of the storage organs.

2.5 Potassium and water relationships

The other important purpose of the stomata is to control water loss from the plant. The stomata close when the plant is subjected to drought thus conserving water against loss through transpiration. When K is deficient, the stomata cannot function properly and water loss from the plant may reach damaging levels. This has been demonstrated, for instance, in field experiments with barley in which plants were exposed to hot wind (Fig. 2). This caused an immediate increase in the rate of transpiration, more severe in low-potassium plants which took a long time to react by closing the stomata, while the well-supplied plants reacted quicker and recovered from the stress rapidly.

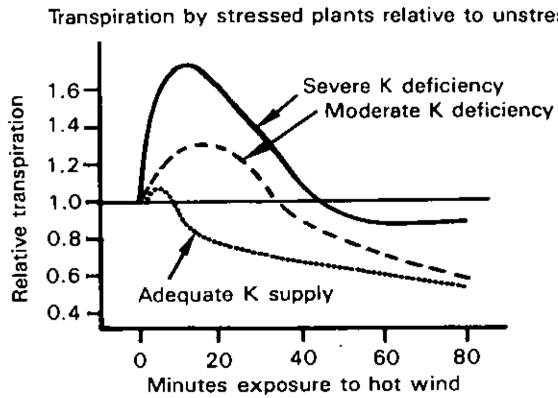

Figure 2. Control of the effects of drought by adequate K supply *(Skogley [1976])*

In addition to the effect of the opening and closing of stomata on *conserving* water within the plant, the plant's potassium status also affects the ease with which it can extract water from the soil. The explanation of this fact is again physical rather than chemical. The large amounts of potassium accumulated in the plant raise the turgor of the cells, improving cell expansion and growth and setting up a pressure gradient between the root and its surroundings which causes water to be taken up.

The control of water relationships is among the most important of the effects of K on plant growth. There are few cases, even in moist temperate areas of the world where crops do not, at some stage in their growth, suffer from at least temporary water shortage, and experience shows that K fertilizer is particularly effective in dry years. In the hotter areas of the world drought is frequently a very serious problem. Some work with the soybean crop in the USA (Fig. 3) shows well the effect of moisture deficit following planting on the response to potassium; in wet years it is not very large, in dry years it is spectacular.

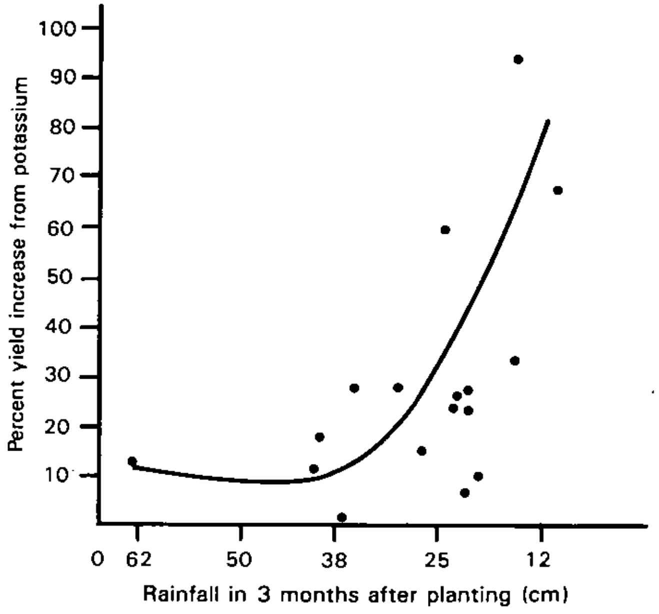

Figure 3. The less the rainfall after planting, the larger the response to K fertilizer *(Barber [1971])*

Too wet conditions are also unfavourable and it is interesting to see from Table 1 that on K responsive soils, K has a stabilising effect on yield of maize in both too dry and too wet seasons.

Table 1. Response by maize to K fertilizer in dry and wet years *(Barber [1963])*

June-August rainfall	kg/ha grain		
	No K	+K	Increase
Low (18 cm)	5708	8154	2246
Medium (45 cm)	9283	9784	501
High (85 cm)	5770	8780	3010

2.6 Salt tolerance

Particular problems arise on saline soils. Some varieties of a crop are more tolerant of salinity than others and this tolerance appears to be related to the ease with which the plant can take up K while not accumulating too much sodium. Salt tolerant varieties show a lower Na/K ratio throughout a wide range of saline conditions. This suggests that increasing the K supply on a saline soil would decrease the uptake of sodium. It should be noted that on saline soils, potassium sulphate which has a low salt index, should be used rather than muriate. The effect of increasing the potassium supply (applied as sulphate) under increasing salinity was investigated in an experiment in Pakistan; adding K greatly improved the Na/K ratio in young maize plants even at very high levels of salinity *(Niab [1982])*.

When broad beans were grown in complete nutrient solution, the addition of salt (NaCl) reduced growth, but the position was largely restored by adding extra potassium (Table 2)

Table 2. Effect of salt (NaCl) on growth and water content of 3 week old broad beans *(V. faba)* grown in solution culture at two levels of potassium *(Helal [1982])*

Treatment	Dry weight (g/plant)	% relative water content
Complete nutrient solution	4.4	96
Complete + 18 meq. NaCl	3.1	97
Complete + 18 meq. NaCl + 6 meq. KCl	3.9	97

Sulphate of potash which has a lower salt index than muriate of potash (KCl) should always be used on saline soils.

2.7 Potassium and nitrogen

Potassium is intimately connected with processes in the plant by which protein is formed from nitrogen.

Potassium is involved in the movement of nitrogen in the plant. When nitrate is taken up from the soil, the negative charge on this ion is neutralized by the positive charge on the potassium ion and the nitrogen is then taken up in the transpiration stream to the leaves where it is manufactured into protein. At the top the potassium ion combines with organic acids and, in this form, flows down to the root again to take part in the next cycle. Thus potassium acts as a kind of nitrogen "pump". In this way both nitrogen utilization by the plant and nitrogen uptake from the soil are improved.

Because potassium is concerned in nitrogen metabolism in the plant, a consequence of low K supply to plants receiving large amounts of N fertilizer is that intermediate products of protein synthesis accumulate. Increasing the K supply improves the conversion of these low molecular weight N compounds into protein.

This point is illustrated in Figure 4 which shows how more nitrogen was taken up and a higher proportion of this was converted to protein in young tobacco plants.

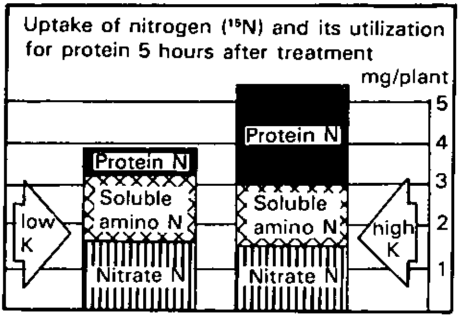

Figure 4. Uptake and conversion to protein of labelled N_2 by young tobacco plants *(Koch et al. [1974])*

2.8 Nitrogen × potassium interaction

As might be expected from the ways in which potassium supply affects nitrogen metabolism, there is a close connexion between nitrogen and potassium fertilizers in their effects on crops. In fact many of the recorded beneficial effects of K fertilizer on crops in the field are the results of the way in which the two interact. In mathematical terms, "interaction" means (in the case of fertilizers) that the combined effect of two nutrients differs from the sum of their separate effects.

Figure 5 illustrates in schematic form how the nitrogen × potassium interaction is expressed in improved crop performance. On the left, simple interaction, as N fertilizer is increased, yield increases until a plateau is reached above which further increase is prevented by lack of potassium; when K fer-

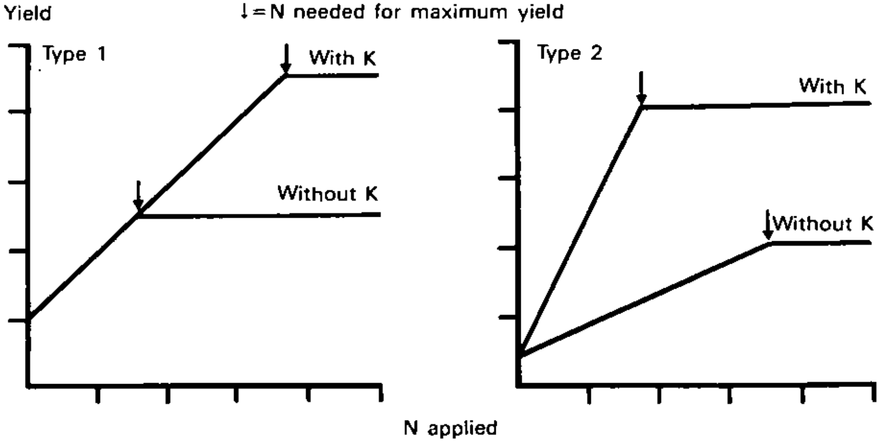

Figure 5. Two types of nitrogen × potassium interaction *(Cooke et al. [1978])*

tilizer is added the barrier is removed and higher rates of N are effective in increasing yield to a higher plateau. On the right, the effect of adding K is twofold; as well as removing the yield barrier, the improved K supply actually results in a steeper gradient of the N response so that not only is the plateau higher but it is reached at a lower level of N. There is a double bonus: higher yield plus economy in nitrogen fertilizer. The topic of interaction will arise again when we come to consider the practical manuring of crops. Many examples of this interaction are quoted under individual crops in Part II.

2.9 Potassium and nitrogen fixation

Leguminous plants have a particular need for potassium. N fixation by the root nodules is enhanced by applying K which increases the number of nodules per plant, the average size of nodules and their N-fixing activity with consequent very large effect on yield. These effects in the case of soya are illustrated in Table 3. Such effects are most probably due to an improvement in energy supply to the nodules by enhanced transport of carbohydrate to the root. This is a particular aspect of the nitrogen × potassium interaction and most important for nitrogen economy.

Table 3. Effects of nutrients on growth, nodulation and nitrogenase activity (C_2H_2 reduction) in soyabeans at anthesis *(Gomes et al. [1986])*

Treatment	Plant top weight (g/plant)	Nodules/ plant	Nodule weight/ plant(g)	Nitrogenase (μmol C_2H_2/g nodule/hour)
– P	8.05	32.4	2.3	52.7
+ P	13.50	74.1	4.5	144.0
– K	9.05	45.7	3.0	86.9
+ K	12.50	60.8	3.9	109.9

When legumes are grown in association with non-leguminous plants (e.g. grass) it is particularly important to maintain soil potassium at a sufficiently high level. Generally the root systems of legumes are not very efficient in extracting K from the soil while most grasses are very efficient. Thus there is a strong competition for K from the associated grasses in mixed grass clover swards and when N fertilizer is used there is a tendency for the clovers to die out. Under these circumstances, potash fertilizer is effective in preserving the proportion of clover, and, by careful management, the farmer can obtain the best of both worlds, using nitrogen to stimulate early growth, yet keeping enough clover to make a sensible contribution of nitrogen in the later stages of growth.

2.10 Potassium and disease resistance

A generous supply of nitrogen to the plant tends to result in "soft" growth more susceptible to attack by disease. Potassium counteracts this tendency with the practical consequence of better disease resistance. In many cases, undue damage to a crop by disease is the result of lack of nutrients or of using fertilizers which are not correctly balanced. Nitrogen, by stimulating vegetative growth, tends to produce lush growth which is prone to be attacked by disease. This effect is more pronounced when potassium is in short supply.

It would be expected that when N application to a crop is increased, yield would increase until it reaches a maximum and then would remain constant (the plant being unable to make use of more N), but experiments frequently show that above the maximum yield goes down. This is often attributable to the effect of disease and can be overcome to some extent at least by crop spraying. Two examples of this effect are given in Figures 6 and 7.

The influence of potassium fertilizer on disease resistance has been extensively reviewed *(Perrenoud [1990])*. While it is difficult to unravel detailed cause and effect, it does seem that many cases of disease susceptibility are due to imbalanced fertilizer use. Plants receiving correctly balanced fertilizer are more resistant to penetration by the pest and, on account of their better vigour are more able to recover from the effects of infection.

The following quotation from a paper by *Fuchs and Grossmann [1972]* sums up current thinking on the topic of potassium and disease and pest resistance: "Beside N, K has the strongest influence on resistance and this almost always in the opposite direction (to that of N) so that ability to resist, particularly fungal and bacterial diseases, depends upon the N:K ratio. Generally speaking, K has a predominating influence on resistance."

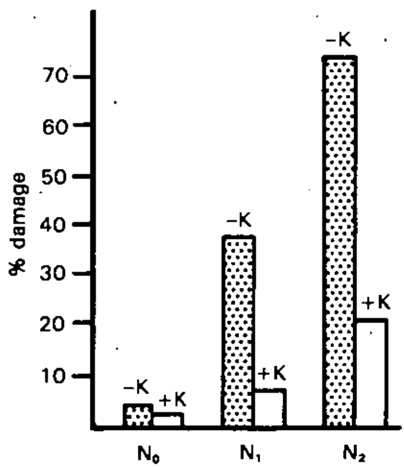

Figure 6. K reduces the effect of N in increasing stem rot of rice *(Yoshi et al. [1949])*

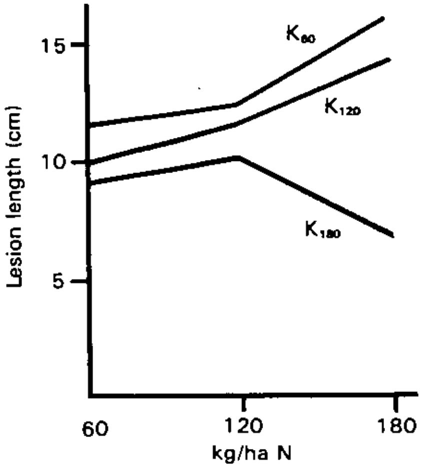

Figure 7. K reduces damage by bacterial leaf blight in rice *(Davadath et al. [1970])*

2.11 Potassium and crop quality

The effects of potassium on the quality of crop produce are somewhat analogous to those on disease resistance; again it is largely a question of balance in the fertilizer.

A good example of the effect of potassium on quality is to be found in the experiments on cassava in India referred to in Part II. As well as a strong interaction in increasing tuber yield, there was additionally an effect of K in increasing starch content; whereas response to N in yield of tubers at the highest rate of K was 43%, the response in starch was 50%.

Potassium has a well deserved reputation for improving quality: longer storage life, better tolerance of handling and transport, especially with leafy or fleshy crops which reach the market in better condition. In most fruits, colour, juice sugar content and acidity are improved.

A generalized summary of recorded effects of potassium on crop quality appears in Table 4. There are further references to this topic under the individual crops in Part II.

Table 4. Effects of potassium on crop quality - a summary *(von Peter [1980])*

	kg/ha K_2O aplied			
	W. Germany		France	
Wheat	0.4*	4.0	0	80
Crude protein % in grain	16.7	17.6		
1000 grain mass/spec. mass	40.3	43.5	70.4	72.8

Rice	Indonesia 0	Indonesia 60	Korea 0	Korea 100
% filled grain	54.3	75.9	83.5	91.8
1000 grain weight	20.1	26.2	24.3	27.3

Maize	Romania 0	Romania 80	USA 0	USA 100
Ear mass (g)	294	297	121	198
1000 grain weight	327	334	203	269

Cassava	Nigeria 0	Nigeria 67
Starch content (%)	25.7	32.4

Sugarcane	Reunion 0	Reunion 200	India 0	India 110
Sugar (%)	14.7	16.2	19.7	20.0
Purity			96.8	97.1

Cotton	USA 0	USA 68
Ripe fibre (%)	67	79
Lint (%)	39.6	39.1

Tomato	India 0	India 100
Acidity (%)	0.384	0.448
Total sugar	4.4	5.0
Carotene	43.8	56.9

Orange	Israel 0**	Israel 25	USA NP	USA NPK
Fruit mass (g)	150.5	205.0	119	190
% juice/mass	50.4	52.8	52.7	57.5
Acidity (%)	1.56	1.72	0.40	0.75

Pineapple	Cameroun 0***	Cameroun 4	Ivory Coast 16***	Ivory Coast 24
Fruit mass (kg)	1.10	1.27	1.51	1.55
Acidity (meq/100 ml)	6.0	8.75	10.3	11.0

Banana	India 0***	India 300	Madagascar 0***	Madagascar 360
Total soluble solids (%)	16.6	18.5		
Total sugars	11.75	20.01		
Fruit length (cm)			16.5	18.1
Fruit mass (g)			126	145

* meq./l ** g/tree *** g/plant

2.12 Potassium deficiency

When potassium deficiency is serious plants exhibit definite symptoms which enable one to detect the condition.

Generally, potassium deficiency results in yellowing and then death of the marginal leaf tissue, though in some plants (e.g. clover) necrotic spots appear all over the leaf surface but concentrated towards the edge. K deficiency symptoms appear first on the older leaves. This is because when the plant is unable to take up enough potassium through the roots, such supplies as are available within the plant are moved to the sites of active metabolism in the young leaves in an effort to make good the deficiency. This means that the K level in the older leaves falls to a very low level. Obviously, the appearance of visual symptoms signals a very severe deficiency and that growth is seriously disturbed. It would be most unwise to wait for the appearance of symptoms before concluding that a crop is suffering from K deficiency. Growth is restricted with resultant loss of yield long before the symptoms become obvious. If the symptoms are seen, serious damage has been done and it is too late to correct matters by a normal application of K fertilizer. Emergency action by spraying with dilute potassium sulphate or nitrate may be taken as a first aid measure and this will reduce the damage.

The earlier and less obvious symptoms of potassium deficiency, sometimes referred to as "hidden hunger" are a general decrease in vigour and notably a decrease in turgor. Under dry condition plants will show signs of stress, becoming flaccid. Such plants show greater susceptibility to drought, saline conditions, frost damage and disease. A further general effect is weakening of the structural tissues, with consequent susceptibility to lodging by wind or rain.

3. The soil

The plant obtains potassium from the soil. This potassium may originate from the material of the soil itself, from plant remains, from manures or from fertilizers. So far as the plant is concerned, it makes no difference what is the original source of the potassium. To get into the plant it must first be dissolved in the soil solution: in the solution it exists as the potassium ion and it is as the ion that it enters the plant.

How will a particular soil measure up to the plant's needs? Can it supply enough K and can it supply it quickly enough? How do the soil's properties affect its ability to supply and how can the soil be managed to ensure that the plant's needs are met?

A soil's properties depend upon the material from which it has been formed and the conditions, of climate and vegetation, under which it has developed. There are many different rocks and sediments (the raw materials of soil); climate varies between extremes of hot and cold, wet and dry and the natural vegetation which has covered the soil through its development is equally variable. It is only to be expected therefore that soil will be just as variable in its ability to support crop growth.

3.1 Forms of potassium in the soil

Chemical analysis of the soil shows that it contains potassium in different forms. Some can be extracted with very mild reagents like water or dilute salt solutions; other parts can be extracted only with strong reagents like boiling nitric acid. This suggests that these different forms differ in the ease with which the plant can extract them. The total potassium content of a soil is no guide to its value to crops.

Soil solution K

K in the soil solution is immediately available but the quantity is only very small – a minute proportion of the total K in the soil. The growing plant would very quickly exhaust the K in solution but as K is withdrawn its concentration is reduced only temporarily. The status quo is restored by release of K from less easily accessible sources.

Exchangeable K

The main source of this replenishment is the so-called exchangeable K. This takes the form of K ions attached to the solid soil material. As the solution K concentration falls, this adsorbed K is released into the solution. Conversely, if, for example by the application of fertilizer, the concentration of K in the soil solution is raised, some of that K will leave the solution and become attached to the solid material. There is *equilibrium* between the two types of K. This can be represented diagrammatically as follows:

K in soil solution	◄——►	K adsorbed
(immediately available)		(exchangeable)

If the value on the left falls (by plant removal) K will move from right to left to restore the equilibrium: if it rises K will move from left to right. Solution K and exchangeable K together are commonly referred to as "available K" as measured in conventional soil analysis.

Reserve potassium

This is not the end of the story, for there are other forms of K which are more tightly held than the exchangeable K. These other forms may be the so-called "fixed K" or they may be "native" K, i.e. chemically combined in the minerals of the rocks from which the soil is formed. There is equilibrium also between these forms and the exchangeable, but this equilibrium differs in that the process of reaching the equilibrium state is much slower. The whole of the K supply mechanism then becomes:

solution K ◄——► {adsorbed or exchangeable} K ◄——► {reserve or tightly held} K
(quick) (slow)

The immediate source of K to the plant is that dissolved in the soil solution; the "back-up" which can maintain supplies at a proper level is, first, the exchangeable, then the reserve potassium. Supply to the plant over a period will depend on (a) the amounts of K in each pool and (b) the rate at which equilibrium between the pools is established. The amount in the solution is always small but this is of less concern to the plant if there is a large pool of exchangeable K which can quickly re-establish the K content of the solution.

3.2 The rate of potassium supply

The rate at which potassium becomes available to the roots is affected by the rate at which K can move through the soil. As the root takes up K, the exchangeable K near to the root will be reduced or exhausted. K will then move from richer zones at a distance from the root (again to re-establish equilibrium). The rate at which it moves (diffuses) depends on the materials from which the soil is made up and on environmental conditions, being higher in moist soils.

3.3 Clay

The pool of exchangeable K is particularly important. The main site of exchangeable K is the clay (to a lesser extent the organic matter). In general, the term "clay" refers to the smallest mineral particles in the soil (less than 2 millionths of a metre in diameter). These are formed by chemical changes from the minerals in the rocks on which the soil develops. The minute clay particles are crystalline. They are made up of layers, differently arranged in the various minerals. Positively charged potassium ions are held by negative electric charges on the surface or at the edges of these layers. The strength with which the K ions are held varies from one part of a clay particle to another. The less strongly they are held, the more easily they are "exchangeable" and released to the soil solution. They can also be held, and held much more strongly, between adjacent layers. Changing conditions in the soil can cause the adjacent layers of some clay minerals to move wider apart (expansion) allowing K ions to enter the inter-layer space, or closer together when these ions are not easily accessible.

There are many different types of these clay minerals but, broadly speaking there are three groups which show important differences with regard to potassium.

The first group, like kaolinite, can adsorb K only on their surfaces and at broken edges. They do not hold the K with any great strength. While they do not fix K neither do they hold it against leaching. Kaolinitic soils behave much like sandy soils.

An intermediate group, the illitic minerals, hold K on their surfaces, at the broken edges and between the layers at the edges of the crystals (wedge sites). These hold K much more strongly than the kaolinites but not so strongly that it is no longer exchangeable.

At the other extreme is a group of clay minerals which, while they hold potassium in the exchangeable form allow K to enter deep between the layers when they expand as the soil becomes moister. When the layers close on drying, the inter-layer K is trapped or «fixed» and is not easily released into the soil solution. Most soils contain a mixture of these different clay minerals; the proportions in which they occur dictate the way the soil will behave as far as potassium is concerned.

3.4 Practical consequences of clay content and type of clay – Buffering

The larger the amount of clay in a soil the higher will be its capacity to adsorb K and the better this will be able to replenish the K in the soil solution when this is depleted. Such soils are said to be well buffered; they can maintain K concentration in the soil solution at a stable level.

The difference between well buffered and poorly buffered soils is illustrated in the diagram (Fig. 8). In the case of the sandy soil (A), with only about

3% clay, a small change in exchangeable K content (which can never be very high because of the lack of exchange sites) brings about a large change in solution K. At the other extreme, the heavy soil (C) which contains K-fixing clay minerals is extremely well buffered and a large change in exchangeable K content changes the solution content little. However, because of the nature of the clay minerals, much of the K in the soil is not exchangeable and can become available only very slowly. In soil B in which the clay minerals are predominantly of a desirable type (non-K-fixing) we have the ideal situation; it is well buffered but little of the soil K is fixed.

In well buffered soils the K supplying power is not greatly affected by the removal of K in crops (Fig. 9) and the solution K is held fairly constant throughout the growth of the crop and from year to year. The effect of adding K fertilizer is long-lasting.

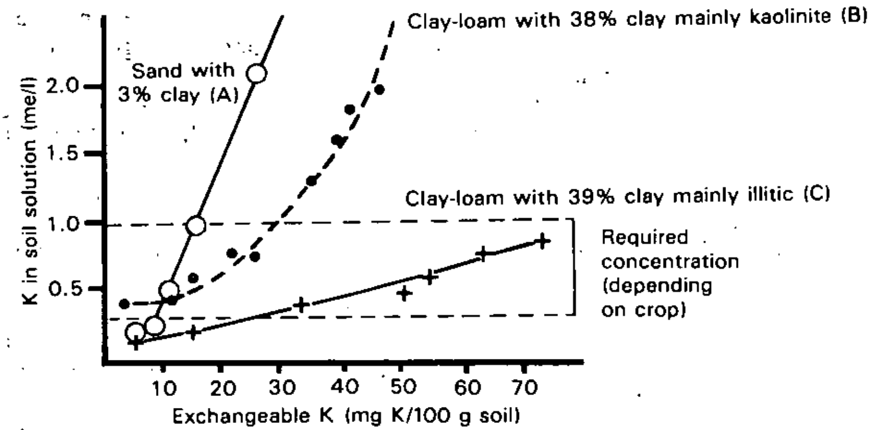

Figure 8. How soil texture and the type of clay affects the availability of potassium to plants *(Kemmler et al. [1986])*

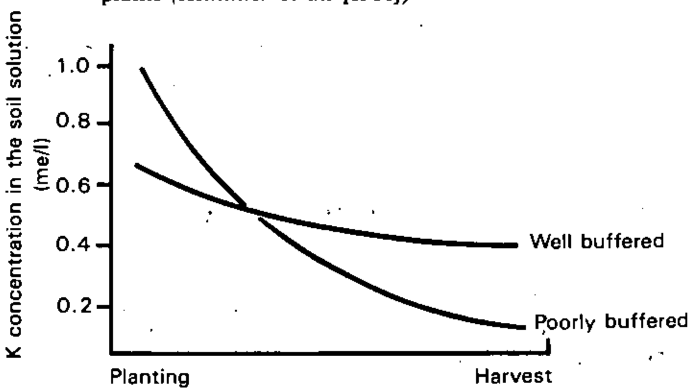

Figure 9. How good buffering affects the supply of K to the plant over the growing season *(von Braunschweig et al. [1971])*

How does all this affect how we should use K fertilizer? If the soil K content is low, so low that plants cannot get enough, i.e. when the solution K concentration is below the lowest dotted line in Figure 8, adding a moderate amount of fertilizer potash will increase the concentration to within the desirable range in the sandy soil (A) but will have very little effect on the solution K content in soil C as K will pass from solution to the exchangeable pool and some will be fixed.

The advantage of the heavy soil is that, provided it contains enough K, it will be able to maintain the solution K at a steady level throughout the growth of the crop. The drawback is that if it is maltreated by applying less K than is removed in crops, it is more difficult, and requires heavy K dressings, to bring it back into the right condition than is the case on a lighter soil.

It is very difficult to improve the potash status of light textured soils permanently. Here, one should concentrate on applying K to meet the needs of current crops, even considering using split dressings to maintain K supply through the growing season. On heavy soils on the other hand, it is quite possible to bring about permanent improvement. If soil K is low, the policy should be to build up the soil K content by applying generous dressings initially and then to make sure that enough potash fertilizer is used on all crops to keep soil K at that desirable level.

Heavy soils, though more difficult to work, are generally more fertile than light, sandy soils which are often said to be "hungry". On the other hand, whereas it is possible with enough manure or fertilizer to raise yields on a sandy soil to satisfactory levels, an infertile clay soil is much more difficult to improve.

3.5 Organic matter

Clay is not the only material in the soil which can hold potassium. The organic matter, or "humus", also has exchange properties, somewhat similar to those of clays. While in most temperate mineral soils containing clay, the contribution of organic matter to the pool of exchangeable potassium is not very important, it is very important in sandy soils and in soils where the clay minerals are predominantly of the kaolinitic type, as in many tropical soils. On these soils every effort should be made to conserve and build up organic matter by avoiding burning, by mulching the growing crop, taking care to conserve all crop residues and incorporating them in the soil. It is not easy to maintain organic matter in the tropics as under the ruling high soil temperatures it declines rapidly under cultivation.

3.6 Liming

The availability of nutrients is affected by pH, the optimum being approximately 5.0 to 7.0 (Fig. 10). Outside this range, the availability of K is reduced and if the soil is very acid or very alkaline there may be aluminium and manganese toxicity (acid) or molybdenum (alkaline). P availability is much affected and, particularly in the tropics, it is important to avoid over-liming which leads to P fixation. In general the optimum pH for tropical soils is in the lower half of the range; in the temperate zone, the reverse.

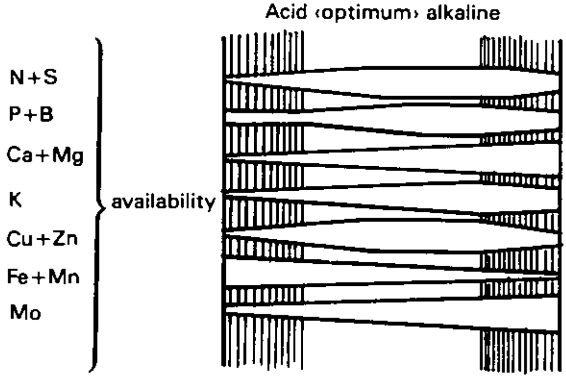

Figure 10. Effect of soil pH on nutrient availability *(Schroeder [1984])*

3.7 Soil water

Experience shows that potassium fertilizer is frequently more effective in dry years. This is both because of the influence of K on water relations within the plant (Chapter 2) and because the moisture content of the soil affects the way in which potassium moves into the plant. Drying a soil impairs K availability, mainly by reducing the rate of diffusion through the soil to the root.

The rooting pattern of a crop along with the distribution of nutrients, including K, through the soil profile is important. If the surface soil dries out, supplies of K will be locally reduced, but, if the subsoil remains moist and it contains good supplies of K the plant can obtain its needs from depth *provided* the roots penetrate deeply. Thus it is important to encourage good root penetration and also not to lose sight of the importance of maintaining adequate K levels throughout the soil profile.

3.8 Leaching and erosion

Because sandy soils do not hold K strongly, if they should contain more K than the plant can take up, the K ions are easily washed out or leached beyond the range of crop roots. Heavier soil has an advantage in that much K is held by the clay, any temporary excess over the plant's immediate requirement is not easily leached. This is another reason why K fertilizing should differ as between light and heavy soils. Leaching can be minimised by keeping the land covered with crops. Deep rooted fallows will restore some deeply leached nutrients to the surface layer of soil. Alley cropping (alternating strips of annual crops and permanent tree crops) can be useful, the tree roots "capturing" nutrients from depth.

Potassium, and other nutrients, can also be lost by erosion which can be very severe on slopes. All possible should be done to minimise erosion. As well as being washed away with eroded soil, potassium moves downhill in the sub-surface soil with the consequence that the upper part of the slope becomes impoverished to the benefit of the lower lying land.

3.9 Arid regions

In the wet tropics, downward movement of nutrients (leaching) is a severe problem; in hot dry areas it is *upward* movement which causes trouble. The high rate of evaporation from the surface causes soil water to move upwards and with it the salts it contains, which accumulate in the surface layers and may reach levels which are toxic to plants. If irrigation water is plentiful, salinity can be reduced by flooding (leaching excess salts downwards). Irrigation can actually increase salinity if steps are not taken to provide good drainage which will allow excess salts to be washed out. In such areas, using fertilizers, which add to the salinity, presents some difficulty. It is then advisable to use sulphate of potash which has a lower salt index than the chloride. It has been shown that potassium can counter the effect of excess sodium in such soils as it reduces the uptake of sodium (see 2.6 above).

4. Fertility and fertilizers

4.1 The nutrient cycle

Whether or not the soil is farmed, there is constant movement of nutrients between the soil and the plants growing on it. Under natural conditions, nutrients taken up from the soil are returned to the soil when fruits, leaves or twigs fall or when the plants die. There is little or no loss, the nutrient cycle is closed and the system continues in equilibrium. When the land is farmed, nutrients are removed in harvested crops and soil fertility declines.

To stand in tropical rain forest, gives the impression of boundless fertility, but to see the poor crops in clearings farmed in the traditional manner shows that this fertility is fragile. When forest is cleared and burned the accumulated fertility is soon washed out; after a year little nutrient remains within reach of crops' roots.

Even so, shifting cultivation, provided land is plentiful, and the period under crop short so that the regenerating forest can be left long enough for nutrients to be recovered from depth, can maintain enough fertility to grow small crops. As population increases, the fallow period shortens, fertility goes down, yields decline and the land will not support the population. Demand on the land is further increased by the demand for a better standard of living - more and better food, a surplus over family needs to be sold for cash income. Shifting cultivation cannot then supply man's needs. Continuous farming, or farming with only short fallows must take over.

Such settled farming imposes a strain on the soil; harvested crops take with them the nutrients they contain; there are losses by leaching and erosion when the soil remains uncovered by crop or natural regrowth. These losses can be reduced by returning wastes to the land. If livestock is kept, some nutrients may be brought in with animal feed, though this is at the expense of some other area,.and merely slows up the decline in fertility; decline there must be. The only way to keep the fertility up without "robbing Peter to pay Paul" is to bring in fertilizers. The only way to improve fertility if the soil cannot grow the yields needed is by using fertilizer.

This discussion is based on the tropical rain forest because it best illustrates the general problem of maintaining fertility but the principles apply universally.

4.2 Nutrient balance sheet

It is useful, as a check on correct fertilizer usage, to draw up a balance sheet, setting amounts of nutrient added as fertilizer against amounts removed in crops. This is particularly important in the case of potassium because the amounts involved in the nutrient cycle are so large. An accurate balance could be obtained if every crop leaving the field were analysed but this is obviously not a practical proposition and often the facilities do not exist.

Tables of nutrient removals by various crops (Table 5 is an example) have been published which can be used to give an approximate balance, but there are limitations:

1. It is not always stated on the table whether the data given refer to removal in harvested produce or to the total content of the crop, including residues (straw etc.).
2. The K content of a crop varies with the conditions under which it is grown.
3. Crops grown with an abundant supply of K may have a percentage K content which is higher than that actually needed for full growth. This applies in particular to leafy crops.
4. Though in grain crops the K content of the grain is reasonably stable, the K content of the straw (which must be taken into account if straw is removed from the field) is much affected by weather. If wet weather precedes harvest, much K is washed out of the straw.

Despite these limitations, the data in Table 5 can assist in working out a nutrient balance sheet for a crop rotation. Approximate figures are given for selected crops or crop groups which represent the range covered in this publication; these are in terms of total *uptake* of N, P_2O_5 and K_2O by the whole crop (e.g. grain+straw) for the indicated yield of actual produce (e.g. grain). *Removals* of K_2O per tonne of marketable produce (grain, tubers, fruit etc. as appropriate) are included for ease of calculation of removal by the crop at the actual yield obtained. Note the distinction between removal and uptake; it is removal which determines the balance. Note also how the method of disposal of crop residues affects removal - e.g. with a cereal crop, if only the grain is removed from the field K removal is only a fraction of that when the straw is taken away for sale or use elsewhere.

A balance sheet constructed in this manner is a useful guide to P and K requirements of the field (or farm) in the long term but is not useful for assessing N needs, as soil N is affected by many factors other than fertilizer application and crop removal and in any case soil N is short-lived and at risk from leaching, denitrification etc. The sole purpose of the estimation of balance is to indicate whether or not the fertilizer policy used is such as to maintain *soil* fertility; it has little bearing on fertilizer recommendations for a particular crop. Removal of P and K by a crop does not indicate its fertilizer needs.

Simple replacement of P and K removals will not be entirely sufficient to maintain fertility; there are inevitable losses from the system through leaching and run-off and by rain washing nutrients out of manure heaps.

The balance sheet is of little use for permanent tree crops. Of course, nutrients are removed in harvested fruit and allowance can be made for this but total nutrient uptakes by the whole tree are not very useful - of greater importance is the total quantity of nutrients in constant circulation in the whole tree.

Table 5. Uptake of nutrients in average to good crops with K removals per t. yield

	Yield		kg/ha		Removals (kg/ha K_2O)	
	t/ha	N	P_2O_5	K_2O	Whole crop	Product only
Wheat, barley, oats ..	5	150	60	160	30	5
Maize	8	210	80	190	25	8
Rice	6	100	50	160	27	8
Potato	40	175	80	320		8
Sugar beet	45	200	90	300	8	4
Cassava	40	150	70	350		9
Field beans	2.5	160	50	120	48	10
Pigeon pea	1.5	70	10	55		8
Rapeseed	3	165	70	220	70	10
Soya	3	220	40	170	57	10
Sunflower	3	120	60	240	80	23
Groundnut (bunches)	2	170	30	110	55	12
Cabbage/Kale	70	370	85	480	7	
Beans (green)	15	130	40	160	11	
Onion	35	120	50	160	5	
Meadow hay	6	135	25	138	21	
Lucerne hay	12	300	65	190	16	
Grass silage	12	80	20	75	16	
Cotton (lint)	1	129	45	90	90	30
Tobacco (dry leaf) ..	2	130	40	240		120
Sugarcane	100	130	90	340	3.4	

Nutrient balance sheets are instructive at all levels. A national balance sheet can indicate the direction in which national fertilizer policy should be steered (Table 6). This shows that removal exceeds application in every case and the deficit is particularly severe in the case of potash where fertilizers used supply only 5% of the amount removed in crops. Clearly this is a serious situation which must lead to severe depletion of soil fertility and declining yields. Even if standard fertilizer recommendations were followed, while there would be a positive balance for N and P, the balance for K would still be negative.

Table 6. Overall nutrient balance sheet for Thailand *(Cooke [1985])*

		1000 t	
	N	P_2O_5	K_2O
Removed* in crops 1984	684	282	941
Fertilizers used 1983/84	255	135	37
Balance	-429	-147	-904
Amounts of fertilizer recommended	1324	382	784

* Estimated from published tables.

Balances constructed for crop rotations or individual fields on the farm show the farmer whether he is on the right lines or whether he needs to make adjustments. The following examples are chosen to show:

1. the very large amounts of potassium that are "at risk",
2. the extreme differences in potassium requirements needed to maintain fertility between individual crops and between one system and another.

Even when the generally accepted fertilizer recommendations are followed, there is a deficit of potash over the rotation in Table 7. If the cereal straw is removed this drain on K reserves is severe even though some farmers increase the K dressing in such a case about 50%. Table 8 shows the balance for a typical rotation in India.

Table 7. Nutrient balance in intensive ley arable system

	kg/ha nutrients						
	Applied (fertilizer)			Removed (crop)			
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	K_2O*
Wheat (8 t/ha)	100	60	60	200	15	40	130
Wheat (6 t/ha)	150	60	60	150	13	30	100
Barley (4 t/ha)	120	30	60**	110	12	20	75
Grass 1st year							
3 silage cuts (65 t/ha) ..	300	120	210		25	300	
1 grazing	80			-	20	12	
Grass 2nd year,							
grazing only	200	30	30	-	50	40	
Total	950	300	420	360	135	462	657
Balance					+165	-42	-237

Applications based on standard U.K. recommendations.
* Removal if straw removed. ** Extra K applied for establishment of seeds.

Table 8. Nutrient balance in a long-term experiment in New Delhi – rotation: pearl millet, wheat, fodder cowpea *(Nambiar et al. [1984])*

	Nutrient balance in kg/ha/year								
Fertilizer	Applied*			Uptake**			Balance		
treatment	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
O	0	0	0	4	7	40	- 47	- 7	-40
NP	260	7	0	137	20	101	+123	+50	-101
NPK	260	70	83	147	22	129	+113	+48	-46

* Fertilizers applied (in accordance with soil analysis) were (N, P_2O_5, K_2O): 120, 60, 40 for millet and wheat and 20, 40, 20 for cowpea. Yields with complete (NPK) fertilizer were about 2 t/ha millet, 4 t/ha wheat and 1.3 t/ha cowpea fodder, double those without fertilizer.

** Nutrient contents of grain, straw and fodder measured at harvest.

The last balance sheet (Table 9) shows the severe drain on soil potassium in traditional systems where, normally, no fertilizer is used. Were fertilizers applied to yams in line with recommendations derived from the results of FAO trials, say 40 kg/ha each N, P_2O_5 and K_2O, yields (and consequently nutrient removals) would be expected to double but nutrient balance would still be seriously in deficit.

Indications from a balance sheet can be checked by soil analysis. Periodical sampling of the field will indicate whether the soil's potassium status is being maintained, built up or being allowed to decline.

It is appropriate at this point to study Figure 11 which compares nutrient removals found in a long-term experiment in India with the average rates of fertilizers applied in the area and with the local advisory recommendations. The amount of K recommended is only a half of the removal found, but, worse still, the average applied in the area is less than 1/20th of removal!

Table 9. Traditional West African system - yams intercropped with maize and beans followed by cassava and no fertilizer used.

	Nutrients removed (kg/ha)		
	N	P_2O_5	K_2O
Yams (6 t/ha)	32	22	65
Intercrops say	25	5	20
Cassava (16 t/ha)	64	48	120
Total	121	70	205
Nutrients in household refuse	10	10	20
Balance	-111	-60	-185

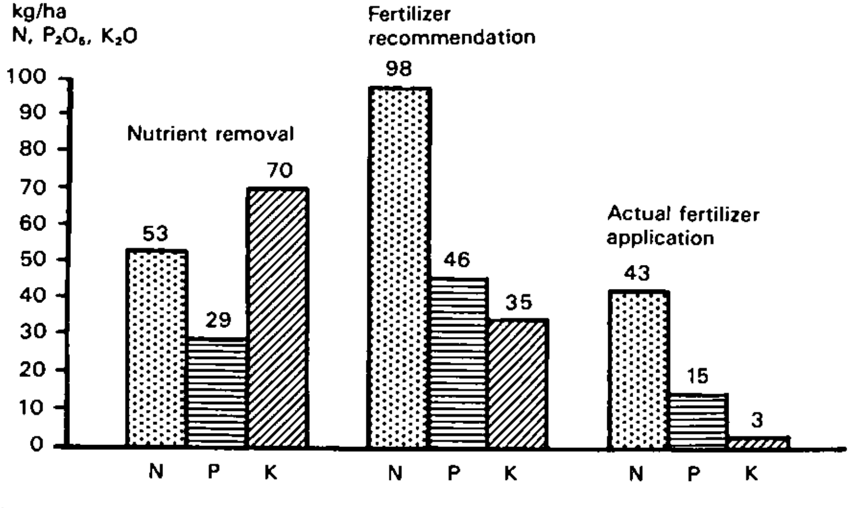

Figure 11. Insufficient P and K applied to replace removals *(Sekhon et al. [1985])*

4.3 How much potash?

It is easy to find out (by analysis or from a table) how much K harvested crops remove and thus how much fertilizer should be used to restore the situation. In the long run, if this (plus some allowance for wastage by leaching etc.) is regularly applied after each crop, soil K should be maintained. But the quantity removed is not a reliable guide to the quantity required. The total potassium in a crop rises to a peak about the stage of maximum growth and then declines towards harvest. This means that the requirement for unrestricted growth is actually larger than that indicated by plant composition at harvest.

Crops which mature over a short growing period have less time in which to take up their needs than crops which have a long growing period. For instance, tomatoes, sugar beet and sugarcane all take up about the same total quantity of K but, while the first two develop over a period of four months or so, sugarcane grows throughout the year.

When growth processes are most active, and the potassium content of the crop is approaching its maximum, large amounts of K have to be taken up over a very short period. It is not only the amount of K that matters; the rate at which it can be taken up is equally so. Soil analysis may show that there is enough potassium in the soil to supply the full needs of the crop, but if this is released only slowly the rate at which it can be taken up over the critical period may be too low and the crop will still suffer from short-term deficiency and this will restrict yield.

Figure 12 shows how K accumulates in a crop of maize as the crop grows, reaching a peak of 175 kg/ha K_2O at about 6 weeks after germination and then falls off as the crop matures. Over the period when growth is at a maximum, the maize needs to take up K very rapidly; as much as 4.3 kg/ha K_2O per day.

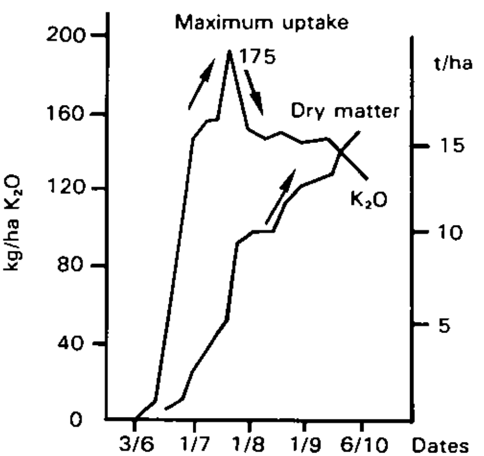

Figure 12. Cumulative K uptake by maize *(Cottignies [1979])*

In order to know how much potash fertilizer to use, we need to know how much potassium there is in the soil and how "available" it is; how much K is removed in crops; the maximum K content of the crop during development. Information on these is given by soil analysis, plus knowledge of soil properties, and crop analysis. But, probably, the best guide of all is experience.

Soil analysis

A soil analysis will indicate whether a soil is sufficiently supplied with potassium. Conventional methods, determine in effect the sum of solution K and exchangeable K, though some of them, using the stronger reagents, also extract a part of the non-exchangeable K.

No conventional method, being arbitrary, is perfect, but, especially where they have been in use for some considerable time and there is experience in their interpretation, they are reasonably reliable, given caution in interpreting the results and will give quite good guidance as to whether or not a response can be expected from K fertilizer especially when comparing the K status of areas lying on the same soil type. It will not give reliable comparisons between different soil types because of differences in soil characteristics (clay type and content, moisture relations etc.) affecting K relationships. They will not however necessarily accurately forecast the exact quantity of K fertilizer needed nor the size of the response to be expected.

It is very rare to find really close correlation between soil analysis and results of fertilizer trials. One should not expect too much. Weather, and with it the way in which crops grow, is seldom the same two years running, and other factors such as disease may have effects so that the way a crop reacts to fertilizer also varies.

While soil analysis cannot give *exact* guidance as to the amount of potash fertilizer that should be used, with experience, norms indicating at least deficiency, adequate and abundant K supply have been established for the major soil types.

If soil K is adequate or abundant, K dressings to restore the K removed in crop (plus a small allowance to cover wastage) should be sufficient, though, if for any reason it is realised that insufficient K has been given to replace removals, steps should be taken to make up the deficit at the earliest opportunity.

If soil analysis indicates deficiency, potash in excess of likely crop needs should be applied in order to build up the soil.

Soil characteristics

All soils should not be treated the same "potash-wise" (chapter 3). This has to be taken into account in interpreting soil analysis. Generally speaking, *sandy soils* are low in K; they would be expected to require more K fertilizer than heavy soils. But they are difficult to build up. The rule is to meet the requirements of the current crop and no more.

Most *heavy soils* are better suppliers of K and, if more K is applied than can be used by the current crop, the surplus will be stored in the soil for the benefit of succeeding crops. They can be permanently improved by generous potash dressings. On the other hand, because these soils are well buffered, moderate dressings do not radically alter the supply of K to the plant; they need heavier dressings than sandy soils. While such soils can be built up, it is not an economic proposition to attempt to put things right with one heavy application (the cost is unlikely to be recovered in increased yield of the immediate crop), and the aim should be for gradual improvement.

Soils with K fixing minerals present a special problem. The fixation capacity could be satisfied by applying a massive dressing but this is not really a practical proposition. What can be done is to achieve this aim on the small scale by placing the K fertilizer near to, but *not* in contact with the seed and to aim for gradual permanent improvement by applying somewhat more K than just sufficient to replace crop removals.

Many *tropical heavy soils* behave more like sands because they contain only kaolinitic clay minerals which are unable to adsorb appreciable amounts of potassium. The K policy should be similar to that for light soils.

There are methods of "correcting" soil K values indicated by analysis for soil clay content, for example the diagnostic diagram used by the official French advisory service illustrated in Figure 13 (A). Alternatively, they may be corrected by relating them to cation exchange capacity (CEC) (Fig. 13, B) which takes account of both the quantity of clay and its type. A given value for exchangeable K will denote a lower availability of K to the plant when the CEC is high than is the case when CEC is low.

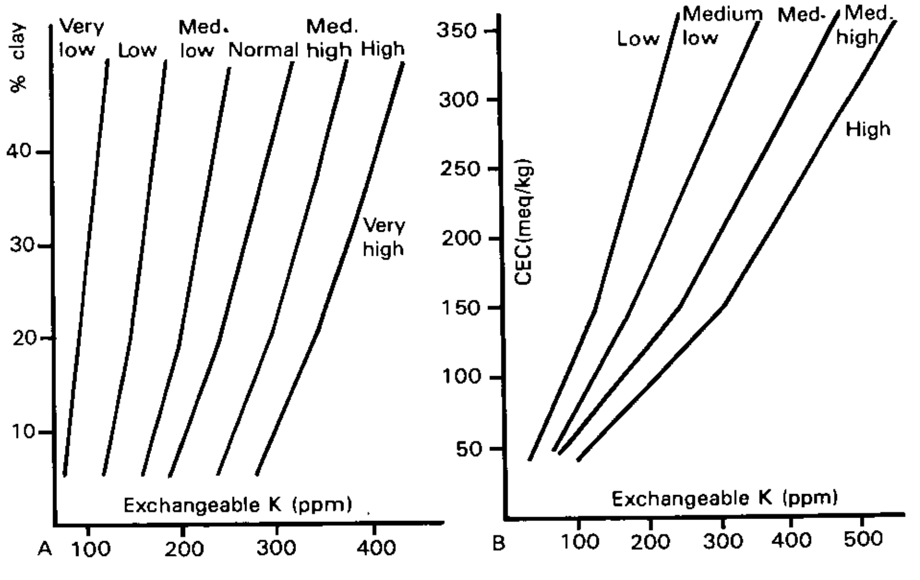

Figure 13. Adjustment of exchangeable K reading for (A) clay content, (B) K saturation of CEC *(Quemener [1979])*

A soil's K supplying power is sometimes judged simply from the percentage K saturation, e.g. in francophone West Africa. K/CEC below 1.5% indicates K deficiency; between 1.5 and 3% low to medium and above 3% sufficiency.

Conventional methods, based on exchangeable K, are satisfactory provided allowances are made for clay content, or for differences between soil types. The more experience has been obtained under prevailing local conditions, the more reliable the methods.

If there are limits to the usefulness of soil analysis for precisely indicating fertilizer needs, there is no question about its value for monitoring the results of past fertilizer practice. Almost any method can indicate change in soil K status over a period and soil analysis at intervals is a check on the effect of fertilizer policy.

Crop analysis

Crop analysis is useful both to indicate crop nutrient status and hence to diagnose a need for fertilizer, and to determine the amount of nutrient contained in the crop.

Leaf analysis is much used with tree crops since soil analysis does not give reliable indications of current requirements. If the timing of sampling and the position from which leaf samples are to be taken are closely specified, analysis gives an accurate picture of nutrient status. Research has established norms for leaf nutrient content indicating shortage, sufficiency and abundant levels and fertilizer recommendations are largely based on these. Leaf analysis has also proved useful for other permanent crops such as grass. Some rapid methods of diagnosis by tissue tests using coloured indicators which can be used in the field have been developed for use with annual crops.

Cropping level

The bigger the crop, the more K it contains and the more it needs. However, if only low-yielding varieties are available and if there are "non-fertilizer" limits so that only small crops can be grown, there is no point in being over-generous with potash. It is futile to apply the K needed by a ten tonne crop when the best that can be expected is a mere tonne and a half. On the other hand, with the right variety, good pest and disease control, high standard cultivations, reliable rainfall and/or irrigation it would be foolhardy to risk failure to grow a full crop (and failure to make a profit) by a niggardly attitude to fertilizers.

Potassium uptake by crops, and hence fertilizer requirement, varies with yield - heavy crops need much potassium: this is why Table 5 includes data for removal of K_2O per unit of harvested crop so that the required amount can be calculated easily.

Advisory recommendations frequently take the expected cropping level into account; as an example, standard advice for potash manuring of rice and wheat on different soils and at different yield levels is quoted in Table 10.

Table 10. Potash recommendations for two yield levels of rice and wheat on various soils in Bihar State *(Reddy et al. [1986])*

		kg/ha K_2O			
	% clay	Rice		Wheat	
Expected yield (t/ha)		3	4	3	4
Location and soil:					
Pusa (young alluvial calcareous)	30	35	60	12	44
Katihar (young alluvial non calcareous)	17	29	52	48	88
Bikramganj (old alluvial)	44	38	76	35	52
Sabour (old alluvial)	19	32	50	43	65
Ranchi (red-yellow)	30	42	79		

4.4 Field experiments

The ultimate test of the effect of fertilizers is the field experiment. Field experiments are expensive and have their limitations; nevertheless, it is upon their results that most practical recommendations are based. Even the research worker let alone the advisor or the farmer needs some practical proof of the efficacy of his recommendations.

Because of year to year variability, experiments should be repeated for several years. Results are only strictly applicable to the site of the experiment. Each series of experiments should be confined to a particular soil type or a particular set of farming conditions. The average of results from such series should then give reasonably reliable results for the particular sets of conditions investigated. In some developing countries with little experience of fertilizers a great deal of information of a "survey" nature has been gathered by FAO and other agencies by siting large numbers of simple experiments over an area. Average responses obtained in these trials indicate whether or not fertilizers are likely to be profitable but often do not furnish the kind of information upon which to base precise recommendations.

The individual farmer is not in a position to carry out elaborate experiments but he can do his own simple trials by applying potash to a small area of crop and weighing the yield obtained and comparing it with that from an adjoining unfertilized piece of land of the same size. If he should try this, he should always duplicate the trial and he should select for the trials pieces of land which appear to be uniform. The "do-it-yourself" trial can be convincing.

Long-term experiments

For potash and phosphate, in contrast to nitrogen, where the effects are relatively short-lived, we are just as much interested in the effects of fertilizer treatment on the soil as in those on the immediate crop. Using potash for a number of years can improve relatively infertile soils and transform them into fertile soils. Witholding K fertilizer on a relatively fertile soil may have no or very slight adverse effect in the short term but disastrous effects in the long. This is very important in the early stages of fertilizer use when it may well be that N fertilizer gives very good returns and the farmer (and sometimes his adviser) sees no need for potash. Using N, and perhaps P, may increase yields but also increases K removals; the heavier removals soon deplete the soil of K and the N or N+P fertilizer no longer produces the desired result. This disaster can be prevented by including a K treatment in the experiment and carrying on the experiment for a number of years to allow the removals or additions of potassium to build up.

This is well illustrated by results from an experiment carried out by the International Rice Research Institute in the Philippines (Fig. 14). If the work had been ended after just two or three crops had been taken, the conclusion would have been that rice needed no potassium or phosphate, yet, after 6 crops, yield from nitrogen alone had declined seriously and the NPK plots outyielded the NP by more than 0.5 t/ha.

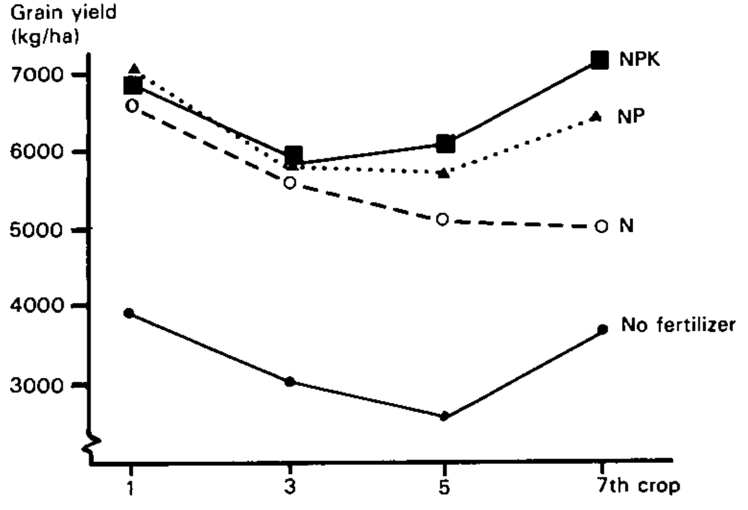

Figure 14. Rice yield responds to N initially but continuous cropping without P and K leads to serious yield loss *(von Uexküll [1979])*

Another example (Fig. 15) shows results from a long-term experiment in S. Africa on maize grown for 28 years. In the first year, yield with nitrogen only was only about 0.6 t/ha less than that from the complete (NPK) treatment; by year 28 yield from N only had fallen to about 0.5 t/ha while the NPK treatment gave 3.5 t – higher than the yield in the first year. The effect of P became marked by the 6th year but then yield from NP declined sharply due to exhaustion of soil K. Addition of K resulted in stable high yields over the whole 28 year period.

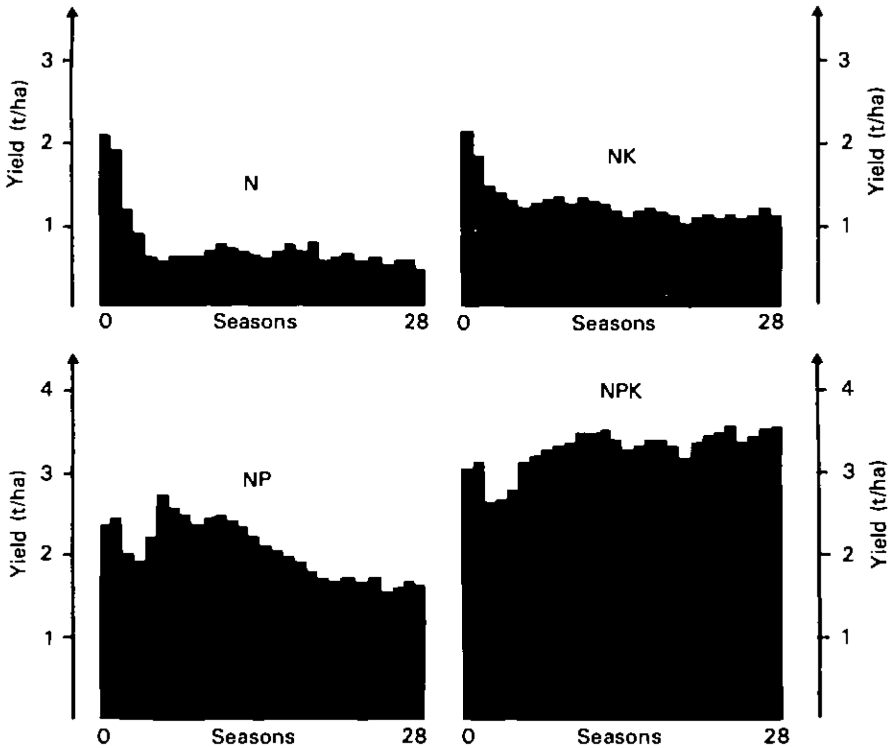

Figure 15. Grain yields of maize grown contiuously for 28 years under different fertilizer treatments *(Stoch et al. [1980])*

4.5 Experience

Neither the farmer nor his advisor has the resources to do detailed, particularly long-term, experiments. However the partnership is not powerless in the face of this problem. The farmer's experience will give him a shrewd idea of the effects of his fertilizer treatment in the long term; the advisor can assist by taking soil samples at intervals; if the K level goes up all is well, if it goes down all is not well. The farmer can also profit by his neighbour's experience; "looking over the fence" is very effective in spreading knowledge.

Successful farming demands a partnership between the farmer's practical down to earth approach, the know-how of the advisor and the expertise of agricultural research as a back-up.

4.6 Potash fertilizers

Potash fertilizer may be used on its own (as a so-called "straight" fertilizer) or as a constituent of a mixture with other nutrients to provide all the needs of a crop in one application. The mixture may be made up on the farm or purchased as a manufactured "compound" or "complex" fertilizer.

Straight potash will be used for supplementary dressings designed to build up soil K status, or where the policy of applying large dressings of P and K once in the rotation with appropriate dressings of straight nitrogen for the individual crops is adopted in preference to putting on only the nutrients required by the immediate crop (4.7). This policy is increasingly adopted in countries with a long history of P and K usage where soil nutrient levels have reached a satisfactory level. The choice of policy depends on circumstances, not least upon the availability and relative cost of fertilizer materials in the market.

Whether straight or compound, the potassic material in most cases will be either sulphate or chloride (muriate).

Potassium chloride (muriate of potash)

Potassium chloride is the form in which potassium mainly occurs naturally in the subterranean deposits from which it is mined. In the natural minerals it is mixed or combined with other materials of which the chief is sodium chloride (common salt). In the process of preparation for the market, the potassium chloride is separated from the other minerals by various processes – flotation, crystallisation, electrostatic. Different products are available according to the degree of purification. Near to the mines there may be a preference for low grade muriate (e.g. 40% K_2O) because the accompanying salt is valued (e.g. for beet) or for a ground raw mineral such as kainit which also contains magnesium. If the fertilizer is transported over long distances, there is a preference for the higher grades (especially 60% K_2O) owing to the saving in freight. Chloride being the most plentiful, it is also the cheapest potassium fertilizer and, on this account, is usually recommended for general use.

Potassium sulphate (sulphate of potash, 50% K_2O)

While potassium sulphate does occur in natural mineral deposits and is mined as such, the greater part of that reaching the market is manufactured by reacting potassium chloride with sulphuric acid or with magnesium sulphate which may occur in the mine. Consequently it is more expensive and is generally reserved for special purposes.

The advantages of the two main types of potash fertilizer are:
Chloride: Easily available, low cost, high K content,
Sulphate: Contains sulphur, low salt index, chloride-free.

Normally, considerations of economy will suggest the choice of muriate. The extra cost of sulphate is justified for chloride-sensitive crops (e.g. tobacco, potatoes for processing, soft fruits), where there is a definite requirement for sulphur, if it is necessary to guard against excessive salinity (e.g. in intensive cropping under glass, intensive fertilizer use on vegetables), in arid areas and on saline soils. There are few cases where chloride is to be preferred on grounds other than cost; coconut and oil palm on sandy soils have large Cl needs and respond to both K and Cl.

Other potash fertilizers

Some potash producers market special potash fertilizers which contain magnesium e.g. sulphate of potash magnesia (30% K_2O and 10% MgO) often sold as "Patentkali" or 40% muriate with 5% MgO and some sodium.

Potassium nitrate is a specialized material used in liquid feeds for glasshouse crops.

All the potash fertilizers can be obtained in granular form (more convenient for handling); if they are offered as powders they are treated with anti-caking agents.

Compound fertilizers

The great majority of compound (NPK or NK) fertilizers contain potassium chloride which is the cheaper and more easily obtainable form. Most compound fertilizer manufacturers also market products based on sulphate designed for special purposes. Though their K content may be lower their total nutrient content (K+S) is actually higher.

There are advantages in using compound fertilizers: a saving in freight costs, their total nutrient content per ton being higher than that of the appropriate combination of straights; uniformity of composition; it is rather difficult to make really homogeneous mixtures by home-mixing.

4.7 When and how to apply potash

Manuring the crop

Usual practice in the case of annual crops is to apply the K fertilizer at the time of or just before sowing, along with phosphate and, usually, a part or the whole of the nitrogen dressing. This is conveniently done by using a compound or mixture of nutrient (N:P:K) ratio suited to the crop. The fertilizer is mixed into the surface soil in the final stages of preparing the seedbed or, if the equipment is available, applied at the time of sowing by combine-drill (see placement).

On most soils, the whole of the potash for an annual crop can be applied at planting but, on light-textured soils, particularly in the tropics where heavy rain after planting may cause serious leaching, there is an advantage in splitting the K dressing so that an adequate level of K is maintained throughout the development of the crop and so that peak uptake rates are covered [see 4.3].

Manuring the rotation

If soil K is at sufficiency level, many farmers now prefer to apply all the potash required for a series of crops at one point in the rotation, normally in the autumn preceding the planting of that crop which has the highest K need (e.g. potatoes or beet). The fertilizer programme is designed to maintain the soil K at a constant or gradually increasing level. Such a plan has two advantages:

1. "Straight" potash may be cheaper than it is as a constituent of compound fertilizer and it is advantageous when the farmer has facilities for bulk handling or can use contractors to do the spreading.
2. It lessens the work load in the following spring when it is only necessary to apply nitrogen.

Placement

Placement of fertilizer with the seed is good practice on K-fixing soils where broadcasting normal rates gives poor results because such a large proportion is fixed and not accessible to the crop. Placement means that the fixation capacity of the soil is satisfied in the zone of placement near the seed and therefore a higher proportion of the fertilizer K is available to the young developing crop. Care is needed in placement since high concentrations of fertilizer cause scorching of emerging sprouts. Only moderate rates should be applied with the usual combine drill which places the fertilizer in contact with the seed. There are special drills which place the fertilizer at a little distance from the seed. This is another instance where sulphate of potash is the preferred form - e.g. in potato growing, a generous fertilizer dressing is often placed by broadcasting over open ridges or by machine and sulphate of potash does not have the strong scorching effect of the chloride.

Permanent crops

Special conditions apply for permanent crops. Time of application in temperate areas would normally be spring, late summer or autumn; in the tropics, at the end of the dry season when access is easy and the first rains will wash the fertilizer into the rooting zone. For tree crops, the usual practice is to apply the dressing around the bole and within the canopy. There may be some advantage in applying the fertilizer at depth in pockets distributed beneath the canopy (a form of placement).

Another permanent crop, grass, needs careful consideration with regard to the timing of potash application (see Chapter 12).

4.8 Profit from potash

In the final analysis, the decision whether or not to use fertilizer depends upon the return to be expected. It stands to reason that, provided the value of the extra crop obtained by using fertilizer exceeds the cost of the fertilizer plus the cost of applying it, the farmer stands to make a profit. Not only is the farmer's gross margin improved, but, what is probably more important, so is the rate of return on his whole investment in the farm. The major part of the total cost of growing a crop is in the fixed costs, i.e. the value of the land plus the cost of any buildings, machinery etc. He needs the maximum possible return from this investment.

Judging from their publications, the majority of agronomists seem to be concerned mainly only to demonstrate that a particular fertilizer yields the best return in terms of weight of crop obtained. Very rarely do their papers mention profit and loss. Those responsible for agricultural research should ensure that all experimental work is properly costed.

In the simplest terms, the profit from using a fertilizer depends upon the relation between the cost of fertilizer and the price received for the additional crop: the value cost ratio (VCR). The "efficiency" of a fertilizer may be stated as kg of increased crop per kg of fertilizer (nutrient) needed to produce it. Fertilizer "A" giving 10 kg grain per kg fertilizer appears better than "B" giving only 5. But if A costs two and a half times as much as B, the "prize" should obviously go to to B.

In a straight comparison based solely on crop yield, potash will often appear less "profitable" than, for instance, nitrogen. But potash is cheaper to buy. The point is well illustrated with data from the Fertilizer Association of India (Fig. 16) showing the effects of using N, P, and K on wheat in terms of rupees per rupee invested in each of the three nutrients. Average results from a large number of experiments showed that 1 kg N produced 12 kg wheat, 1 kg P_2O_5 gave 7 kg and 1 kg K_2O 5 kg. But the unit costs of the fertilizers were N (urea) Rs 5.11, P_2O_5 Rs 5.83 and K_2O Rs 2.17. So in money terms the return per rupee spent on potash was Rs 3.82, much the same as the figure

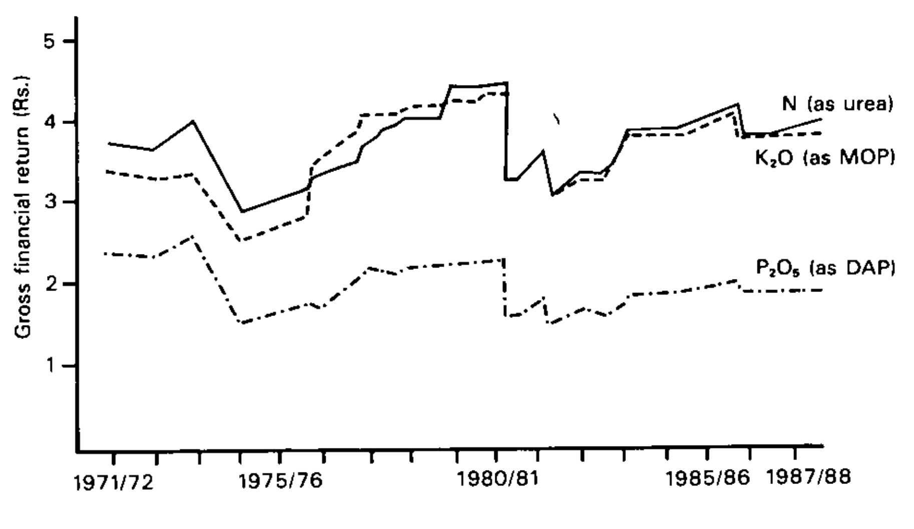

Figure 16. Profitability of N, P and K use in India *(FAI [1987])*

for nitrogen (3.90). The result is quite different from that based only on weight of crop.

FAO has summarized results of the Fertilizer Programme experiments throughout the developing countries (over 100 000). In Table 11, the returns from N, P and K fertilizers applied to rice in a total of 6550 field trials and demonstrations are given both as kg grain per kg nutrient and as value cost ratio (VCR). Taking all the trials and demonstrations together, the return in kg grain per kg nutrient was less for potash than for N or P but in value terms the return from potash was higher than that from phosphate and about the same as that from nitrogen:

	Productivity index (kg grain/kg nutrient)	Value cost ratio
N	9.3	4.1
P	8.2	3.2
K	6.3	3.9

Table 11. Response of rice to individual nutrients in Far East countries *(FAO [1989])*

	Sri Lanka	Nepal	Bangladesh Aus	Bangladesh Aman	Bangladesh Boro	Thailand	Indonesia	Philippines
No. of sites	534	509	529	2000	839	405	688	1046
Control yield, t/ha	3.23	2.79	1.83	2.69	2.97	3.03	2.32	3.52
Response to N, kg/ha	556	857	509	658	830	565	1036	825
Treatment, kg N/ha	60	70	90	90	110	63	75	66
kg grain/kg N	9.3	12.1	5.7	7.3	7.5	9.0	13.8	12.5
VCR 1986 (N)	5.3	3.6	2.3	3.0	3.1	2.2	8.9	5.2
Response to P, kg/ha	371	412	458	510	679	328	311	254
Treatment, kg P_2O_5/ha	40	40	67	67	67	52	45	30
kg grain/kg P_2O_5	9.3	10.3	6.8	7.6	10.1	6.3	6.9	8.5
VCR 1986 (P)	5.3	3.8	2.7	3.0	3.9	1.0	4.4	2.0
Response to K, kg/ha	264	330	259	252	418	263	96	122
Treatment, kg K_2O/ha	40	30	45	45	45	25	50	30
kg grain/kg K_2O	6.6	11.0	5.7	5.6	9.3	10.5	1.9	4.1
VCR 1986 (K)	5.0	8.5	3.5	3.4	5.7	3.6	1.6	2.2
Response to NPK, kg/ha	1226	1291	1226	1420	1927	1156	1453	1289
Treatment, kg NPK/ha	140	140	202	202	222	140	170	126
kg grain/kg NPK	8.8	9.2	6.1	7.0	8.7	8.3	8.5	10.3
VCR 1986 (NPK)	5.3	3.4	2.6	3.0	3.7	1.8	5.9	3.7

In considering the profitability of potash fertilizer, it is important to take into account its effects in improving crop quality. Higher quality produce commands a higher price, so that there is a double benefit. This is seen in Table 49 (p. 84) where the increase in yield for the high rate of potash compared with the lower rate is only one or two per cent while the increase in cash return is as much as 70%.

Part II
Practical recommendations for the use of potash fertilizers

5. Introduction

The fertilizer programme has to make sure that:

1. the individual crops lack for nothing;
2. the growing of the crop or series of crops leaves the soil in as good condition as we found it, or, preferably, in a better state.

Concentration on the first aim without considering the second may lead to declining soil fertility, declining yields, declining response to fertilizer and declining profits.

There are difficulties in a book intended for wide use in making specific recommendations. Conditions vary from country to country, from region to region and from soil type to soil type. All that can be done is to make suggestions.

In many parts where we hope this book will be useful, fertilizers will be new to farmers (and advisors). They will in the first place wish to tread softly and feel their way; they may be hesitant to commit themselves too far. They are advised in the first place to try recommendation on a small area using the full recommended amounts rather than to try out lesser amounts on a large area.

It is convenient to divide crops loosely into categories: annual arable crops, vegetables, grassland, plantation crops and fruit. Into which of these categories a particular crop should fall is debatable, though unimportant. Within the main categories the crops are divided into groups which have similar fertilizer needs and similar general characteristics.

It is not possible to treat each crop exhaustively and, rather than attempt this, we have chosen to deal fairly thoroughly with chosen examples, leaving the reader to "extrapolate" from these examples to other generally similar crops which may not be mentioned. For some crops the emphasis is on well-established methods and examples of practical fertilizer recommendations; for others there is more discussion of the results of field experiments and of nutrient requirements in more general terms.

6. Cereals

Cereals are usually thought to be not very responsive to potassium and, to a large extent, this is true in comparison with other groups such as root crops. All gramineae have well developed root systems and are efficient in extracting K from the soil. Their K requirement is also relatively small if only the grain is removed from the field, since two thirds of the total K content at harvest is in the straw. Potash fertilization then depends very much on what is done with the straw; where it is removed (for feed, fuel, thatching or sale) one can no longer regard the cereals as only moderate K feeders.

However, though the K removed in grain in the mature crop is not very great, the total K content at the stage of maximum vegetative development may be three or four times as high and, further, this amount of K is taken up over quite a short period; the rate at which K is available to the crop is as important as the total amount which the soil can make available. On low K soils, more potassium should be applied than just the quantity required to replace removals in order to ensure an adequate supply at the critical period.

The three most important cereals on a world scale are wheat, rice, and maize. In the temperate zone barley (for malting and as a stock feed) is also important; oats and rye are not so widely grown. In the tropics and subtropics, and particularly in more arid parts of the world, millet *(Pennisetum)* and *Sorghum* are also important and there are a number of minor grain crops. There is no need to go into recommendations for all these crops because the needs of the group as a whole are similar.

6.1 Wheat

World production has increased by 40% over the past 10 or 11 years though the area planted has remained much the same. Yields per hectare have doubled in temperate developed countries (in the United Kingdom for instance, from about 4 to around 8 t/ha nowadays). The main contribution to the increase in yield has been made by the plant breeders but, without better disease control and, above all, without proper fertilizer use the new improved varieties could not have fully expressed their potential. Overall average yields are still well below those obtained by the best farmers and on research stations and even the latter are still well below the theoretical maximum yields. Obviously, when yields are doubled, the character of a crop changes, its nutrient requirements double also; whereas small "token" potash dressings used to be sufficient, now the potash need is high.

From the fertilizer point of view, the key to high wheat yield is nitrogen and total dressings of 200 kg/ha or more are now used. It is essential that these high N dressings be supported by adequate levels of K (and P). There are two reasons for this: (1) the larger crops remove more K from the soil, (2) nitrogen and potassium interact – if K is too low, nitrogen cannot be efficiently used by the plant. Point 1 is illustrated by results of Indian experiments illustrated in Figure 17 showing both the effect of potash on wheat yield and on soil K status.

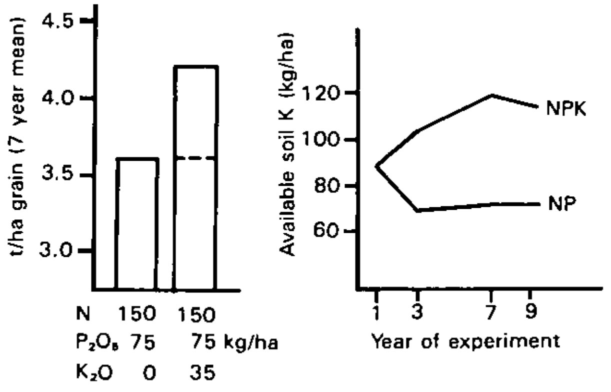

Figure 17. Long-term effects of K on wheat yield and soil K status at Ludhiana *(Ghosh [1979])*

The second point is illustrated in results from a series of 26 French experiments where the response to extra nitrogen (150 vs. 90 kg/ha N) increased regularly as the K application increased (Table 12). Though the average response to K was only small (0.3 t/ha between extremes), applying K greatly increased the efficiency of N fertilizer.

Maintenance K dressings depend on what happens to the straw, and, should be per t. grain yield about 5.5 kg/ha K_2O when straw is ploughed in or burned and 18 kg/ha when straw is removed.

The following general recommendation for improved wheats is suggested as a starting point: N: 100–150 kg/ha, P_2O_5: 40 kg/ha, K_2O: 40 kg/ha. Unimproved traditional types cannot make use of so much nitrogen. P and K should be applied during seedbed preparation, N as a top dressing. On low K soils (particularly on K fixing soils), it is recommended to apply the P and K by combine drill. For spring sown crops it is convenient to use a compound fertilizer (2:1:1 $N:P_2O_5:K_2O$) which can be applied in the final preparation of the seedbed or by combine drill at sowing.

Table 12. Nitrogen × potassium interaction in wheat (t/ha grain) *(Loué [1978b]*

	kg/ha K_2O			
	0	50	100	150
Mean	5.21	5.37	5.47	5.51
Response to N (150–90 kg/ha N)	0.48	0.59	0.72	0.80

6.2 Rice

Many traditional wet rice soils are comparatively well supplied with K; the water used for irrigation contains some K though surplus water running off carries away some K. It may not be surprising then that in traditional systems using low yielding varieties large responses to K fertilizer are rare. However high yielding varieties are now available and economic and other reasons have resulted in a change of attitude to the growing of this crop. Potash, once a "poor relation" has become important because higher yields now possible, the intensification achieved through multiple cropping and more generous use of N fertilizer put a strain on soil potash supplies. Long term trials by IRRI in the Philippines showed that in continuous rice growing the crop responded only to N in the first year but, as time went on and much P and K were removed from the soil by the nitrogen-stimulated crops, responses to P and K fertilizers increased until, after several years they were very large (Fig. 14, p. 39). N alone doubled yield in the first year but was not effective thereafter. In the ninth year, yield from complete fertilizer was still good and the effect of potash (with N and P) had increased from 300 kg in the first year to nearly 1.4 t/ha.

The Chinese have experience of this problem. Fertilizer experiments on farmers' fields have shown a remarkable change over the period 1958 to 1982. In 1958, 29% of 62 experiments showed response to K; in 1982, 63% of 260 experiments did so. Each kg N used in 1958 produced 16.5 kg grain; in 1982, the comparable figure was only 10.1 *(Lin Bao [1984])*. Over the years farmers had used N without replacing the potassium removed by the heavier crops grown, consequently, soil K supply became limiting. The extent of the N×K interactions recorded in 1982 experiments is shown in Table 13. Raising the N level under potassium deficient conditions in Zhejiang reduced yield but when K was also applied there was a large yield increase.

Table 13. Effect of K on rice yield at different N levels (t/ha grain) *(Lin Bao [1984])*

Province	kg/ha N	kg/ha K_2O applied			Effect of K
		0	56	112	
Guangdong	30	4.07	4.69	4.67	0.60
	60	4.48	5.20	5.20	0.72
	90	4.55	5.24	5.45	0.90
Zhejiang	60	3.37	4.83	5.23	1.86
	120	3.02	4.83	5.60	2.58

The Chinese suggest that when soil K is deficient rice should receive 150 kg/ha K_2O and that maintenance dressings should be 20 kg K_2O per tonne of padi when yield is above 3 t/ha.

Indian work to correlate crop response with soil test results has resulted in the recommendations for different soil types illustrated in Figure 18 which relate to a target yield of 6 t/ha. For instance, when the soil test shows 10 mg K/100 g soil, the recommendation at Pantnagar would be for no K while at the same indicated soil K level at Coimbatore it would be for 160 kg/ha K_2O. At 20 mg K/100 g the recommendation would be nil at New Delhi but still as much as 130 kg/ha at Coimbatore. It appears that the soils of Coimbatore and Aduthurai fix K while the others do not.

In Sri Lanka K recommendations are:

Acrisols (red-yellow podsolic soils, ultisols)	60 kg/ha K_2O
Luvisols (alluvial soils and lessives)	80 kg/ha K_2O

General suggestions for fertilizer treatment at different yield levels quoted from the IPI Bulletin on rice fertilization are given in Table 14.

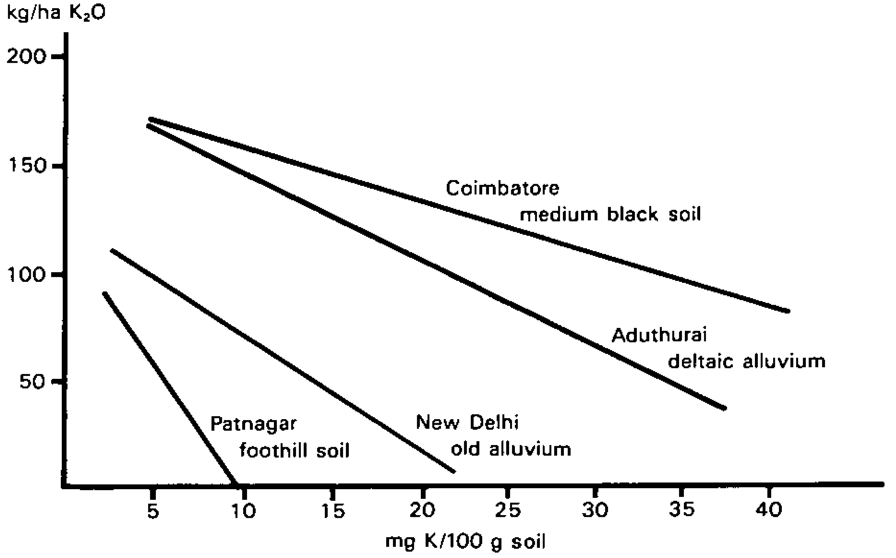

Figure 18. Potash recommendations for rice at 4 places in India for a target yield of 6 t/ha *(Randhawa et al. [1982])*

Table 14. Suggested fertilizer schedules for rice *(von Uexküll [1979])*

Season	Expected yield (t/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Dry	4	50– 80	30– 50	30– 50
	6	100–140	60– 75	60–120
	8	130–180	90–120	100–150
Wet	4	30– 50	30– 50	30– 50
	6	75– 90	60– 75	75–100

When rice is transplanted, fertilization of the nursery bed is most important. Plants given a good start in the nursery will grow away faster after transplanting and in this connection potash is important in guaranteeing robust seedlings resistant to transplanting shock.

6.3 Maize

Characteristic of warmer areas, this crop has been pushed further north by advances in plant breeding; where the summer is too short to produce good grain yields, it is a useful silage crop.

As might be expected from the varied climatic conditions under which it is grown and the associated differences in potential yield, fertilizer recommendations show a good deal of variation. In the U.K. for instance, the crop has been found not very responsive to P and K, and the recommendation is for 40–75 kg/ha P_2O_5 and K_2O with 40–60 kg/ha N. In West Germany and France, up to 200 kg/ha P_2O_5 and 280 kg/ha K_2O are recommended with N at up to 240 kg/ha.

As a forage crop, maize removes much K from the soil and though the crop itself may not always be very responsive to K, and the K recommendation therefore quite modest, additional potash should be applied, preferably to other crops in the rotation, to make up the deficit (about 150 kg/ha K_2O for a crop of 12 t/ha dry matter).

The extent of K removal by this crop is indicated by data from American work *(Stangel [1965])* with high yielding (11–15 t/ha grain) crops: 226–259 kg/ha N, 41–63 kg/ha P_2O_5 and 265–374 kg/ha K_2O, the last figure when extra potash was applied. Even when grown for grain, with crop residues returned to the field, the latest hybrid varieties yielding over 20 t/ha grain need to take up potassium at a very high rate to a high total amount around the period of maximum growth. Hence the high K recommendations cited above.

Response to potassium has been recorded at quite low yields in the tropics. In an early rotation experiment in N. Nigeria *(Singh et al. [1983])* mean yields were 2.0 t/ha without potash against 2.9 when potash was given to all crops of the rotation. With continuous maize in S. Nigeria (Table 15) though there was considerable year to year variation in yield and in response to K, it was clear after 3 years that without K fertilizer soil K had declined to levels insufficient to support even a low yield of maize. It seems that somewhere between 45 and 90 kg/ha/year K_2O would be sufficient to maintain soil K. Soil Ca and Mg also declined, the more so when K was applied, indicating that dolomitic lime to supply both would be useful.

As with other crops, potassium becomes more important the higher the yield and the more nitrogen fertilizer is applied. The nitrogen-potassium interaction is illustrated by the results in Table 16 from Wisconsin (USA) and by Figure 19 summarizing results of French experiments in which there was little or no response to K at 33 kg/ha N, and a large response to K at 99 kg/ha N.

Table 15. Grain yields (t/ha) from continuous maize in S. Nigeria *(Osiname et al. [1986])*

kg/ha/year K_2O	Year 1	2	3	4	5	6
0	2.4	1.7	3.8	2.2	1.8	0.6
45	2.7	1.8	3.7	3.3	2.5	2.0
90	3.2	2.0	3.7	3.4	2.7	2.2
135	3.3	2.1	3.2	3.8	2.5	2.3

Table 16. Potash improves the effect of N on grain yield (t/ha) *(Stangel [1965])*

kg/ha N	kg/ha K_2O 0	145
0	2.91	3.25
176	6.14	8.15
Difference	3.23	4.92

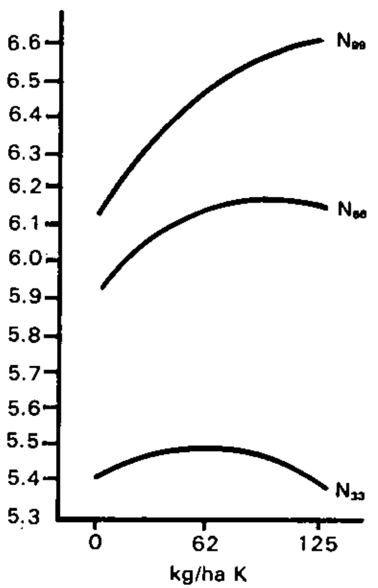

Figure 19. N×K interaction in maize yield in French experiments (mean of 9 crops). Little or no response to K at 33 kg/ha N, large response to K at 99 kg/ha N *(Loué [1978b])*

Potassium can reduce the incidence of stem rots *(Fusarium culmorum* and *F. monoliforme)*, which is encouraged by high rates of N and causes lodging as demonstrated on a strongly K-fixing soil in Bavaria (Table 17). The rates applied were much higher than would be recommended on a normal non-fixing soil, much of the K applied being used to satisfy fixation capacity.

Table 17. Effect of increasing rate of K on stem rot incidence and grain yield (t/ha). Mean of 3 sites *(Siebold [1974])*

kg/ha K_2O	grain (t/ha)	stem rot (%)
0	4.48	35
300	6.91	19
600	8.73	8

These few examples demonstrate the effects of potassium under very widely differing climatic conditions and at differing levels of potential yield. Even when yields are rather low, as in reports from West Africa, the effects are considerable; at higher yields they are greater. With suitable climate, improved varieties and high standard cultivation, high yields are possible and generous fertilizer treatment will be repaid.

6.4 Sorghum and millet

These two crops are of considerable importance in drier tropical and subtropical regions and are increasingly grown outside the tropics. Their behaviour in response to fertilizers is similar to that of other cereal crops provided other cultural conditions (e.g. water availability) are not severely limiting, though, under arid conditions without irrigation, fertilizers can be very effective, increasing yield in the example of Figure 20 from a paltry 0.8 without fertilizer to a respectable 2.3 t/ha with NPK.

The yield stabilizing effect of potash when rainfall is uncertain is shown in some results from Senegal (Table 18). The table shows mean yields achieved at various rates of K applied along with 45 kg/ha P_2O_5 and a total of 60 to 90 kg/ha N together with the standard deviation of yield, which indicates the degree to which yield varied from year to year. Potash improved average yield by about 1/4 t/ha, but, just as important, reduced the year to year variation in yield i.e. it ameliorated the effects of poor seasons.

Table 18. Effect of potassium fertilizer on millet yield (t/ha grain) and yield stability. Mean over years 1973–1977 *(Pieri [1982])*

	Mm useful rain	No fertilizer	kg/ha K_2O with uniform NP 0	30	60	90
Mean	462	1.28	2.25	2.49	2.51	2.51
Standard deviation	84	265	261	188	118	67

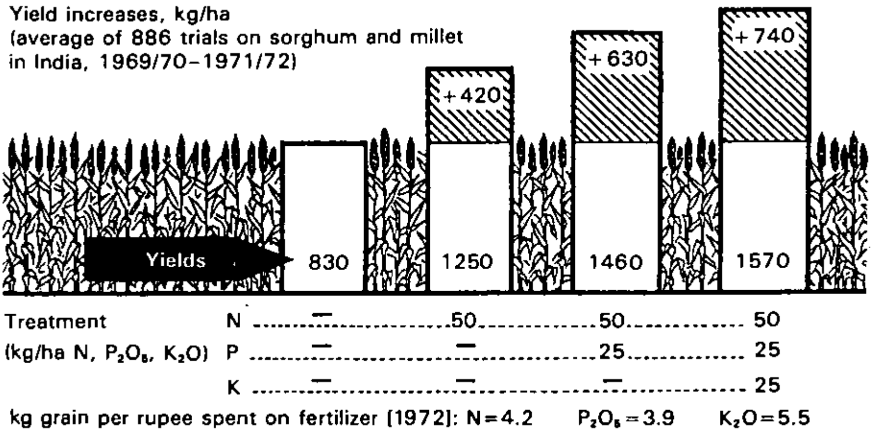

Figure 20. Yield doubled in semi-arid region *(Mahapatra et al. [1973])*

6.5 Cereals - general conclusions

It is not possible to discuss the fertilizer requirements of all the cereal crops in detail and, in the above, some selected points have been treated under the different crops. The same general principles apply for the whole group:

- High yields many times those obtained in traditional farming are possible with the modern varieties grown under favourable conditions including adequate water supply, high standard cultivation (tillage, weed and pest control).
- For long regarded as having only very modest potassium requirements, the modern varieties grown under intensive conditions are a different proposition; their K requirements, certainly in the longer term are more akin to those of the high K-demanding root crops.
- The potential of the new varieties will only be realised through generous use of N. Unless sufficient K (and P) is also used the crop cannot respond fully to N and, in the long term, yields will surely decline and the money spent on nitrogen is wasted.
- The amount of potash fertilizer needed to maintain soil K supplies depends very much on how the straw is used. If it is burned in the field or ploughed in, the K removal is not very great - about 5 or 6 kg for each tonne of grain. If the straw is removed from the field, the K removal is at least three times as high.
- Potassium acts against the tendency of N to produce "soft" growth and, as a result confers resistance to lodging (weak straw, root and stem rots), resistance to disease and pests and ability to recover from attacks.
- Potassium is a yield stabiliser. Where weather varies greatly from year to year crops well fertilized with K are less likely to be reduced in bad seasons.

7. Root crops

All root crops require much potassium, whether the essential crop product is stored as starch (potato, cassava, yam etc.) or sugar (beet). Reasons are that K is important in carbohydrate synthesis and storage, and that many of these crops have poorly developed root systems, so they are not good potash foragers. Important temperate crops are potatoes and sugar beet; in the tropics, cassava which is the main staple food over much of Africa, sweet potato and yam, and some lesser crops such as cocoyam *(Colocasia)* in the moist tropics.

7.1 Potatoes

Because they are so responsive to potassium potatoes have been used as a test crop to calibrate the relationship between soil K status and yield (or response to applied K). Consequently, much is known about the effects of K fertilizer.

Table 19, summarizing general recommendations from various countries demonstrates the impossibility of arriving at a general recommendation.

Table 19. Examples of fertilizer recommendations for potatoes from several countries *(Perrenoud [1983])*

Country	N	kg/ha P_2O_5	K_2O
West Germany	80–200	120–150	200–320
France	30–180	80–180	120–240
India (Himachal Pradesh)	75–100	75–125	80–125
USA (Massachussets)	180–200	145–300	145–300
Zimbabwe	0–160	0–310	0–130
United Kingdom:			
- maincrop	0–220	100–350	100–350
- early/seed/canning	0–180	200–350	60–250

Within these generalisations, there are great variations according to soil types, nutrient status and purpose for which the crop is grown (table, starch, seed etc.).

As would be expected, in a crop so responsive to potassium, there is often a large N×K interaction as exemplified in Figure 21 showing results from a series of 17 crops in France.

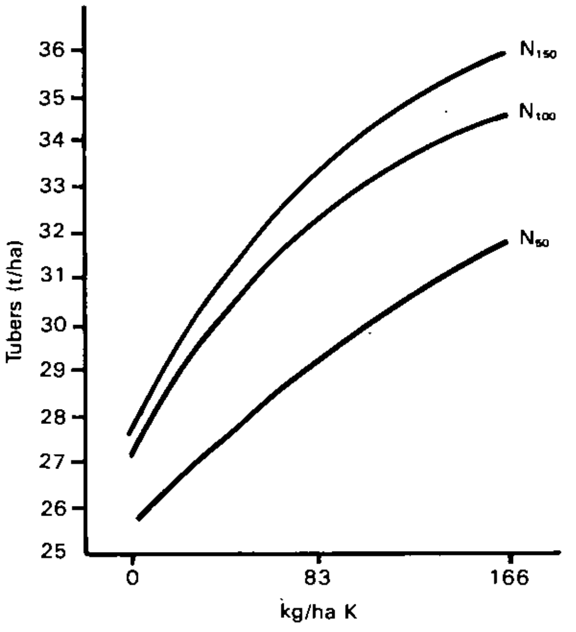

Figure 21. N×K interaction in potato in French experiments (mean of 17 crops) *(Loué [1978b])*

Method of application

Until recently it was usually recommended to apply fertilizers by placement near the seed, either by placement planter or by broadcasting over the open ridges immediately before planting. This resulted in some economy of fertilizer, particularly on soils low in P and K. The normal method now is to broadcast on the flat before planting using a compound fertilizer of the appropriate N:P:K ratio, or, when high rates are used, to apply all or part of the P and K in the autumn. This minimises scorch damage to emerging sprouts. A response to high levels of K, benefit of autumn or split application (less seedbed scorch) and reduction of internal blackspot is shown in Table 20.

In so-called "blueprint" trials where all inputs have been maximised in the quest for maximum possible yields, very heavy rates of fertilizers have been used (e.g. 250, 500 and 400 kg/ha N, P_2O_5 and K_2O) in the production of yields of 90–100 t/ha, applying part of the P and K in the autumn with the rest to the seedbed and half the N at planting with half after sprout emergence. This splitting of the dressing ensures good distribution of P and K through the whole rooting depth.

Table 20. Ware tubers (t/ha) and (in parentheses) % internal blackspot. Mean of 3 years *(Palmer et al. [1982])*

	kg/ha K_2O applied as chloride			
	0	200	400	600
Autumn	25.0 (33.2)	31.0 (20.4)	33.2 (15.1)	34.8 (12.1)
6–8 weeks pre-planting	24.5 (33.5)	31.8 (22.5)	33.5 (19.6)	34.5 (13.9)
Planting	23.4 (31.0)	29.7 (28.4)	30.4 (27.3)	31.5 (24.2)
Split*	23.1 (31.7)	31.2 (23.6)	34.3 (16.0)	35.6 (11.3)

* 100 kg/ha at planting, remainder in autumn.

Quality

Important quality criteria are:

- Tuber size. Relevant for table potatoes, crisp manufacture and seed crops.
- Dry matter and starch contents. Particularly important for industrial (dehydration, alcohol) potatoes.
- Internal blackening (blue spot) as a result of mechanical damage.

The effect of potassium in increasing yield may be accompanied by undesirable effects on quality, the increase being largely through increase in size (and water content) of tubers. High water content is to be avoided in industrial potatoes. If the crop is intended for seed, the aim is for the maximum proportion of small to medium tubers; even for the table there is some prejudice against very large tubers. On the other hand, high moisture content tubers are more resistant to internal blackening. The farmer has to strike a balance and adjust the fertilizer programme according to the needs of the market.

Type of potash

The effects on quality are greatly affected by the form of potash. The tendency to lower dry matter (and starch) content is reduced when sulphate is used and, when such crops are grown on contract to the factory it is often specified that sulphate of potash should be used.

Chloride is more effective in reducing internal blackening (higher water content of tubers).

It is advantageous to use sulphate for seed crops, where the object is to produce a maximum proportion of small to medium sized tubers.

When fertilizer is placed, there is, at least where quite high rates are used, less danger from chitting scorch if sulphate is substituted for muriate.

Some examples of the effects discussed above, from various sources are illustrated in Figure 22.

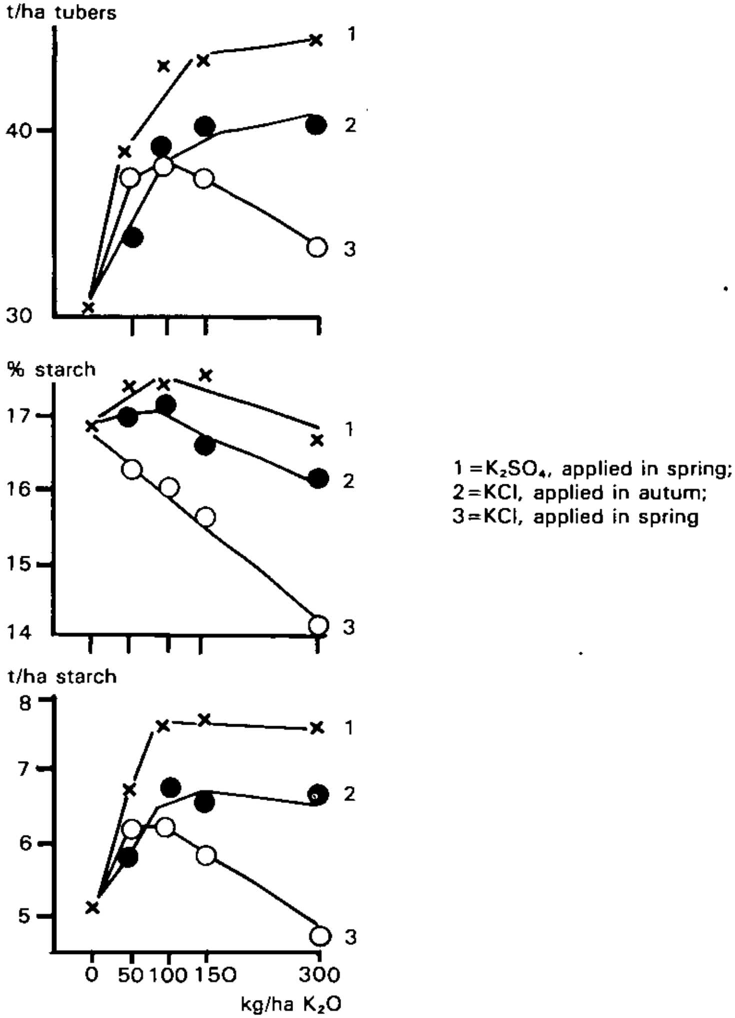

Figure 22. Effect of increasing rates and form of K applied at different times on tuber yield, starch content and starch yield *(Prummel [1981])*

7.2 Sugar beet

Beet is a maritime plant and naturally responsive to both potassium (K) and sodium (Na); both are important. The functions of these two nutrients have probably been confused because on the European continent the crop has normally been treated with low grade potash fertilizer which contains large amounts of sodium and responses which were ascribed to "potash" may often have been responses to sodium.

The grower should aim for the maximum yield of refined sugar; this does not necessarily correspond with the maximum yield of roots. Nitrogen increases top growth and root yield, but at the expense of a lowering in beet "quality", high N reducing sugar content and the content of impurities which hinder extraction of sugar. Potassium tends to counter these undesirable effects, but too high rates should be avoided as they increase the K content of the juice which also reduces extraction as does high Na content.

Sodium should always be given except on peats and marine silts high in available Na. If lower grade potash fertilizers are habitually used (kainite, sylvinite or 40% muriate), sufficient Na will automatically be applied. If such materials are not to hand, common salt should be applied. In the UK where potash is normally applied as compound fertilizer free from salt the general recommendation is to apply 150 kg/ha Na_2O as salt with 75 to 200 kg/ha K_2O according to soil K level and 50–100 kg/ha P_2O_5. Recommended rates of N vary between nil and 140 kg/ha N according to soil type and cropping history. If salt is not available the K rates should be increased by 100 kg/ha K_2O.

Treatment of crop residues greatly affects K requirement. If the tops are carted off for stock feed, K removal is increased by some 200 kg/ha K_2O or more which should be made up from extra potash fertilizer either to the beet or elsewhere in the rotation.

Recommendations in other European countries are very similar to the above if allowance is made for the fact that sodium often receives no special attention owing to the wide use of lower grade sources of potash.

The precise forecasting of fertilizer requirements is very difficult, root yield and quality being very much affected by seasonal conditions. This is demonstrated in Table 21. Yields, and consequently nutrient removals were appreciably lower in 1983 than in 1982, but whereas in 1982 180 kg/ha K_2O was enough, in 1983 there was response in both root and sugar yield to as much as 500 kg/ha.

Removals of N, P_2O_5, K_2O and MgO by the harvested beet crop are given in Table 22.

Table 21. Illustration of variability in yield, yield response to K and P and K removal *(Beringer [1987])*

	1982			1983		
	K_0	K_{180}	K_{500}	K_0	K_{180}	K_{500}
Root d. m. (t/ha)	14.4	15.9	15.5	12.0	12.9	13.4
Leaf d. m. (t/ha)	42	42	40	37	36	39
Extractable sugar (t/ha)	9.6	10.5	10.2	8.3	8.8	9.3
	Nutrients in root + leaf at harvest (kg/ha)					
K		255–311			199–254	
N		191–200			171–173	
P		29– 35			23– 24	

Table 22. Nutrient removal by sugar beet (kg/10 t roots) *(Beringer [1987])*

	With leaves	Without leaves
N	40– 55	15–22
P_2O_5	15– 20	8–10
K_2O	60–100	25–50
MgO	10– 20	5–10

7.3 Cassava

This is a most important food crop – the main staple food of much of Africa and growing in importance elsewhere – it is also grown as a cash crop, for starch manufacture and an ingredient of animal feeds. Traditionally, cassava is grown as the last crop before allowing the land to revert to bush and is reputed to tolerate low fertility. But it can benefit from high fertility and, like all root crops, it is very responsive to fertilizers and in particular to potash. Average yields on peasant holdings are only in the range 5–15 t/ha, but improved varieties can yield up to 60 t/ha at which level it takes pride of place among all crops as a producer of starch. Such yields are not achievable if the crop is confined to run-down soils and it merits more attention than it has received up to now from the fertilizer point of view.

The general yield level has been low (only around 10–20 t/ha fresh tubers) in most field experiments and responses to potash only moderate, of the order of 3–4 t/ha with optimum potash rates around 60 kg/ha K_2O. At CIAT in Colombia where a comprehensive research programme on the crop is in progress, yields have been around 30–40 t/ha and responses to potash much larger with higher optimum rates of K_2O.

The low yields in some of the work may be because the crop was grown in the traditional way, at the end of the rotation when general soil fertility is at a low level. In this connection some results reported from CIAT (Fig. 23) are striking. Cassava was grown on adjacent areas for 5 years following clearing, one area moderately generously treated with fertilizers and lime, the other without. In the 5th year yields averaged 37 t/ha on the well treated area but only 9 t on the starved land. In the 6th year, after liming, response to K fertilizer was tested. The previously well treated area yielded well above the other at all levels of K, though even here there was a profit from fresh K, demonstrating the importance of maintaining the soil K level (best yield on higher fertility plots 10 t/ha). Obviously it is worthwhile to treat this crop more generously than is customary; more work with maximum inputs would be well justified.

Cassava was also found to respond to S (Fig. 24 comparing sulphate and muriate). Phosphate is also important and at Carimagua the crop responded to K only when P was also applied.

Reputedly, nitrogen is credited with encouraging leafy growth at the expense of the root. CIAT found that the crop did not respond in root yield to N unless K was also applied *(Howeler et al. [1980])*. K alone at 120 kg/ha K gave a response of a little over 5 t/ha (doubling the K further increased yield a little). There was no response to 100 kg/ha N in the absence of K but it increased yield by 5 t/ha in the presence of 120 kg/ha K.

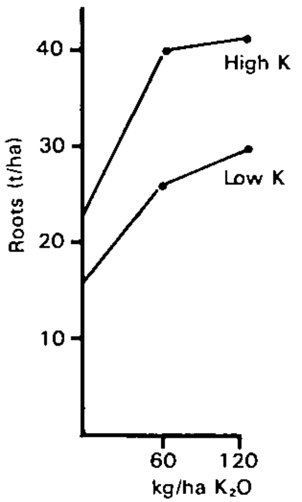

Figure 23. Response of cassava to applied potash on low and high fertility soils *(CIAT [1984])*

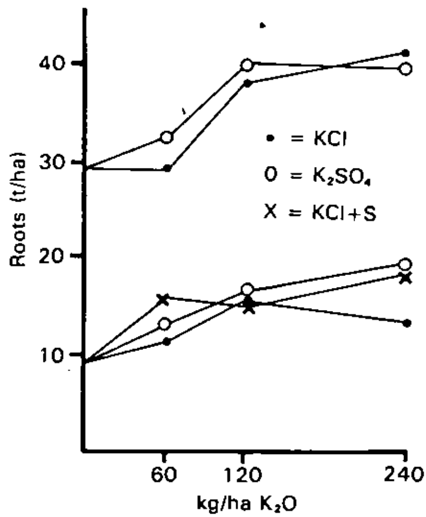

Figure 24. Response of cassava to potassium at two sites and response to S *(Howeler et al. [1980])*

In a factorial trial in India with 4 rates of each potassium and nitrogen, it was shown that the optimum rates of fertilizer were 50 kg/ha N plus 240 kg/ha K (N was applied in the experiment at rates up to 150 kg/ha). At this level of N, the N×K interactions were as listed in Table 23.

Results from IITA Ibadan, Nigeria (Table 24) are interesting in demonstrating two things: decline in soil K status under continuous cropping without restitution of K removed in crop (response to K increasing with time and a higher K fertilizer need in the third year than in years 1 and 2) and the limitation of K response by lack of magnesium. The soil was initially low in K (0.13 meq/100 g) at the start of the experiment. After the 3rd crop it had declined on plots receiving no K to 0.05 meq/100 g and even the highest rate of K applied failed to maintain the soil K level.

There are reports of potassium enhancing resistance to bacterial blight *(Adeniji et al. [1976])* and to Cercospora *(Muthuswamy et al. [1979])*.

Table 23. Increase in yield of cassava (t/ha fresh tubers) due to applying 50 kg/ha N *(Muthuswamy et al. [1979])*

K applied (kg/ha)	Increase from 50 kg/ha N
0	3.6
80	10.7
160	6.4
240	14.2

Table 24. Response of cassava to K fertilizer with and without Mg. Mean of 2 varieties *(Kang [1984])*

kg/ha		T/ha fresh tubers Year 1	Year 2	Year 3
K	Mg			
0	40	14.7	15.4	14.3
30	40	14.0	19.0	15.5
60	40	15.8	19.1	17.5
120	40	12.7	19.6	18.9
120	0	13.8	19.4	16.3

Small farmer trials

Table 25 with results from 2203 farmer trials in E. Nigeria, shows what can be achieved with modest fertilizer inputs. The comparison was between traditional practice and an improved "package" (with improved varieties, plant protection and fertilizers). Good responses should be obtained from fertilizer dressings similar to those of Table 25. It would seem unwise to increase the N dressing above 100 kg/ha but more phosphate, say 100 kg/ha P_2O_5, could well be justified. Higher rates of K may be advisable when yields of 30 t/ha or more can be obtained. It is likely that sulphur in the form of single superphosphate, sulphate of potash or ground elemental sulphur will be beneficial on many soils *(Howeler [1985])*.

Table 25. Yields and returns from cassava intercropped with maize in demonstrations on farms *(Ezeilo [1977])*

	Traditional	Improved
Maize:		
- yield (t/ha)	0.36	2.44
- cash (Naira/ha)	47	317
Cassava:		
- yield (t/ha)	4.8	14.2
- cash (Naira/ha)	192	569
Fertilizer* cost (Naira/ha)	-	16

* 60 kg/ha each N, P_2O_5 and K_2O

7.4 Sweet potato

This is another root crop typically responsive to potash, not surprising when it is known that total uptake by a 40 ton crop amounts to some 350 kg/ha K_2O. The example shown in Table 26 from Taiwan is interesting in showing response at various yield levels. In the first example yield was restricted by frost damage; in the third, high yields (and higher responses to K) were possible owing to the availability of irrigation.

Table 26. Response (t/ha fresh roots) of sweet potato to potassium in Taiwan *(Ho [1965])*

	kg/ha K_2O applied				
Experiment*	0	60	120	180	240
1.	14.9	16.3	18.0	17.2	
2.	25.5	26.9	29.8	29.5	27.6
3.	36.3	41.3	43.0	44.5	43.4

* N and P_2O_5 applied at 60 and 50 kg/ha resp. N and K applied half at planting and half one month later.

Sweet potato is sometimes grown for the foliage to feed livestock, the leaves being harvested during growth. This greatly increases K removal by the crop and K fertilizer must then be increased to replace the removals.

A summary of the kind of responses to potassium which have been obtained at various centres is given in Table 27.

Table 27. Effect of K fertilizer on sweet potato on K deficient lateritic soils *(Juo [1986])*

Country	kg/ha K	t/ha tubers	Country	kg/ha K	t/ha tubers
Indonesia	0	14	Tanzania	0	28
	90	22		60	37
India	0	12	USA, N. Carolina	0	19
	90	23		76	30
Hunan, China	0	23			
	76	33			

7.5 Yam *(Dioscorea* spp.)

In quantitative terms less important than cassava, this is nevertheless an important crop wherever it is grown because it is a superior food and commands a relatively high price. Much care is taken in its cultivation which resembles gardening rather than farming. It is usually grown widely spaced on hills or large ridges constructed by drawing together topsoil from the surrounding area and interplanted with short term crops like cowpea and cassava which will take over when the yams have been harvested. So it is more sensible to talk of fertilizer rates in terms of kg per hill or per stand since it would obviously be uneconomic to scatter fertilizer over the whole area, though in the following FAO trial results (Table 28) rates are given as kg/ha.

Table 28. FAO fertilizer trials on farmers' fields - Nigeria *(FAO [1982])*

	Number	t/ha no fertilizer	Best fertilizer treatment (kg/ha) N	P_2O_5	K_2O	t/ha best treatment
Kwara State						
Sole crop						
Trials	79	9.66	38	38	38	14.35
Demonstrations	398	5.00	38	38	38	9.93
Plateau State						
Intercropped maize						
Demonstrations	34	11.64	81	38	60	14.34

Data from an experiment in Taiwan with *D. alata* (Table 29) indicate that the crop is most responsive to potassium; the yield increase from the second 50 kg potash applied was large and it is probable that the optimum rate would be above 100 kg/ha K_2O.

Clearly, the behaviour of yam in response to fertilizer is similar to that of other root crops and the nutrient ratio of the fertilizer ($N:P_2O_5:K_2O$) should be 1:1:1:5. When the crop is planted in the traditional manner (on widely spaced hills) appropriate rates of fertilizer to be applied *per hill* would be about 180 g N, 180 g P_2O_5 and 270 g K_2O or alternatively 1.4-1.8 kg of a 13:13:20 compound fertilizer per hill mixed in during hill forming. It is convenient to devise a volumetric measure to give the appropriate weight - accurate application is then easy.

Table 29. Response by yam *(D. alata)* to N, P and K in Taiwan *(Shyn et al. [1978])*

Fertilizer applied (kg/ha)			
N	P_2O_5	K_2O	Yield (t/ha)
50	0	0	6.12
50	50	0	6.80
50	50	50	8.24
50	50	100	9.98

7.6 Minor root crops

Few data are available on the fertilizer treatment of the less important tropical root crops such as cocoyam, taro or edda but it can be suggested with some confidence that they would respond in a similar manner to cassava or yam and that similar rates of fertilizers should be used.

8. Legumes

This group has a dual importance: as a provider of high-protein food and in fixing atmospheric nitrogen which may benefit the succeeding crop. Important leguminous crops in the temperate zone are peas and beans grown either for grain or as vegetables for sale fresh or for processing; in the warmer areas soya (the most important legume on a world scale); in the sub-tropics and tropics, again soya, groundnut (here treated as an oilseed (chapter 9)), pigeon pea, beans, cowpeas and various small grained crops such as lentils, chickpeas or grams which are important sources of protein in the diet. They are also grown for fodder either as arable break-crops or mixed with grasses for both cut fodder and grazing (see chapter 12).

Potassium is very important for legumes; they generally respond well to K fertilizer which benefits the N-fixing root nodules.

8.1 Peas and beans in the temperate zone

Dry beans (horsebeans) though a useful crop in the rotation especially on heavy land are less widely grown than formerly. Peas are grown for both drying and freezing (vining peas). For peas, placement of P and K fertilizer (not combine-drilling when there may be severe scorch) is widely advocated and the rate of potash recommended for placement is actually higher than that for broadcasting. If K is combine drilled, the rate should not exceed 50 kg/ha K_2O (less if widely spaced) and if more is required on low K soils, the balance should be broadcast. The rate recommended for placement is from 50 to 150 kg/ha K_2O (medium to low K soil). The recommendation for field beans is somewhat more conservative (about 20% less).

8.2 Soya

It has been shown that nitrogen fertilizer can adversely affect nodulation and *Rhizobium* activity and so reduce yield. However, in many places it is advisable to apply some N as a "starter" (15–20 kg/ha N) because symbiotic fixation begins to supply the plant only from about 40 days after sowing.

The best means of ensuring N supply to the crop is to inoculate the seed with a good strain of *Rhizobium*, to see that the soil is well aerated to encourage root development and to back up the natural N fixing process with good supplies of P and K. In all climates, soya has proved to be responsive to K. The quantity needed is large and has to be taken up over a short period.

Recommended potash dressings vary according to soil K content. In the absence of definite information on soil K status, the standard recommendations are for regular application of 70–150 kg/ha K_2O according as to whether the soil is thought to be high or low in K and according to expected yield.

Normally, muriate of potash is used, applied during seedbed preparation but sulphur deficiency is becoming more widespread and it is possible that a preference for sulphate of potash will develop. Sulphate should also be the choice if the soil is saline. Sulphur fertilizers are important especially on soils low in organic matter in the tropics and sub-tropics; responses to applied S as high as 37% have been obtained (Table 30).

Table 30. Effect of sulphur application on yield of soya at 3 localities in Brazil (soils low in organic matter) *(Mascarenhas et al. [1967])*

	kg/ha grain Sites		
S applied (kg/ha)	1	2	3
0	710	1955	1955
30	870	1905	2018
60	1060	2030	2205

If soil pH is below 5 there is no nodulation so it is important to maintain the lime status. This is also important in the elimination of P fixation by iron and aluminium in heavily leached acid tropical soils.

While phosphate can be placed close to the seed without causing trouble, the same does not apply to potassium chloride which adversely affects the young plants. For this reason some experiments on soils where a positive response would have been expected have failed to respond. It is best to apply potash before cultivation so that the material is incorporated into the whole plough layer. Some examples of fertilizer response are given in Tables 31–33.

Lin Bao et al. [1984], in 41 field experiments in different parts of China, found that application of 81 kg/ha K_2O gave an average yield response of 283 kg/ha grain. In Guangdong Province, *Zhu Wei-he et al. [1981]* reported a 31% response from applying 47 kg/ha K_2O in 3 experiments on rice soils.

Table 31. Response to applied potassium at Muscle Shoals, USA. Soil medium-low in K *(Terman [1977])*

	kg/ha grain		
Variety	Yield no K	Response to 90 kg/ha K_2O	Response to 180 kg/ha K_2O
Dare	3250	720	1540
Lee	2250	680	940
Bragg	2430	640	970

Table 32. Response to potassium on Norfolk sandy loam soil low in K (USA) *(Terman [1977])*

kg/ha K_2O	Yield (kg/ha)	Response (kg grain/kg K_2O)
0	500	
45	2100	36
90	2900	27
135	3200	20

Table 33. Effect of inoculation, P and K fertilizers without irrigation in Senegal *(IRAT [1981])*

N	P_2O_5	K_2O	Grain (kg/ha)
0	0	0	1220
Inoculated	0	200	1640
Inoculated	100	0	1854
Inoculated	100	200	1994
200	100	200	1916

Quality

An example of K effects on yield and grain quality is in Table 34.

Seed quality (germination potential) is affected by fertilizer treatment of the seed crop. Table 35 shows the effects of P, K and their interaction on percentage germination.

Table 34. Effect of P and K on yield and grain quality. Piedmont, Virginia, USA. Mean yields (kg/ha) over 5 years on 2 experiments *(Camper et al. [1978])*

		Experiment 1		Experiment 2	
P_2O_5	K_2O	Yield	Q*	Yield	Q
0	0	1290	5.0	1370	3.9
134	0	1458	5.0	2237	1.1
134	33	2284	3.9	2681	1.2
134	67	2493	2.4	2701	1.0
134	134	2755	1.0	2721	1.0

* Grain quality index, 1 = good–5 = poor

Table 35. Germination as affected by P and K fertilization of seed crop, Virginia, USA. Mean of 16 replications *(Camper et al. [1978])*

kg/ha P_2O_5	K_2O	Germination (%)
0	0	62
134	0	70
0	134	85
134	134	95

Disease

K can decrease the incidence of fungal disease and so improve yield. An example is to be seen in the American results quoted in Table 36.

Table 36. Effects of P and K on resistance to stem and pod rust and *Cercospora*. Mean of two years *(Camper et al. [1978])*

kg/ha*		Rust	*Cercospora*	kg/ha
P_2O_5	K_2O	(%)	(%)	grain
0	0	12.0	13.9	1552
450	0	7.9	11.1	1760
0	450	1.0	5.2	2412
450	450	0.7	4.5	2607

* Applied once, 2 years before starting the experiment

As a general recommendation where there is little experience of fertilizing soyabean, we may give the following:

N: 0–30, P_2O_5: 50–100, K_2O: 50–150 kg/ha

the higher rates of P and K are applicable where soils are known to be low in these nutrients and where high yields are obtained.

8.3 Tropical grain legumes

Though it is generally accepted that the leguminous crops as a whole are responsive to potassium, it is surprising that they appear to have received little attention in field experiments and published data on fertilizer response is scattered and fragmentary. In field investigations of soil fertility covering a variety of soils in East Africa it was found *(Anderson [1973])* that Phaseolus beans gave responses of from 110 to 370 kg/ha beans (PK-P) though if K was applied without P it was not usually so effective.

In Puerto Rico *pigeon pea* receiving 45 kg/ha each N, P_2O_5 and K_2O took up 168 kg/ha K_2O at a yield of 8 t/ha green pods (approx. 3 t/ha dry matter) and the recommended rate of K fertilizer, allowing for losses, is about 200 kg/ha K_2O for a full yield.

Recent Indian information gives the following (Table 37) yields of a range of grain legumes at increasing rates of potash applied in addition to adequate N and P on a K deficient soil; K uptakes ranged from 16 to 34 kg/ha K_2O.

Other Indian work *(Tiwari et al. [1985])* found that applying 50 kg/ha K_2O increased yield of chickpeas by 34% (control yield 1859 kg/ha).

Detailed work in pot culture in Pakistan indicates that yield and N content of grain is improved by K fertilizer through its effect on nodule weight and, thus, on N fixation (Table 38).

Table 37. Effect of K fertilizer on grain yield of pea, lentil and chickpea *(PRII [1986])*

	Grain yield (kg/ha) kg/ha K_2O			Response to 50 kg/ha K_2O	
	0	25	50	kg/ha	kg/kg K_2O
Pea	1751	2136	2524	773	15.5
Lentil	1603	2016	2165	562	11.2
Chickpea	2408	2795	2945	537	10.7

Table 38. Effect of potash on dry matter and grain yields, nodulation and N_2 fixation by chickpea *(Idris et al. [1983])*

kg/ha K_2O	g/pot d.m.	Shoot/root ratio	g/pot grain	Nodules per plant	Mean nodule weight (g)	% N in grain	Total N in plant (g)
0	44.9	4.3	30.8	85	7	3.8	1.94
40	55.3	3.4	35.9	123	11	4.1	2.40
80	64.4	3.1	38.6	143	12	4.5	2.91
120	69.8	3.0	41.6	169	18	4.5	3.20
160	77.7	3.0	42.7	185	17	4.4	3.23

Good responses to K by broad beans have been reported in Egypt - 4718 kg/ha from beans receiving 70 kg/ha P_2O_5 and 5222 kg/ha when 114 kg/ha K_2O was applied with the phosphate.

It would appear that the small tropical grain legumes will give a profitable return from K fertilizer on low K soils but that their yielding capacity is normally low and that moderate (say 50 kg/ha) dressings should suffice. These crops are important from two points of view: they are sources of high grade protein and consequently valuable in the diet; they are useful crops in the rotation as they fix atmospheric nitrogen. Their reactions to fertilizer merit more attention than they have received up to now.

9. Oilseeds

Oilseed rape is widely grown in the cool temperate region; other brassicas such as mustard are important oil crops in some subtropical countries. Sunflower is widely grown in warmer temperate regions, and progress in plant breeding is pushing the crop further north, notably in France and Germany. Sunflower is also cultivated in the drier tropics.

The most important tropical oilseed crop, also grown in the sub-tropics, is groundnut (peanut); there are others which may be locally important such as sesame. These crops have a relatively high sulphur requirement, and potassium sulphate is often the preferred potash fertilizer.

9.1 Rapeseed (colza)

Oilseed rape increased in popularity when the low erucic acid varieties became available. It is a valuable break crop in predominantly cereal rotations and conveniently handled with cereal equipment.

The total potassium requirement is high though the crop is not particularly responsive to K fertilizer. K removal in harvested seed is quite modest but during the period of rapid growth in the spring a plentiful supply of readily available K is essential. The rate of uptake can reach 15 kg/ha/day K_2O.

It is interesting that there is quite a variation in fertilizer K recommendations between countries. For instance in France, *CETIOM* recommend 120–150 kg/ha K_2O on medium K soils and 200–250 kg/ha on low K soils, while standard recommendations in the United Kingdom are for 40–75 kg/ha depending on soil K status on the grounds that rape seldom gives an economic response to K. The French recommendations rest on the need to provide adequate K at the critical period but also carry the proviso that such dressings to the rapeseed crop should supply the total K needs of a rape-cereal rotation because the removal of K in the seed is low, only 30 kg/ha K_2O for a 3 t/ha crop. The French recommendations pay attention to the needs of the whole crop rotation while the English are based only on response by rape to applied fertilizers in annual experiments. The range of rates advised covers a range of conditions; of soil indices from low to satisfactory for P and K, for nitrogen largely depending on previous crop. Some standard recommendations are given in Table 39.

In apparent contradiction with UK advice that rapeseed seldom responds appreciably, results from French field trials (Table 40) showed response up to quite heavy rates of K fertilizer. The application of 180 kg/ha K_2O increased the gross margin by 796 F/ha.

Table 39. French and British fertilizer recommendations for rapeseed (kg/ha)

	N autumn	N spring	P_2O_5	K_2O
France*	0–60	100–180	50–80	120–250
UK**	40–60	150–225	40–75	40– 75

* CETIOM ** ADAS

Table 40. Response by rapeseed on a low K soil to K fertilizer *(SCPA [1986])*

kg/ha N	T/ha grain (9% moisture) kg/ha K_2O 0	60	120	180
120	2.27	2.43	2.90	2.81
180	2.50	2.82	2.98	3.28

Interesting results were obtained in 8 field experiments over two years in which the effect of a spring top-dressing of 200 kg/ha sulphate of potash (100 kg/ha K_2O) in addition to the farmers' normal fertilizer treatment was tested. On the average, yield was increased from 2.53 to 2.85 t/ha; in only one trial was there no response. Superphosphate (18%) as an alternative source of S was not as effective as sulphate of potash. 1000 grain weight was also increased *(Fauconnier et al. [1983])*. When other crops in the rotation receive no S, or after a bad winter (rain and cold) or when rooting is poor, *CETIOM* advise applying 20–30 kg/ha S from mid-February on low sulphur soils. Sulphate of potash is a convenient source of S and 200 kg/ha K_2SO_4 can be applied without risk of scorch. The resulting residue of K (application > removal) benefits the following cereal crops.

9.2 Sunflower

This crop is attracting considerable attention in temperate areas and has penetrated further north as suitable dwarf varieties have become available. In France it has largely replaced oilseed rape as a break crop in cereal rotations, partly because rape is subject to serious pest attack and also in its own right as a profitable crop to grow.

Regarding fertilizer treatment, the points to note are: only moderate N requirement, excess is to be avoided as it increases susceptibility to disease *(Botrytis, Sclerotinia)* and to lodging; high K requirement; susceptibility to boron deficiency. Advisory recommendations in some countries are summarized in Table 41 with estimates of nutrients taken up in total crop and removed in harvested seed in Table 42.

CETIOM note that while 100–120 kg/ha K_2O is sufficient for soils moderately well supplied with K, it can be expedient to apply higher rates to meet the K needs of the following crops. Figure 25 shows the development of dry

Table 41. Fertilizer recommendations for sunflower *(Glas [1987])*

	N	P_2O_5	K_2O
Bulgaria	90–100	90–100	50– 90
France	30– 80	80–120	120–180
Hungary	40– 80	125	70–150
Jugoslavia	80–120	120–140	160–180
Romania	70–100	60– 80	80–160
Spain	50–100	50– 80	50–100
Turkey	40	50	40
USA	10– 50	20– 60	30– 60
USSR	20– 45	60	45– 50

Table 42. Nutrient requirements and removals in harvested seed for a yield of 3.5 t/ha rapeseed *(CETIOM [1986])*

	Total uptake (kg/ha)	Removal (kg/ha)
N	131	66
P_2O_5	87	54
K_2O	385	82
MgO	70	14
CaO	210	6
B	0.4	0.08

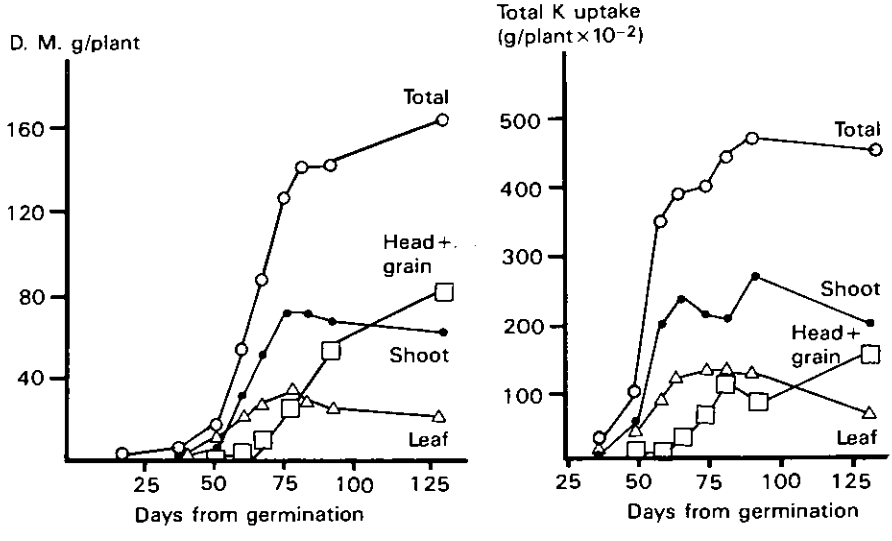

Figure 25. Patterns of dry matter accumulation and potassium uptake by sunflower *(Merrien et al. [1986])*

matter accumulation and the uptake of K throughout the growth of the crop; potassium is taken up at a very high rate (12 kg/ha K_2O per day) between 50 and 60 days from germination. Consequently, the amount of K removed in the grain is not a sure guide to fertilizer requirement; it is essential that available soil K should be high enough to allow it to supply K to the plant at this very high rate. Because K removal at harvest is relatively small, a residue of K will be left in the soil to meet the needs of the following cereal crops.

CETIOM lay considerable emphasis on the boron needs which are 4 times as high as those of sugar beet.

9.3 Groundnut *(Arachis hypogea)*

This crop is a legume but since it is grown mainly for oil production with some for the "hand-picked selected" market it is included here. It is, after soya, the most important tropical and sub-tropical oilseed, widely grown in the savannah of West Africa, in India, China and the USA.

As a typical legume it would be expected not to respond to N fertilizer and to be responsive to P and K. In practice, small N dressings (about 20 kg/ha) at sowing often assist the establishment of the crop (ready supply of N before symbiosis becomes effective). It responds well to P and to K fertilizer if soil K content is low. It is responsive to calcium as lime or gypsum and response to K can be limited by lack of Ca. It responds to sulphur, indeed many recorded responses to P, customarily applied as single superphosphate have been due to the S content of that fertilizer. So long as single superphosphate remains in use, the crop's sulphur needs will be met but if it is replaced by S-free P fertilizer other sources of sulphur must be used. Some responses to N may also have been due to S if sulphate of ammonia was the N fertilizer. When grown in rotation with other well fertilized crops or in mixed cropping systems, satisfactory crops can often be grown by relying on the fertilizer residues left by the other crops; some even say that residues are more effective than fresh fertilizer.

Groundnut is an important cash crop in the savannah zone of West Africa; it is also an important constituent of the local food supply. Under extensive conditions, it usually responded only to phosphate (single superphosphate) and the usual fertilizer recommendation was for a modest phosphate dressing only (say 20 kg/ha P_2O_5). However, with increasing pressure on the land and shortening rest-periods it has been found to respond to K; the results from a long-term trial in N. Nigeria (Table 43) are interesting in showing how in continuous rotational cropping with cereals and cotton there was little or no response to K for three years but substantial responses thereafter.

Average yields obtained by farmers in West Africa are low – from 600 to 1300 kg/ha unshelled pods. Using quite simple improvements in general culture with modest fertilizer dressings as recommended for general use, these yields can be doubled, while, in experimental work yields of from 2.25 to 4 t/ha have been recorded. However the crop is very much at the mercy of the weather, without irrigation as is normally the case, the date of the first rains is critical and under such circumstances fertilizer recommendations remain modest. Something of the order of 20 kg/ha N, 20–40 kg/ha P_2O_5 and 40 kg/ha K_2O should be suitable.

Table 43. Response of groundnut in continuous rotational cropping to K fertilizer *(Singh et al. [1983])*

Year	Pod yield (t/ha)* No K applied	K to all crops**
1970	4.45	4.28
1971	1.44	1.47
1972	1.04	1.19
1974	2.75	3.11
1975	1.92	2.28
1976	3.43	3.88
1977	1.64	2.06
1978	1.31	1.52
1979	2.68	2.89

* Meaned over other treatments (N, lime and micronutrients) applied in factorial combination. P at 20 or 30 kg/ha uniformly applied to all crops.

** K applied to each crop in rotation at 46 kg/ha for 1st 3 years and then at 68kg/ha.

Sulphur is often critical, more evident as sulphate of ammonia and single superphosphate are replaced by S-free materials. According to the availability and cost of alternative sources of sulphur, it is worth considering substitution of potassium sulphate for the more usual muriate for groundnuts. Results (Table 44) of an experiment with N given as ammonium nitrate (S-free) and P alternatively as single superphosphate (containing S) or dicalcium phosphate (S-free) with potassium as muriate, are of interest in this connection.

In general, the fertilizer needs of the crop are modest (quite low yields). Removal of nutrients in 1 tonne of pods is: 50 kg N, 3 kg P, 12 kg K, 7 kg Ca and 5 kg Mg; the drain on soil nutrients is not high. Removals are much greater when, as is sometimes the case, the haulm is used for stockfeed. This practice may justify the use of more N which increases top growth.

In South India, the Tamil Nadu Agricultural University recommends (in kg/ha) 10 N, 10 P_2O_5, 45 K_2O for rainfed and 17 N, 34 P_2O_5, 54 K_2O for irrigated groundnuts. In Punjab and Sindh Provinces in Pakistan the recommendations are in kg/ha: 20–30 N, 30–80 P_2O_5, 40–50 K_2O.

Table 44. Combined effect of sulphur and potassium on groundnut yield (average of 3 N rates) *(Ollagnier [1973])*

	kg/ha pods K_0	K_1	K_2
No S	892	1217	1193
With S	901	1300	1493

9.4 Other tropical oilseeds

Sesame is an important oilseed crop in some areas; there is little published information on its fertilizer requirements which may be assumed to be similar to those of groundnut but with a more definite N fertilizer need.

10. Industrial crops

10.1 Cotton

This valuable cash crop fits well into rotational cropping with food-crops in the drier tropics and sub-tropics. It can be grown year after year without serious problems provided sufficient fertilizer or manure is used to maintain fertility, but is better grown in rotation with cereals (rice, maize, sorghum, wheat) and legumes.

Cotton usually responds to all the major nutrients. Nitrogen and phosphate are particularly important and potassium is essential except on high K soils. Boron deficiency is relatively common and compound fertilizers for cotton usually have boron added. Sulphur also frequently gives response.

Total K uptake by a good crop yielding over 4 t/ha seed cotton amounts to 180–210 kg/ha K_2O and the maximum rate of uptake at mid-growth may be as high as 4.5 kg/ha/day. Clearly, the soil must be well supplied with K if yield is not to be limited. Much of this K is returned to the soil after harvest provided all crop residues are returned; removal in the lint only amounts to about 3 kg K_2O per 100 kg. When yields are lower as with un-irrigated cotton in West Africa the total uptake of a crop of 1.75 t/ha seed cotton is about 90 kg/ha K_2O.

As well as increasing yield, potassium accelerates the maturity of the lint and reduces the proportion of empty capsules. It increases the length of fibre. It also improves the oil content of the seed. An example of the effects of potash fertilizer on seed cotton yield, percentage lint and fibre properties is given in Table 45 derived from work with the irrigated crop in Alabama.

Table 45. Yield and lint properties as affected by rate of K fertilizer *(Bennett et al. [1965])*

			Lint properties				
kg/ha K_2O	Seed (kg/ha)	Bolls (no./kg)	%	Length (cm)	Strength (kN m/kg)	Elongation (%)	Fineness (micronaire index)
0	3020	242	41.0	2.13	149	8.7	3.70
70	4480	176	39.1	2.34	156	8.1	4.80
140	4700	163	38.6	2.29	157	8.9	4.28
280	5150	163	38.5	2.24	147	8.7	4.23
420	5260	159	38.7	2.16	144	10.3	4.31
560	5380	156	38.0	2.13	143	9.0	4.32

Much work on the fertilizer requirements of cotton has been done in francophone West Africa and IRCT has a very effective extension programme to small farmers. Formerly, the standard recommendation was for small amounts of fertilizer containing only N, P and S (limited yield expectation) but long-term experiments have shown that while yields might be satisfactory in the first year without K, they declined seriously thereafter. Experiments in Burkina Faso where yields are normally low, comparing the old standard recommendation (20 N, 34 P_2O_5, 7 S, 1 B) with the same plus K and plus extra N gave seed cotton yields at various centres as listed in Table 46. As a result of this work, all growers are now recommended to apply K at around 30 kg/ha K_2O.

Table 46. Effect of adding K and extra N to standard fertilizer *(IRAT [1981])*

Seed(kg/ha) No fertilizer	Normal fertilizer	Normal +K*	Normal +K+N**
507	903	1116	1275
794	931	1035	1285
641	548	692	629
684	924	1002	1143
851	1070	1061	1104
580	963	996	1188
794	941	1015	1189
441	702	753	813

* Mean effect of K at 8 sites: +86 kg (2.9 kg/kg K_2O)
** Mean effect of K+N at 8 sites: +200 kg.

Recommendations for West African countries are as in Table 47. Except in Chad an additional 50 kg/ha urea should be put on at 50 days.

In India, recommendations vary a good deal according to locality, variety and the availability of irrigation. Without irrigation, N can be applied at from 20–80 kg/ha, normally divided between planting and 50 days; with irrigation at 100–150 or even more. Phosphate rates vary from 30–80 kg/ha according to soil P and potash generally from about 20 to 70, occasionally as much as 100 kg/ha.

Table 47. Fertilizer recommendations for cotton in West Africa *[IRCT]*

	kg/ha at sowing				
	N	P_2O_5	K_2O	S	B
N. Benin	30	24	24	9	1.5
S. Benin	10	25	60	0	1.5
Mali	30	37	0	15	1.5
Ivory Coast	28	28	28	10	3
East Senegal	18	48	24	7.5	1.5
West Senegal	11	30	54	8	1.6
Chad	25	20	15	5.5	0.8
Cameroun	25	25	20	10	1.2

10.2 Tobacco

For this crop quality is the most important consideration and it is in its effects on quality of leaf that potassium is of dominant importance. Though on low K soils potassium has a definite yield-increasing effect, quality is much improved when K is applied at rates well above that needed for maximum yield. There is a definite connexion between high leaf K content and quality as measured by colour, fineness, elasticity, taste and burning quality. It is perhaps the one crop where the grower has no need to worry about "luxury consumption".

In 8 years of experiments with Burley tobacco in West Virginia maximum yield was given by 271 kg/ha N with 300 kg/ha K, but the best quality was obtained with much less N (184 kg/ha) and more K (322 kg/ha). The best cash return (a combination of yield and unit price, as a measure of quality) was obtained with 237 kg/ha N and 308 kg/ha K *(Colyer et al. [1972])*.

Fertilizer requirements differ considerably as between the different types of tobacco. The N needs of flue cured tobacco are very modest as compared with Burley and dark or sun-cured types. Thus in the USA, an average fertilizer recommendation for flue cured would be: N: 40–80, K_2O: 72–144 kg/ha *(Chouteau et al. [1988])*. In Zimbabwe it would be N: 10–70, P_2O_5: 55–110, K_2O: 55–100 kg/ha *(De Geus [1973])* the P and K dressings being varied in accordance with soil nutrient status.

In contrast, West Virginia recommendations for Burley tobacco would be: N: 90–112, P_2O_5: 112–168, K_2O: 145–280 kg/ha *(De Geus [1973])*.

Zimbabwe recommendations for Burley are more generous for N and about 150 kg/ha N may be applied with rates of P and K as for flue-cured *(De Geus [1973])*.

In India, fertilizer recommendations for flue-cured tobacco range from (kg/ha) 20 N, 30–50 P_2O_5, 30–50 K_2O in black soil areas of Andhra Pradesh to 70 N, 80 P_2O_5, 80 K_2O for light textured soils of Andhra Pradesh and Karnataka *(Chouteau et al. [1988])*.

The choice of form of potash fertilizer is of crucial importance. It is absolutely necessary to avoid high Cl content in the leaf which spoils leaf quality, increasing hygroscopicity, making curing difficult, increasing the protein content and adversely affecting burning properties and flavour. It is essential to use the sulphate form.

Experiments have been done in several tobacco growing districts in Spain and these gave the average results shown in Table 48.

Table 48. Yield of dry tobacco leaf (18% moisture) with financial return in pesetas and combustibility as affected by form of potash *(Llanos Company [1984])*

Treatment	Yield (kg/ha)	Return Pts/m²	Return Pts/kg	Combustibility (glowing time in sec.)
Sulphate	1950	20.9	107	13.3
Chloride	1630	14.9	92	7.4

Experiments in S. W. France showed that while sulphate of potash improved yield and quality, the tobacco crop still suffered ill effects by taking up chloride originating from dressings of KCl to the crop preceding tobacco. The results quoted in Table 49 show that when tobacco is grown in rotation, it is advisable to use sulphate of potash on all the crops in the rotation. Using sulphate rather than chloride on the crops preceding tobacco more than doubled the profit obtained from applying K to tobacco.

These results underline in an emphatic manner the importance of using sulphate of potash for this crop.

Table 49. Effects of potash rate and form on tobacco yield, quality and crop value *(Loué [1978b])*

kg/ha K_2O to		Quality index* (0-13)				Whole crop	
Prec. crops**	Tobacco	Lower	Middle Leaves	Upper	Yield (kg/ha)	Value (FF/ha)	Margin (FF/ha)
0	0	1	7	7	3534	15440	-
KCl	*K_2SO_4*						
80	150	2	7	5	3749	16301	861
160	300	3	6	7	3793	16560	1120
K_2SO_4	*K_2SO_4*						
80	150	4	9	8	3646	17070	1630
160	300	5	11	10	3717	18269	2829

* Includes combustibility ** To wheat (year 1), ryegrass (year 2).

11. Vegetables

11.1 General

Though many vegetables are now grown more as ordinary arable field crops, market-gardening is still practised for the supply of fresh vegetable and salad crops to nearby urban populations. In the tropics too we find the specialist vegetable grower near the towns where his produce finds a ready market.

While the nutrient requirements of the various groups of vegetables are similar to those of the corresponding arable crop groups (legumes, brassicas, and roots), market-gardening is a much more intensive operation than ordinary arable cropping. Crops follow each other in quick succession and the aim should be to build up the soil fertility to a really high level by generous additions of organic manures and fertilizers.

The leafy vegetables can make use of much nitrogen, the legumes have a low N requirement and in fertile gardens will cope satisfactorily without any N fertilizer. Phosphorus is important for crop establishment and the development of a good root-system.

The growth and yield of legumes is increased through the favourable effect of K on the N-fixing nodule bacteria. Root crops also make profitable use of much potassium. In general, the K fertilizer treatment of vegetable crops should be on the same lines as for the corresponding field crops but at a rather higher rate.

Though potassium does increase yield of vegetable crops, its over-riding importance is seen in its effects on quality. It balances the effects of heavy N dressings on leafy crops such as lettuce, cabbage or Chinese cabbage, producing much firmer heads which withstand the effects of transport so that they arrive in the market in better and more attractive condition. In roots, it increases the starch or sugar content as the case may be.

The form of potash (chloride or sulphate) is an important consideration. Because heavy rates of fertilizer are customarily the rule in vegetable gardening, there is always a danger of the build up of salt concentrations and the use of potassium sulphate is a way round this difficulty. So sulphate of potash is usually recommended even though the cost is higher – the results will more than repay the extra cost. Some vegetables are particularly sensitive to Cl, among them green beans and onions. The sulphur content is of particular benefit for onions and the brassicas.

The yields obtained in intensive vegetable gardens are high; removals of potassium are correspondingly high, hence high rates of fertilizer need to be used to replace removals. Potash removals by good crops are listed in Table 50.

Table 50. Potash removed in good crops of some vegetables *(Kemmler et al. [1986])*

Crop	Yield (t/ha)	kg/ha K_2O	Crop	Yield (t/ha)	kg/ha K_2O
Asparagus	5	150	Lettuce	30	160
Beans green	15	160	Okra	20	90
Cabbage	70	480	Onion	35	160
Carrot	30	200	Pumpkin	50	160
Cauliflower	50	350	Radish	20	120
Celery	30	300	Spinach	25	200
Cucumber	40	120	Beet	30	220
Eggplant	60	300	Tomato	50	190
			Leeks	35	280

11.2 Tomatoes

It is of interest to include some discussion of this crop for two reasons:

- It is most responsive to K fertilizer and, at the high yields which are possible, removes much K from the soil,
- The effects of K on various aspects of crop quality have been studied in great detail.

Much of the detailed work on this crop has been done in the temperate climate under glasshouse conditions where yields of up to 180 t/ha can be obtained regularly. Yields of field grown crops are much lower and vary greatly according to local conditions; about two thirds of the world tomato area yields only an average of a little over 15 t/ha, though open-air crops in Florida under intensive cultivation may range up to 125 t/h in a growing period of 120–150 days.

The crop removes an estimated 5 kg K_2O per tonne of fruit, so to maintain the status quo for soil K under a 15 t/ha crop requires about 75 kg/ha K_2O – the high Florida crop requires ten times as much. Not only is the total K requirement of such crops very large, but it has to be taken up fast (750 kg over 120 days = more than 6 kg/ha/day). The fertilizer dressing actually used in Geraldson's "gradient mulch system" experiments was 360 kg N, 96 kg P_2O_5 and 415 kg K_2O per hectare *(Usherwood [1985])*.

K fertilizer also improves fruit quality, both "superficial" fruit quality and juice composition. These aspects were thoroughly investigated at the Glasshouse Crops Research Institute (U.K.) with the finding that fruit quality is appreciably improved by applying K at rates well in excess of that required for maximum yield (Table 51).

Effects of N and K fertilizer combinations on total yield and quality (as indicated by proportion of marketable fruit) are illustrated in the experimental results obtained with the irrigated crop at the University of Illinois (Table 52). The K effect on marketable yield (i.e. cash return – a combination of yield and quality) is greater than that on total yield.

Table 51. Effects of K on fruit quality *(Winsor [1973])*

	K_2O applied (kg/ha)					
	470	940	1880	470	940	1880
	% unevenly ripened fruit			% hollow fruit		
cv 1	18.1	5.1	1.4	56	23	10
cv 2	29.5	9.3	3.1	32	14	9
	% irregular shaped fruit			Titratable acidity (me/100 ml)		
cv 1	17	11	9	5.4	6.9	9.1
cv 2	22	14	11	6.0	7.2	8.0

Table 52. Effect of N and K fertilizers on total yield and marketable yield (t/ha) of tomatoes *(Usherwood [1985])*

	kg/ha N		
kg/ha K_2O	135	200	270
0	15.9	16.8	20.8
	(6.5)	(9.4)	(11.4)
336 preplant	33.8	34.7	36.3
	(24.0)	(26.4)	(27.9)
168 preplant + 168 side dressed	39.5	46.6	59.9
	(31.6)	(39.6)	(50.9)

This brief discussion of some aspects of the fertilizer treatment of tomatoes illustrates how important it is to realise the heavy K demand of intensively grown high yielding vegetable crops and the importance of crop quality in this market.

12. Grassland

Grass is essentially a long-term crop; the approach to manuring must also be long-term. Like all leafy crops, grasses remove much potassium from the soil. They have well-developed root systems and are very efficient in extracting potassium from the soil. This means that, though grass can flourish at quite low levels of soil potassium, it may do so at the expense of other crops. Consequently:

- in mixed grass-legume swards the legume, not an efficient potassium forager, suffers severe competition;
- when grass is a "break" in a series of arable crops, the crop or crops following grass will be short of potassium unless removal by the grass is made good.

There is a contrast between grazed grass, where most of the potassium is returned to the field through the animal, and grass cut for feeding housed stock or for conservation, where very large amounts of K are removed from the field.

12.1 Cut grass

Properly nourished grass contains about 2% K in dry matter. Every tonne of grass dry matter removed from the field takes with it 20 kg K (24 kg K_2O). So, a 12 t/ha silage cut removes about 75 kg/ha K_2O. A 5 t/ha grass hay crop removes about 80 kg/ha and a good crop of lucerne hay about 190 kg/ha K_2O.

12.2 Grazed grass

When grass is grazed, at least in theory, very little potassium is removed from the field because there is comparatively little in animal products (meat or milk). However, the return of K through the animal is uneven. It is concentrated in urine patches; it is concentrated in parts of the field as a consequence of the grazing behaviour of the animals (near drinking points, in frost-free areas).

How much this uneven return matters in practice depends on the type of soil. On light, sandy soils, there is very severe leaching under the urine patches. On heavier soils there is little leaching and, given time for the whole area to be covered by urine patches, restitution of K will eventually be even. Though on K retentive soils the K fertilizer requirement may be almost nil, on light sandy soils it is as high as it is for cut grass where all the K is removed from the field. Density of stocking is an important factor. The more animals are carried on the field, the more even is the return of K.

Some K is lost from the field when stock are temporarily indoors for milking. When stock are fed indoors on cut grass (zero-grazing) or in winter on silage and hay, provided the manure is properly stored and protected from the weather (washing out of K by rain), most of the potassium can be returned to the soil if the manure is carried back to the fields whence it originates. In practice this is often not the case; manure tends to be used on nearby fields (so that there is a transfer of fertility from the distant fields). The cost of transporting the manure is high. There is usually a large loss of nutrients from the system because of poor storage of manure.

The timing of K fertilizer application is very important. The availability of soil K is at its maximum in spring or at the onset of the rains when there is a natural flush of growth. Then, grass will easily take up more K than it really needs and some of the fertilizer K applied at these times might be wasted. It makes more sense to apply the K fertilizer later on (a) to replace that removed in the spring flush and (b) to raise the soil K which may fall to a critical level as the season progresses. It is good practice to apply supplementary K dressings at the end of the growing season in the temperate climate to achieve a more even distribution through the profile.

As a rough guide, it can be taken that on medium textured soil and with good management, the removal of potassium by grazing adult animals is about 15 kg/ha K_2O.

Soil and management factors which affect K requirement can be summarized as follows:

Higher K requirement	Lower K requirement
Grass cut for hay or silage	Grass grazed
Grass legume mixtures	Pure grass
Low stocking rate	High stocking rate
Non-K-retentive soils	Good K retention
Manure not returned	Manure returned evenly
Large animals (cows)	Small animals (sheep)
Much N fertilizer	Little or no N fertilizer

12.3 Alternate husbandry

In alternate husbandry the grass break affects the succeeding crops. Frequently, the effect of the grass removing much K may not be noticed until the field is ploughed and planted with arable crops because grass will grow at moderate levels of soil K supply. But the following arable crops require a higher level. Sufficient potassium must be applied to the grass to replace removals, otherwise the arable crops will suffer. If sufficient has not been applied during the years under grass, the deficit should be made up in preparation for the arable crops.

The effect of the removal of potassium by cut grass, generously treated with N fertilizer on long-term productivity of a sward is illustrated in Figure

26. Using NP or N alone high yields were obtained in the first year but then declined rapidly until after 3 or 4 years the yield was less than half that obtained in the first year. Including potash in the fertilizer maintained yield at a high level indefinitely; adding potash after 5 years under NP soon restored productivity.

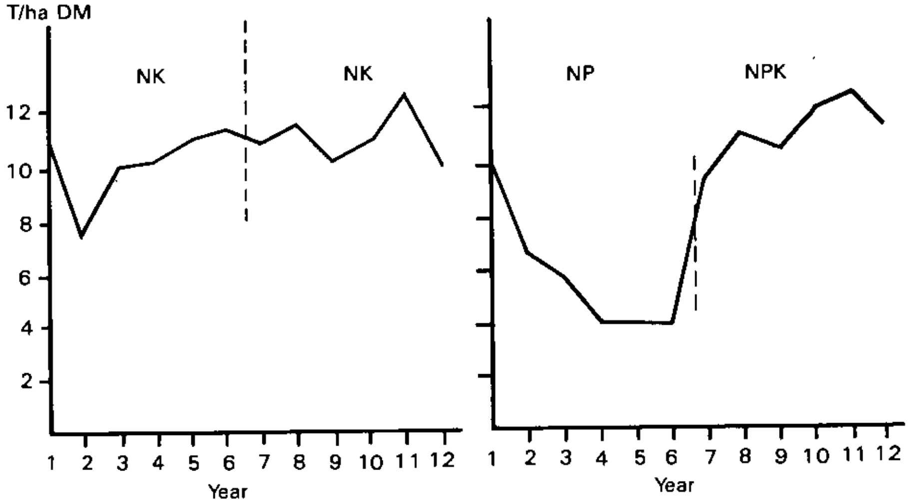

Figure 26. The effect of heavy dressings of nitrogen with or without potash on the production of herbage *(Holmes et al. [1954])*

12.4 Temperate grassland – practical fertilizer recommendations

Total production of a sward over the year and the pattern of that production (i.e. tailoring food supply to seasonal stock requirements) can be controlled by judicious use of N fertilizer. Usually the sward will be used for both grazing and conservation, so that the simplest way to establish the fertilizer programme is to consider first the programme for grazing and then to modify that programme to allow for nutrient removals whenever the grass is cut for conservation as hay or silage.

According to stocking rate and general intensity of management, nitrogen will be applied at intervals in accordance with grazing requirement at about 75 kg/ha per grazing, somewhat more for the first grazing, to an annual total in the most intensive systems of 400 kg/ha. For grazing only, P and K should be applied at 20–60 kg/ha P_2O_5 and K_2O per annum according to soil analysis (medium to low). The P and K can conveniently be supplied in one autumn dressing; alternatively a high nitrogen, low P and K compound fertilizer (3:1:1 ratio) can be used throughout the season. Whenever the sward is cut for conment will be only modest as most of the K in the herbage is recycled back to the soil. If the herbage is cut and carried off for conservation, K is removed from the field and should be replaced with fertilizer K if fertility is to be maintained. An approximate guide to requirement would be 30 kg/ha K_2O for each tonne of herbage dry matter.

13. Plantation crops

These are essentially permanent crops and need fertilizer treatment different from that given to short term arable crops. The long-term effects of treatment must be kept constantly in mind.

In the first place they must be given a good start, for trees whose growth is restricted by nutrient deficiency in the establishment phase never make up the lost ground. This means two things:

a) Generous treatment of young trees in the nursery to ensure that the planting material is in a vigorous condition.
b) Ensuring before planting that the soil is sufficiently supplied with all essential nutrients.

Soil analysis of the field to be planted will be useful to indicate possible deficiencies to be made good by fertilizer. Corrective fertilizer dressings should, if possible, be worked well into the soil.

From planting out in the field the first aim is to get the trees into bearing as soon as possible and from then on to maintain them in good shape so that yield is not limited.

Soil analysis is not very helpful for the bearing trees because large amounts of nutrients are stored within the tree and these are at least as important as soil nutrient supplies. For this reason, plant (foliar) analysis which indicates the nutritional status of the tree is a better guide.

Critical values for each nutrient above which response to the relevant nutrient is unlikely (and below which response is likely) have been defined but the value of average data is limited, except to distinguish between gross deficiency and sufficiency, because the value varies with soil and other conditions. On large commercial plantations, with the necessary facilities fertilizer trials can be combined with leaf analysis to confirm or adjust the critical value to conform with site conditions. Such a refined procedure while well justified on the large plantation is beyond the resources of the small-scale grower who will only be able to resort to leaf analysis occasionally if indeed an appropriate laboratory service is available locally. He has to rely on generalized advice.

Table 55 adapted from one compiled by *von Uexkull [1985]* shows the progress made in yield of the main plantation crops and the fertilizer use therewith associated since pre war days. Except for coconut, yields have more than doubled and the potash application rates to support these higher yields have increased 3 to 5-fold. Satisfactory as this may be, the maximum yields achieved in 1983 were very much higher than the average, showing that the yield potential of these crops is not everywhere fully exploited while the K application rates are well below what are needed to support the best yields currently obtained. Doubtless further progress may be expected giving even higher yields in the future.

Table 55. Pre-World War II, 1983 average and 1983 maximum yields (t/ha) of plantation crops and K application rates (kg/ha K)

	Pre-World War II		1983 average		1983 maximum	
	Yield	K	Yield	K	Yield	K
Oilpalm (oil)	1.5–1.8	35–50	3.5–4.5	150–175	7–8	275–300
Coconut (copra)	0.7–0.8	0–25	0.7–1.2	0–45	5–7	250–300
Rubber (dry rubber)	0.4–0.6	0	1.2–1.5	45–60	3.5–4.5	90–120
Cacao (dry beans)	0.3–0.4	0–25	0.8–1.2	70–90	3.5–4.5	200–320
Banana (fruit)	10–20	40–60	25–45	220–290	60–80	1000–2200
Pineapple (fruit)	10–20	40–80	20–40	160–200	60–75	350–450

13.1 Oil palm

Potassium and magnesium are the keys to growing oil palms. This crop originates from West Africa where it was traditional and widely distributed in the palm groves on the acid sands of south central and south eastern Nigeria. It was found some 40 or 50 years ago that the principal cause of declining yields and vigour was potassium deficiency and that even on these virtually wild palms, potassium fertilizer could bring about spectacular improvement. In early trials, the response to K was not so good because these soils are also low in magnesium and one effect of K was to reduce the uptake of Mg, causing Mg deficiency.

Total K and Mg uptakes by bearing oil palms are estimated to be 302 kg/ha K_2O and 101 kg/ha MgO, while removals in harvested bunches (at 15 t/ha) are 112 and 35 kg/ha respectively *(Ng et al. [1985])*. If all bunch refuse or ash is returned to the field there is a big economy in fertilizer. Fertilizer requirement obviously varies with soil type and other conditions – ranges quoted by *(Ng et al. [1985])* are: 1–4.3 kg K_2O and 0–0.4 kg MgO per tree.

An example of yield response to K fertilizer is shown in Table 56. As in all experimental work by IRHO, leaf analysis was carried out throughout the experiment and the table shows the trends in leaf K content (leaf 17) as well as the yield of bunches.

An example of the interaction between potassium and magnesium from an experiment by IRHO on the Ivory Coast is given in Table 57. Increasing K fertilizer produced only a modest yield increase but when magnesium, as kieserite was also put on, though the Mg without K had little effect, it greatly increased the return from potash fertilizer.

Like the coconut (q.v.), oil palm may respond to Cl. In an experiment in Colombia *(Ollagnier and Olivin [1986])* KCl increased yield of fruit bunches from 175 to 192 kg/tree/year; leaf K contents were around 0.9% and actually declined slightly with application of KCl so that it was unlikely that yield was restricted by lack of K, while the increased yield from applying KCl was associated with a marked increase in leaf Cl content (from 0.15 to 0.65%).

Recommendations used in Malaysia for oil palm in the years of establishment are listed in Table 58. As the palms grow the nutrient rates (particularly of K) increase.

Table 56. Development of yield and leaf K content in an experiment on the Ivory Coast *(Ollagnier and Olivin [1986])*

	kg/tree/year bunches		
	K_1	K_2	K_3
Mean 1969/70–1972/73	65	68	67
Mean 1974/75–1981/82	85	95	97
% leaf K 1969	1.08	1.22	1.26
1972	0.96	1.08	1.10
1974	0.92	1.07	1.13
1975	0.82	0.98	1.01
1979	0.66	0.88	0.96
1983	0.58	0.87	0.97

Palms planted 1965. No K applied till 1967. K_1: KCl at 0.35, 0.50, 0.75 kg/tree in 1967, 1968 and 1969 and 1 kg/tree from 1970 on. $K_2 = K_1 \times 2$. Response to K develops as leaf K approaches and then falls below 0.9% (the critical value).

Table 57. Effect of combined application of K and Mg fertilizers *(Ollagnier and Olivin [1986])*

KCl (kg/tree)	No kieserite	Kieserite (0.5 kg/tree)
0.5	87	89
1.5	90	104
3.0	93	113
Effect of KCl (3–1.5 kg/tree)	6	24

Table 58. Recommendations for oil palm on coastal alluvium – Malaysia *(FADINAP [1984])*

Year from planting	N	P_2O_5 (kg/ha)	K_2O
1	32	32	29
2	46	46	150
3	66	66	218
4	67	67	263
5	67	67	305

13.2 Coconut

The behaviour of coconut in response to fertilizers is similar to that of oil palm. Potassium is the most important nutrient. Nutrient uptakes and removals in harvested nuts for hybrid coconuts are as in Table 59.

Table 59. Nutrient uptakes and removals by bearing palms *(Ouvrier et al. [1978])*

	kg/ha						
	N	P	K	Ca	Mg	Cl	S
Removed in nuts	108	15	193	9	15	125	9
Total annual uptake	174	20	249	70	39	249	30

In view of the high Cl uptake it is not surprising that the coconut has been found to respond to Cl and some of the early reported response to potash, applied as KCl, may have been partly due to the Cl content of the fertilizer.

The effects of KCl application on copra yield in widespread experiments by IRHO are shown in Table 60. Indications were that optimum leaf K content, on the basis of Ivory Coast experiments, would be around 1.4% and that here the main response was to K, but that at the third Indonesian site most of the response would be due to Cl, leaf K content being 1.51% even at the K_o level.

Table 60. Effect of potassium chloride fertilizer on copra yield *(Ollagnier and Mardiana Wahayuni [1986])*

	Ivory Coast (3 sites)			Indonesia (3 sites)		
Copra (kg/tree/year)						
KCl_0	17.2	16.3	8.2	17.2	8.7	11.4
KCl_1	18.0	18.0	21.7	27.0	15.7	16.7
KCl_2	20.4	19.4	21.0	27.5		18.7
Copra (g/nut)						
KCl_0	233	215	192	203	168	131
KCl_1	239	219	227	262	233	177
KCl_2	242	218	221	279		187
KCl (kg/ha/year)						
KCl_0	120	120	0	0	0	0
KCl_1	240	240	240	257	286	351
KCl_2	480	480	480	514		702

Response to Cl is most likely on light textured soils at a distance from the sea. In coastal areas there is considerable deposition of Cl from the sea breezes, estimated at some 100 kg/ha/year Cl. In any event, KCl is the preferred form of K fertilizer.

Magnesium is also an important nutrient as illustrated in the results quoted in Table 61. It would appear that, under most conditions, application of 240 kg/ha KCl with 120 kg/ha kieserite (magnesium sulphate) can be recommended.

Recommendations issued by the Coconut Research Institute of Sri Lanka, which vary with soil and climatic zone, are given in Table 62. Either urea or sulphate of ammonia may be used to supply N. P is applied as rock phosphate except on light textured soils in dry zones where triple superphosphate is recommended. Muriate is the preferred K fertilizer. Mixtures in line with the recommendations are available with instructions to apply at 2–3 kg/palm. Magnesium deficiency is prevalent and is corrected in the long term by using dolomitic limestone or for quicker results kieserite at 2 kg/palm in the 1st year and 1 kg thereafter.

Table 61. Combined effect of KCl and kieserite – Ivory Coast *(Ollagnier and Mardiana Wahayuni [1986])*

KCl (kg/ha/year)	Yield of copra (kg/tree/year) kg/ha/year kieserite 0	120	240
0	7.5	7.5	8.7
240	19.4	22.1	22.8
480	12.8	25.5	22.8

Table 62. Fertilizer recommendations of the Coconut Research Institute of Sri Lanka (160 palms/ha) *(Pethiyagoda [1980])*

Climatic zone (Soil type)	kg/ha N	P_2O_5	K_2O
Wet and intermediate zone (Lateritic loams and gravels, Cinnamon and coastal marine sands)	52	31*	154
Wet, intermediate and dry zones (Reddish brown and sandy loams, sandy loams, clay soils, limestone derived, chocolate brown loamy soils)	37	26*	86
Dry zone (Coastal marine sands, lagoon sandy deposits)	44	20**	106

* Rock phosphate
** Triple superphosphate

13.3 Cacao

When cacao was grown under shade, as used to be universal, response to fertilizer was comparatively slight and erratic. On deep soil and in the proper climate, yields are much higher when it is not shaded. Unshaded cacao is more responsive to nitrogen and needs more potassium, indeed yields can only be maintained with an appreciable level of fertilizer input. However, if the climatic conditions are marginal, i.e. with a severe dry season, the effect of drought is severe unless the crop is shaded. In Malaysia, the nutrients required for attaining the full yield potential on different soil types are as listed in Table 63.

Table 63. Nutrient requirement of cacao for full yield (kg/tree/year) *(Ng et al. [1985])*

N	P	K	Mg	Soil
0.13–0.16	0.05–0.065	0.09–0.11	0.21–0.25	Oxic Paleaquult
0.11–0.135	0.07–0.09	0.11–0.135	0.25–0.30	Typic Paleudult
0.10–0.13	0.08–0.10	0.09–0.11	0.25–0.30	Tropeptic Haplorthox
0.08–0.10	0 –0.02	0.05–0.06	0.30–0.40	Aeric Tropaquept

The rates of K to be applied vary with soil K content. Rates of Mg vary according to soil K/Mg ratio, e.g. the last soil type is higher in exchangeable Mg than the others but has a much higher K content; it needs more Mg fertilizer to maintain the correct K/Mg ratio. Proven fertilizer recommendations vary over a fairly small area showing that a general recommendation cannot suit every case.

Young cacao requires shade, e.g. from interplanted bananas, until the cacao canopy is closed. The fertilizer programme should allow for the needs of the shade crop. As an example, the practice in Grenada is to apply for both the cacao and banana, a compound fertilizer (12:8:24 or 13:13:21 or similar) at 110 to 450 g/tree as age increases to cacao and at 900 g/plant to banana. When the cacao is established and banana removed, applications to cacao increase to 900 g/plant by the sixth year.

An example of the way in which unshaded cacao responds to K in Malaysia is given in Table 64.

Table 64. Response of young cacao to potassium *(Mainstone et al. [1978])*

	kg/ha applied			kg/ha dry beans Years from planting			
N	P_2O_5	K_2O	MgO	3	4	5	6*
82	38	0	11	578	888	1965	1496
82	38	103	11	840	1269	2354	1700
82	38	206	11	884	1271	2355	1693

* severe dry season

Ng et al. [1985] describe how, following a rational fertilizer policy from the earliest stages, unshaded cacao was brought into bearing in two years and reached over 2 t/ha by the fourth year from planting. This underlines the importance of generous treatment of the crop in the establishment phase. The importance of achieving full yield in the shortest possible time cannot be overemphasized.

13.4 Coffee

Though Arabica coffee requires somewhat cooler conditions, being grown at high altitude in the tropics or in the sub-tropics, the general ecological requirements of the crop are similar to those of cacao and similar considerations as to the interrelationship of shade and nutrient requirements apply. Other, lower value, types of coffee (Robusta, Liberica, Excelsa) are more truly tropical plants.

While phosphate is important during establishment for the development of a good rooting system, the bearing crop does not normally respond to phosphate fertilizer and the predominantly important nutrients are nitrogen and potassium.

At the time of berry setting and development there is a very heavy drain on carbohydrate reserves in the plant and this may cause starvation of the vegetative tissues with the result that the tree dies back. Dieback is more likely under unshaded conditions since light promotes fruiting and more berries are set than the tree can support (over-bearing). When growing conditions are sub-optimal (shallow soils with restricted rooting or imperfect moisture relationships) growth and development are improved by shade though yields are lower than when soil and climatic conditions are nearer the ideal. Die-back is really a result of inadequate nutrition and the problem is largely overcome if steps are taken to ensure that the trees' N and K requirements are fully met. It has been found in Brazil that the incidence of die-back is inversely correlated with leaf N and K contents and that it was virtually completely overcome if these were kept at or above 2.5% N and 1.5% K. It has also been demonstrated experimentally in differential shading trials that die-back is reduced both as shading is increased and as more fertilizer is applied, this effect of N being more marked in the absence of shade.

About 35 kg N, 7 kg P_2O_5 and 50 kg K_2O are removed in 1 t marketable beans but, in order to cover also the needs for vegetative growth, total annual requirements to be met from fertilizers are at least 135 kg N, 34 kg P_2O_5 and 145 kg K_2O per ha.

The peak requirement for K is during berry development when leaf analysis shows that leaf K content declines; it is recommended to apply K fertilizer in two stages rather than applying all at the onset of the rains.

Recommendations for fertilizer treatment vary a good deal according to soil and other conditions and potential yield. With really high yields (e.g. over 20 t/ha berries in Hawaii) total annual applications can reach as much as 412 kg/ha N, 112 kg/ha P_2O_5 and 448 kg/ha K_2O, applied as compound fertilizer + straight nitrogen divided into four dressings.

An example of yield responses to N and K fertilizers obtained in Colombia is given in Table 65.

Table 65. Average yield of Arabica coffee (2 varieties, 8 sites over 4–5 years) *(Uribe-Henao et al. [1976])*

kg/ha N	kg/ha coffee	kg/ha K_2O	kg/ha coffee
0	2248	0	2555
120	3394	120	3243
240	3607	240	3408

13.5 Tea

Tea reacts to shading in much the same manner as cacao and coffee, unshaded tea yielding better than shaded but requiring higher fertility.

Since the harvested produce is the leaf, it is to be expected that like other leafy crops, tea will be responsive to nitrogen and that much potassium will be removed from the soil. Each tonne of made tea contains approximately 21 kg K_2O so that with yields of 2 t/ha or more on good tea gardens well fertilized with N, annual K removal is considerable. Potassium withdrawal is increased if the prunings are removed from the field. The nutritional requirements of tea have been thoroughly investigated by the research institutes in the important tea-growing countries. In essentials, nitrogen, by promoting vegetative growth, is the key nutrient, while in the establishment phase phosphorus is essential in promoting root growth. Potassium is the second most important nutrient for tea, it is essential for bush and crop growth and the development of sound and healthy frames to carry the crop. Thus all the standard recommendations include N, P and K plus, according to conditions Mg, Zn and S. Many of the recommendations are based on the use of compound fertilizers of the high N type. This makes for simplicity and convenience in the fertilizer programme (Table 66).

Table 66. Some recommendations for tea fertilization *(De Geus [1973])*

Country		N	P_2O_5	kg/ha/year K_2O	MgO
N. India:	young	90	45	90	
	bearing	90–135	20	40*	
S. India:	bearing (2–4 t/ha made tea)	200–300	40– 50	100–300	
Sri Lanka:	young	100–150	72–108	78–118	31–47
	bearing	224–270	62	134	27
Indonesia:	bearing	120	30	60	
Malaysia:	bearing	135	34	34	
Central Africa:	bearing	150–200	30– 40	30– 40	
East Africa:	bearing	100–380	20– 75	20– 75	
		plus if K deficiency		50–200**	

* +40 in Assam. Supplement 20 P_2O_5, K_2O when due for prune.
** as sulphate according to severity of deficiency.

It was found in East Africa that response to nitrogen was frequently limited by lack of potassium and that, under these conditions, applying K fertilizer results in large positive interactions (Fig. 27). N increased yield only when the K deficiency had been corrected.

Similar interaction was shown in results from Tocklai (Assam) (Fig. 28). When N was applied at up to 100 kg/ha K did not increase yield but at the highest rate of N (200 kg/ha) K increased yield of made tea by over 200 kg/ha.

Soil analysis is not a very good indicator of the K requirement of the bearing crop; leaf analysis is more reliable and *Willson [1975]* found in East Africa that response to K was to be expected when K content of the third leaf was 1.57% or less in dry matter. The critical level in Sri Lanka is set higher (2%).

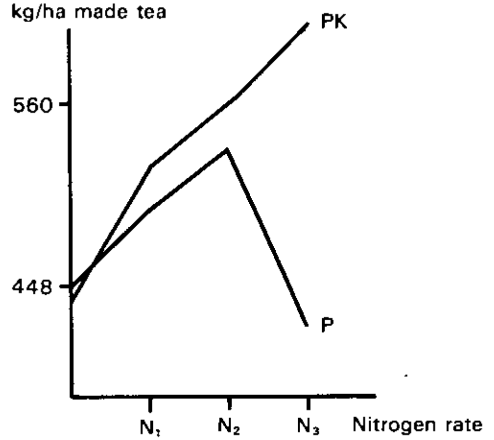

Figure 27. Effect of potassium in improving N response by tea *(Usherwood [1985])*

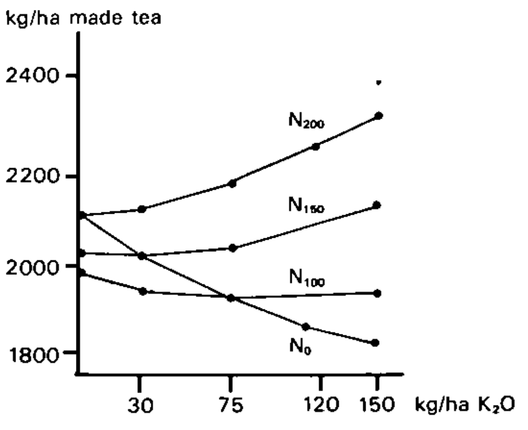

Figure 28. NK interaction in tea (Assam) *(Sharma et al. [1978])*

13.6 Rubber

The use of potassium fertilizer on rubber in Malaysia, the main world producer of this crop, has been reviewed by *Pushparajah* and *Tajuddin Ismail [1982]*. The need for potassium has only been realised relatively recently. The total potassium immobilised in a mature stand of rubber may amount to 1800–2100 kg/ha K_2O over a life of 30 years, the amount depending on soil K supply and cultivar. This is a very considerable drain on soil K reserves and a permanent loss if the timber is removed at replanting. Removal of K in latex, increasing as yield increases after the first year of tapping, is estimated to average 22 kg/ha K_2O per year with total uptake by the trees at 148 kg/ha K_2O.

Factors which have increased the K requirement of rubber are the availability of higher yielding clones and the use of latex stimulants which are less effective if K is low. The latter point is illustrated in Table 67 showing little or no effect of K when no stimulant is used but a large effect with stimulant (Ethephon).

An example of N×K interaction in rubber yield is given in Table 68. Soil K content declines with time with a consequent decline in the efficiency of N fertilizer unless the K supply is corrected.

Leguminous cover crops planted under rubber make an important contribution to nitrogen supply to the trees and these covers are responsive to K. An investigation in Malaysia showed that raising the rate of K fertilizer from 0 to 150 kg/ha K_2O increased N supplied by the cover-crop from 216 to 386 kg/ha N – worthwhile economy *(Pushparajah et al. [1982])*.

Whether or not rubber will respond to K fertilizer depends upon soil K status; requirements depend also on clone. The Rubber Research Institute of Malaysia has developed a system combining the indications from soil and leaf analysis and this is illustrated in Figure 29.

Table 67. Effect of K on latex yield with/without stimulation *(Pushparajah and Tajuddin Ismail [1982])*

Fertilizer	kg/ha latex No stimulant	Stimulant
N_0K_0	645	1336
N_0K_1	677	1447
N_1K_0	1001	1791
N_1K_1	869	1854

Table 68. Effect of N and K fertilizers on rubber yield *(Pushparajah and Tajuddin Ismail [1982])*

	Yield increase (g dry rubber/tree/year) due to N fertilizer Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
No K fertilizer	–0.1	+0.1	–7.1	–10.8	–12.2	–13.4
With K fertilizer	–2.8	–0.8	+2.3	+ 1.2	+19.9	+12.2

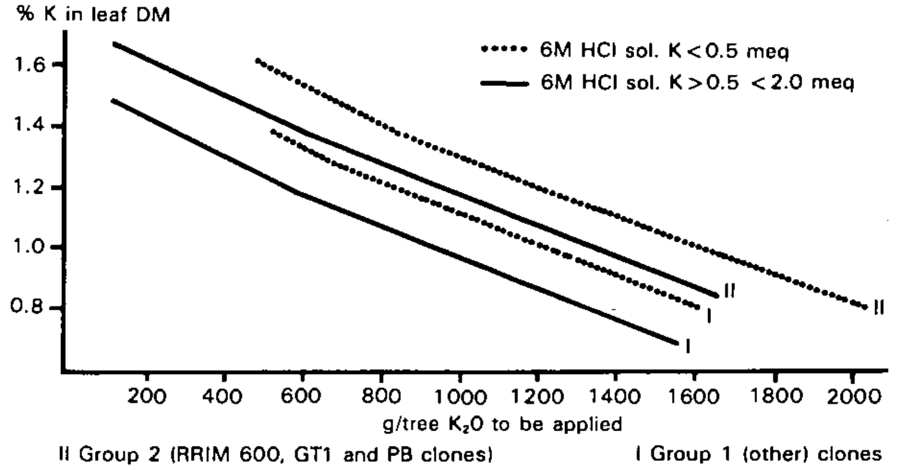

Figure 29. Recommended rates of application (g/tree K_2O per year) for different clonal groups on low and medium K soils (adapted from *Pushparajah et al. [1982]*). Response is not expected on soils with more than 2.0 meq 6 M extractable K per 100 g.

13.7 Sugarcane

The potassium requirement of this crop is high; each tonne of a well-nourished crop contains about 1.5 kg K_2O so that, with yields running up to well over 100 t/ha, very large amounts of potassium are involved. Removal can be doubled when the K supply is really abundant though then the crop is taking up more K than it can utilise.

Like other gramineae, sugarcane is highly responsive to nitrogen and potassium and nitrogen interact. Nitrogen increases the total dry matter yield but adversely affects sugar content. Potassium counteracts the latter tendency and, in fact, this is the most important way by which K fertilizer increases *sugar* yield. This is clearly seen in results from a South African experiment (Table 69).

Table 69. Effect of N and K fertilizers on sugar content of cane *(Du Toit [1959])*

	% sucrose in cane				
	N_0	N_{100}	N_{200}	N_{300}	N_{400}
K_0	17.34	16.56	16.18	15.84	15.72
K_{100}	16.98	18.26	17.30	16.31	16.38
K_{200}	17.28	17.25	17.59	17.18	17.60
K_{300}	18.08	17.45	17.66	17.66	17.10
K_{400}	17.44	17.64	17.10	17.02	17.37

It would appear that the best results are obtained at a 1:1 ($N:K_2O$) ratio in the fertilizer and, in practice, most of the standard recommendations approximate to this. Much of this effect is because an adequate supply of K improves the movement of photosynthates (sugar) into the storage tissue of the cane.

As well as increasing the total sugar content, K reduces the proportion of reducing sugars and improves sugar extraction in the factory. However, too high a concentration of K in the juice increases the percentage ash which adversely affects sugar crystallisation.

The N×K interaction is well demonstrated in results of a Chinese experiment on a paddy soil shown in Table 70.

Table 70. Yields (t/ha cane) from combinations of N and K *(Liang De-yin [1982])*

kg/ha K_2O	kg/ha N 0	105	Response to N
0	75.3	90.6	15.3
120	81.0	103.4	22.4

Soil analysis is a guide to the K fertilizer requirement of sugarcane. Critical soil K test values have been established in different countries which vary from about 50 to 150 ppm K or more. The economic return from K fertilizer depends on the relation between produce price and fertilizer cost and Table 71 shows how, in Brazil, K fertilizer recommendations vary with both soil K value and price/cost ratio.

Table 71. Potassium fertilizer recommendations based on soil test and the ratio of cane price to fertilizer cost *(Orlando et al. [1982])*

Fertility class (Soil K ppm)*	Very low <40	Low 40-80	Medium 80–130	High 130–260	Very high >260
Price ratio**			kg/ha K_2O recommended		
20	141	116	75	50	0–42
25	158	133	85	58	0–42
30	166	141	91	66	0–42

* 0.5N H_2SO_4 extract. ** Price per ton cane/price per kg K_2O

Table 72 is an example from India (Maharashtra State) of how the rate of potash fertilizer recommended varies with soil K status and with target yield – higher yields require higher K rates.

Table 72. Potash recommendations on black soil, Maharashtra State, for plant cane at different expected yield in relation to soil K status *(Sonar [1984])*

Available K status of soil (kg/ha K)	kg/ha K_2O recommended at stated target cane yields			
	80	100	120	140
200	121	159	197	235
300	107	145	183	221
400	92	130	168	206
500	77	115	153	191
600	62	100	138	176
700	47	85	123	161

It used to be generally accepted in South Africa that 112 ppm exchangeable K indicated sufficiency for sugarcane but more recently it has been found that a level of 150 is desirable on soils with 30% clay and of 200 with 40% clay. Figure 30 shows results of a trial covering the plant crop and 10 ratoons on such a heavy soil. K was applied at 110 kg/ha K_2O to every crop up to the 10[th] ratoon. There was no appreciable response to K fertilizer up to the third ratoon but thereafter response increased. Despite the application of K fertilizer the soil K level declined though not as seriously as on plots receiving no K.

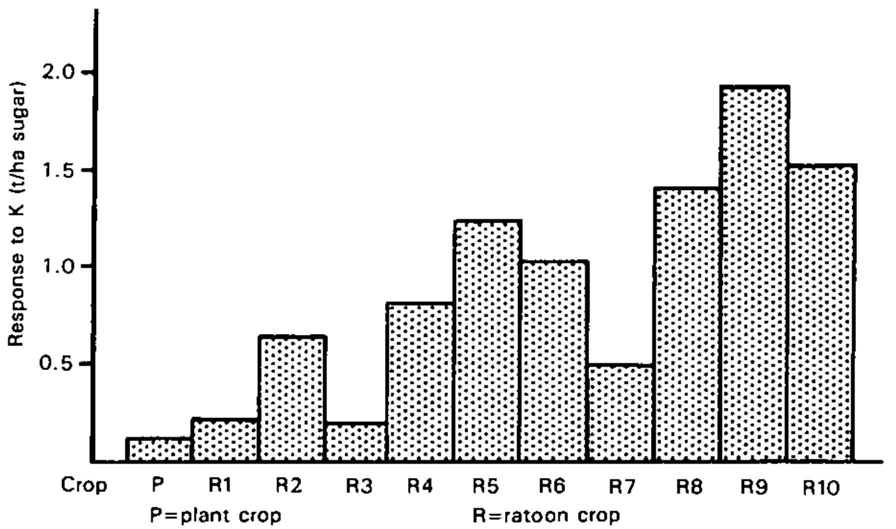

Figure 30. Effect of applying 110 kg/ha/year K_2O on sugar yield *(Moberley [1983])*

14. Fruit

Temperate fruits are discussed only briefly; three tropical and sub-tropical fruit crops are treated in rather more detail. The points raised illustrate the general requirement of the group. So far as potash is concerned the points to be noted are:

- the importance of maintaining potash supplies to secure sustained yield through the life of the crop
- the marked effect which it has in improving fruit quality.

As with all permanent crops it is important to ensure adequate nutrient supply in the establishment phase; trees never recover from a poor start.

14.1 Temperate fruits

Temperate fruit crops can be roughly classified as tree crops (pome and stone fruits) or soft fruits (bush or cane fruits and strawberries) and grapes (dessert or wine). Fertilization needs to be considered both for establishment and maintenance of the established crop.

In the first, soil analysis is helpful in indicating the steps needed to correct any deficiencies in soil nutrient supply. P and K amendments given pre-planting should be thoroughly incorporated to rooting depth. Dressings of up to 350 kg/ha K_2O may be required on low potash soils.

For the established tree crop, fertilizer requirement is much affected by the cultural system. When the soil is covered by grass, the N requirement is increased as compared with bare soil (maintained by shallow cultivation or herbicide). Rates of N recommended may be from 30–120 kg/ha/year in accordance with soil cover and variety and these rates should be increased by about 30% in drier areas (less than 350 mm rain). Annual potash recommendations run between 220 kg/ha and 80 kg/ha K_2O according to soil analysis. In many fruit growing areas, the evident benefits from K fertilizer which were demonstrated in the early stages of investigation of fertilizer requirements led to widespread adoption of K fertilizer by fruit-growers but, particularly on the lighter soils, this eventually caused magnesium deficiency. It is necessary to maintain a correct balance between the two nutrients by applying magnesium in accordance with soil analysis (60 kg/ha Mg on low Mg soils). The magnesium can conveniently be supplied by using kieserite or sulphate of potash-magnesia.

For soft fruits, the same conditions as for tree crops apply for pre-planting treatment. For bearing crops, nitrogen needs vary from nil to 50 kg/ha for strawberry to about 50 to 150 kg/ha for cane and bush fruits (rather more for blackcurrant than other sorts and more in dry areas). Potash requirement varies from 60 kg/ha on high K soils to 250 kg/ha on very low K soils and it is advisable to apply magnesium (Mg) at about one quarter the rate of potash (K_2O).

The choice of form of potash is important. Among soft fruits, all except blackcurrant are chloride-sensitive and chloride should be avoided. For top fruit, except near the sea, chloride is satisfactory if applied in autumn.

Potassium is important from the point of view of quality, increasing sugar content and acidity (improved flavour) and improving superficial quality (colour) and fruit size. The latter point is indicated in results from a long-term trial (Table 73).

It is important to have a correct balance between the mineral nutrients, for instance too high K with low Ca increases the incidence of bitter pit in apples.

Table 73. Total yields over 15 years from a fertilizer experiment with apples at Aspach-le-Bas *(Chevalier [1978])*

N	kg/ha* P_2O_5	K_2O	Total yield (t/ha)	% in size grade 1	2	3
0	0	0	207	31.7	55.8	12.5
75	75	0	215	19.6	60.6	19.8
75	75	150	331	28.4	57.3	14.3
150	75	150	418	29.6	57.6	12.8
75	75	300	397	33.0	54.1	12.8

* Average annual application over 15 years

14.2 Citrus

While soil analysis is useful for indicating fertilizer rates before establishment and for monitoring the effect of fertilizers on soil nutrients, leaf analysis is really necessary for determining the immediate needs of the established crop. However, leaf analysis needs to be used with discretion; suggested leaf levels of the various nutrients indicating deficiency or sufficiency vary considerably according to local conditions. A K content of 1.0–1.7% in spring flush leaves from bearing terminals 4–10 months old (quite a wide range) is said to indicate sufficiency.

Though leaf analysis has been recommended since 1940 actual fertilizer usage is often based more on experience or tradition. Examples of widely used fertilizer recipes in various areas are given in Table 74. The tabulated recommendations give an indication of what dressings may be suitable and the variation makes clear the extent to which generalized advice may have to be varied to suit any particular set of conditions.

Effects of K on yield have been mainly noted in long-term experiments. Examples are given in Tables 75 and 76.

An example (Table 77) from South Africa shows how, though there was no effect of K in the first year (yields from NP and NPK the same), after 10 years its effect was large, increasing yield by 50%, due to decline in soil K level under treatments receiving no K fertilizer.

Table 74. Fertilizer usage on citrus (adapted from *Cohen [1976] and Hernando [1979]*)

	kg/ha N	P_2O_5	K_2O	
Spain	400–600	120–200	300–400	+FYM every 2–3 years
Israel	100–180	50–100	300–600	
Morocco	300–350	250–300	300–400	
Florida	100–300	100	100–200	+50–100 MgO
California	200–500	P & K according to leaf analysis		
Brazil – Sao Paulo	200	100	200	
Japan	300	180	240	
Taiwan	200	200	250	+FYM
Australia	145	24	200	
S. Africa	200–300		270–540	(g/tree at 5–10 years old)

Table 75. Effect of K fertilizer on grapefruit yield – Florida *(Koo [1972])*

	kg/ha K_2O applied					
	80	160	240	80	160	240
Year	Yield (boxes/tree)			Fruit size (g/fruit)		
1968	2.89	2.87	2.88	337	350	364
1969	2.24	2.81	3.33	349	374	399
1970	3.28	4.33	4.54	328	382	398
1971	4.43	5.24	5.19	432	481	499

Table 76. Long-term experiment, orange in Brazil – effect of K on yield and number of fruit *(Hiroce [1984])*

g/tree K_2O	kg fruit per tree	No. fruit per tree
0	93.7	720
150	126.9	896
300	134.7	930

Table 77. Yield of selected treatments, Nelspruit *(Naude [1954])*

g/tree N	P_2O_5	K_2O	kg/tree fruit Year 1	Year 10
0	0	0	149	124
580	0	0	134	173
0	660	0	167	139
580	660	0	193	207
580	660	480	192	310

Quality

Potassium has important effects on fruit quality. It increases fruit size, which is desirable when size is small due to low K supply, but as K supply increases further, it also increases coarseness and rind thickness (except in lemon where it has the opposite effect) so that excessive rates should be avoided. It tends to increase greenness – of lesser importance when fruit are coloured by ethylene treatment. It increases juice acidity and usually increases vitamin C content. Low K increases puffing or creasing, lowering the market value. In trials reported by *Cohen [1976]*, spraying with KNO_3 reduced the proportion of creased fruit from 43 to 27%, the spray being more effective than soil application of K_2SO_4. Table 78, compiled from various sources, summarizes recorded effects of potassium fertilizer on citrus quality.

Table 78. Effect of increased rates of K fertilization on fruit quality factors of various types of citrus in various citrus-growing areas *(Cohen [1976])*

Citrus type	Fruit size	Green color	Rind thickness	Juice (% wt.)	Solids (%)	Acids (%)	Ratio (S/A)	Vitamin C (conc.)	State or country
Orange			O		O	++	--	+	California
Orange				O	O	++	--	+	California
Orange	++	+	++	--	-	++	--	-	California
Orange	+		+	-	-	++	--	O	Florida
Orange	++	++	+	-	-	+	-	-	Florida
Orange	++	+	++	--	O	++	--		Florida
Orange	++	O	O	O	O	++	--	+	Florida
Orange	++	++		-	-	++	--	+	Florida
Orange						++			South Africa
Orange	++		O	O	-	++	-		South Africa
Orange					O	++	--		South Africa
Orange	++		-	-	-	++	--		Australia
Grapefruit	+				O	+	-	+	Florida
Grapefruit	+	O	+	-	O	++	--	+	Florida
Grapefruit	+		+	-	O	++	-	++	Florida
Grapefruit					+	+	O	+	Jamaica
Lime					O	+	-		Florida

Key to symbols: + indicates a positive relation; – indicates a negative relation; ++ or -- indicates a marked effect; O indicates no change as a result of increased K; the absence of a symbol means no measurement was made for the factor in question.

Except on soils tending to salinity, potassium chloride is the preferred form of K for soil application. In the established crop, soil application of K will not achieve a rapid increase in K uptake by the tree (leaf K content), so, in cases of evident K deficiency, it is better to apply K as a spray of potassium sulphate or nitrate to produce rapid improvement while continuing soil application until leaf K values reach and maintain a satisfactory level. 15–20 litres per tree of 4% KNO_3 is the recommendation.

14.3 Banana

This crop has a voracious appetite for potassium. In the tropical climate it grows rapidly, indeed the rate of dry matter production must be among the highest of all crops. Consequently it requires a high level of fertility. Apart from the large quantity of K needed, the soil must be able to supply K to the plant at a very rapid rate if growth is not to be restricted. Potash is the key fertilizer for this crop.

A tonne of bananas contains about 6 kg K_2O, thus on a good plantation yielding 60 t/ha bunches some 400 kg/ha K_2O is sent away with the fruit. The total taken up by the plants producing such a yield is in the region of 1200 to 1500 kg/ha K_2O and a figure as high as 2 t/ha has been recorded. An interesting sidelight on this point is that it can be calculated that the total world banana crop contains 120000 tonnes of K_2O which is removed from the soil at harvest and, since more than one third of the produce is exported, 40–50000 t K_2O leave the banana-growing countries every year.

When soils are low in K, very generous applications are recommended for the plant crop – up to 1500 kg/ha K_2O. Requirements for the fully established crop will be less, since a large proportion of the K taken up during growth is recycled when the old pseudo-stems are chopped.

Some typical rates of fertilizers used in various growing areas are given in Table 79.

Some experimental results from Panama (Table 80) are given to show the sort of response to potash fertilizer which may be expected on a low-K soil, exhausted by some years cropping without K fertilizer.

Table 79. Fertilizer usage on banana in different areas *(Lahav and Turner [1983])*

Country	Cultivar	kg/ha/year N	P_2O_5	K_2O
N. Australia	Williams	110	100	630
Queensland	Mons Mari	280–370	70–200	400–1300
Caribbean	Robusta	160–300	35– 50	500
India	Robusta	300	150	600
Ivory Coast	Grand Nain	110–180	–	190– 310
Israel Coastal plain	Williams	400	90	1200

Table 80. Effect of K on yield and fruit size *(Rodriguez-Gomes [1980])*

kg/ha/year N	P_2O_5	K_2O	Bunches/ha	Mean bunch weight (kg)	Yield (t/ha)
390	112	0	2741	23.3	70.4
390	112	450	2797	28.8	88.6
390	112	900	2932	31.2	100.8

The Cuban results in Table 81 show in some detail how potassium fertilizer treatment affected the various components of yield and fruit quality.

In some tropical areas *plantains* are widely grown as a food crop. It is to be expected that their nutrient requirements are similar to those of sweet bananas.

Table 81. Yields* and yield components (mean values over 4 years) from a field experiment on a red ferralitic soil overlying limestone in Cuba *(Garcia [1980])*

g/plant K_2O	Average bunch weight (kg)	Rachis length (cm)	Hands/ bunch	g fruit/ hand	Average fruit length (cm)
0	15.9**	41.6	7.5	114	18.5
150	33.1	49.4	8.1	130	19.7
300	33.4	54.2	8.4	135	19.9
450	35.8	55.2	8.9	140	19.9
600	37.8	57.7	9.0	141	20.1
750	38.7	59.4	9.2	164	20.2

* Yields for each potash rate averaged over low and high rates of N and P applied.
** Severe K deficiency with loss of leaves.

14.4 Pineapple

Potassium is a key nutrient for pineapple as regards both yield and fruit quality. A good crop of fruit removes from the field about 130 kg/ha K_2O, total uptake by the crop being almost 400 kg/ha – requirements are high.

Some fertilizer recommendations are listed in Table 82.

Table 82. Some fertilizer recommendations for pineapple *(De Geus [1973]; Py et al. [1984])*

	N	P_2O_5	K_2O	MgO
		kg/ha		
South Africa	350–400	0– 70	0– 350	
India	90–112	60	224– 240	
Puerto Rico	350–400	50– 75	125– 180	
West Africa	480–600	0–300	480–1500	
		g/plant		
Florida	12	3	11	11
Martinique	6– 7	2	10–12	2
Malaysia (peat)	8–10	–	10–12	+ copper

K fertilizer increases the yield of pineapples principally by its effect on fruit size (Fig. 31) but effects on fruit quality are at least as important or more so.

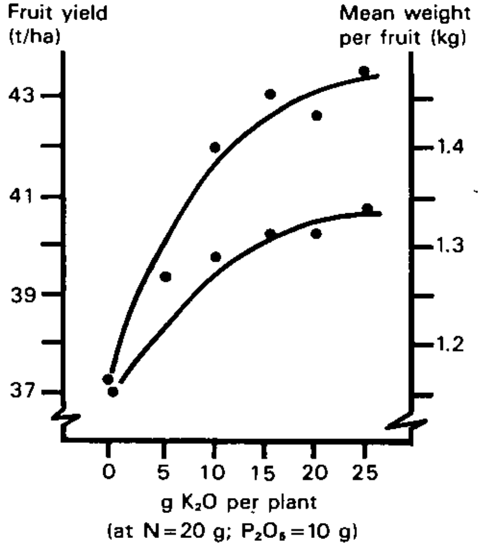

Figure 31. Effect of potassium on yield and fruit size *(Su [1969])*

Figure 32 illustrates the effects on fruit size, juice acidity and dry extract showing that while maximum fruit size (and yield) is attained at quite a moderate rate of K (6 g/plant), the quality characteristics continue to improve up to a K rate 3 times as high. The quality criteria (acidity and sugar content) are important not only from the point of view of flavour but also because low acidity is associated with internal browning, a serious defect which develops when the fruits are shipped.

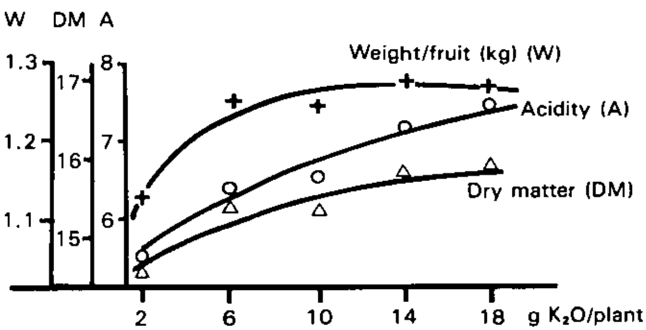

Figure 32. Effect of K fertilizer (KCl) on fruit size, acidity and degree Brix *(Marchal et al. [1981])*

The form of potash fertilizer (sulphate or chloride) is also important and this aspect has been thoroughly investigated on the Ivory Coast. Sulphate produces a larger fruit of lower acidity. When applied by dusting, sulphate results in reduced uptake of potassium because it is less soluble in water. In this experiment (Table 83), the N fertilizer was urea and it might be expected that the sulphate effect would be less in the presence of sulphate of ammonia.

Table 83. Effect of potash carrier (sulphate or chloride) on fruit size and quality. Ivory Coast *(Marchal et al. [1981])*

Method of application	Sulphate* Dusting	Leaf axil	Soil	Chloride* Dusting	Leaf axil	Soil
Weight/fruit (kg)	1.88	1.80	1.79	1.67	1.66	1.69
Acidity (me/100 ml) ..	9.2	9.5	9.4	11.9	12.1	11.8
° Brix	15.1	15.1	15.0	14.8	14.8	14.8
% K in dry matter ...	4.06	4.12	3.80	4.70	4.10	3.96

* Rate of application: 20 g/plant K_2O

The demands of yield and quality may sometimes be opposed and there is great scope for manipulation of the fertilizer programme (rate of N, rate of K and its form) in aiming for the best balance between yield and fruit quality. It is not a simple matter.

14.5 Other tropical and sub-tropical fruits

Though less important than the three major groups dealt with above, there are a number of tropical fruits which are of particular local importance and some, such as avocado, papaya, mango, which, with the growing use of air freight are already, or potentially, export crops. Because their commercial possibilities have been realised more recently and, in some cases, they are not so well suited to large scale (plantation) growing, comparatively little is known in detail about their fertilizer needs.

In general, their reaction to fertilizer is similar to that of other tree crops. In an experiment on *mango* in India yield (no. of fruit per tree) increased as the rate of K increased – 284 without K, 313 with 0.5, 346 with 1 kg and 406 with 1.5 kg K_2O per tree *(Thakur et al. [1983])*. A difficulty with mango is its tendency to biennial bearing. It can be corrected to some extent by generous fertilizer treatment.

Papaw appears to be responsive to both N and K and usual fertilizer recommendations for the bearing crop are for about 100–200 g/tree of each N, P_2O_5 and K_2O applied in two dressings, but some recommend rather more potash. Phosphate is most important in the establishment phase.

A result from Cameroon (Table 84) indicates the dominant importance of potassium on a low K soil.

Table 84. Effect of N and K fertilizer on yield (t/ha/year) of papaw *(Gaillard [1972])*

g/tree K_2O:	0	125	250
g/tree N			
0	13.6 (285)	–	–
250	11.2 (343)	40.4 (331)	45.2 (324)
500	16.6 (390)	33.2 (310)	30.0 (330)

* Mean fruit weight (g) in parentheses

In American work *(Awada et al. [1971])* applying 90 g K_2O per tree every 6 weeks through the season doubled the yield (many more fruit of larger size) and increased the soluble solids content.

Postscript

We have attempted in this little book to sketch very briefly the main principles of plant nutrition and the part soils play in the growing of crops. After dealing with general aspects of the use of fertilizers in crop production and in the maintenance and improvement of soil fertility we have dealt with the fertilizer, and specifically potash fertilizer, treatment of individual crops. It would be quite impossible in a book of this size to deal with every crop but examples have been chosen to cover a range representative of the main groups. These examples should give indications as to how other crops, not mentioned here, should be treated.

Because the book attempts to cover a vast range of conditions, only general guidance can be offered. This we hope will be useful as a starting point for those with little or no knowledge of fertilizers. We cannot, however, hope to give exact guidance for any particular set of circumstances and the reader should always seek advice from experts in the Advisory and Research Services or technical representatives of the Fertilizer Industry who will have knowledge of local conditions.

Further and more detailed information on different crops and more general matters can be obtained from the publications listed below.

Individual Crops

IPI BULLETINS "Fertilising for High Yield" Wheat, Cotton, Rice, Citrus, Maize, Avocado, Banana, Potato, Soya, Sunflower, Tobacco

More General Topics

IPI RESEARCH TOPICS

The Potassium-Nitrogen Partnership
The Need for Long-term Experiments
Potassium Sulphate and Potassium Chloride
Potassium and Plant Health

Finally, we should like to thank our many colleagues in and associated with the International Potash Institute whose help has been indispensable.

15. References

Adeniji, M. O. and Obigbesan, G. O.: The effect of potassium nutrition on the bacterial wilt of cassava. Nigerian J. Plant Phytopath. 2, 1-3 (1976)

Anderson, G. D.: Potassium responses of various crops in East Africa. Proc. 10th Colloq. Int. Potash Inst. 413-418 (1973)

Anon.: Summaries of results of potassium manurial experiments on various tropical crops. Potash Review Subj. 27, Suite 65 (1974)

Awada, M. and Long, C.: The selection of potassium index in papaya tissue analysis. J. Amer. Hortic. Soc. 96, 74-77 (1971)

Barber, S. A.: Rainfall and response. Better Crops with Plant Food 47, 6-9 (1963)

Barber, S. A.: Soybeans do respond to fertilizer in a rotation. Better Crops with Plant Food 55, p. 9 (1971)

Bennett, O. C., Rouse, R. D., Ashley, D. A. and Doss, B. D.: Yield, fiber quality and potassium content of irrigated cotton plants as affected by rates of potassium. Agron. J. 57, 296-299 (1965)

Beringer, H.: Recent data about P, K, and Na fertilizer application to sugar beet in Central Europe. Intl. Sugarbeet Inst. Winter Congress (1987)

Braunschweig, L. von and Mengel, K.: Der Einfluss verschiedener den Kaliumzustand des Bodens charakterisierender Parameter auf den Kornertrag von Hafer. Landw. Forschung 20 Sonderheft 26/1, 65-71 (1971)

Camper, H., Jones, G. and Lutz, J.R.: Phosphorus and potassium increase quality reduce diseases of soybeans. Better Crops, Fall, 27-29 (1978)

CETIOM: Fertilization of rapeseed. CETIOM Brochure 7-11 (1980)

CETIOM: Ne pas dépasser 80 unités d'azote. CETIOM Booklet 9-10 (1986)

Chevalier, H.: Potassium fertilization of apple trees. Potash Review Subj. 8, Suite 30 (1978)

Chouteau, J. and Fauconnier, D.: Fertilizing for high quality and yield Tobacco. IPI Bulletin No. 11 (1988)

CIAT: Cassava Program Annual Report, 1984

Cohen, A.: Fertilizing for high yield citrus. IPI-Bulletin No. 4 (1976)

Colyer, B. and Pohlman, G. G.: Yield and quality response of Burley tobacco to nitrogen and potassium fertilizers. Potash Review Subj. 12, Suite 16 (1972)

Cooke, G. W.: Potassium in the agricultural systems of the humid tropics. Proc. 19th Coll. Int. Potash Inst. 369-405 (1985)

Cooke, G. W. and Gething, P. A.: Changing concepts on the use of potash. Proc. 11th Congress Int. Potash Inst. 361-406 (1978)

Cottignies, X.: Potasse et Agriculture, 1-112 (1979)

Davadath, S. and Padmanabhan, S. Y.: Approaches to the control of bacterial leaf blight and streak disease of rice in India. Indian Phytopath. Soc. Bull. 6, 5-12 (1970)

De Geus, J. G.: Fertilizer guide for the tropics and subtropics, 2nd edition, 774 pp. (1973)

Du Toit, J. L.: Recent advances in nutrition of sugarcane in S. Africa. Proc. 10 Congress ISSCT, Hawaii, 432-441 (1959)

Ezeilo, W. N.: The effect of fertilizers and other inputs on yield and nutritive value of cassava and other tropical root crops. Proc. 13th Coll. Int. Potash Inst. 193-208 (1977)

FADINAP: Marketing, distribution and use of fertilizer in Malaysia, 41 pp., 1984

FAI: Annual review of fertilizer production and consumption 1986-1987. Fertilizer News 32, 10, 55-106 (1987)

FAO: Fertilizer and food production (1989)

FAO Fertilizer Programme: 20 years increasing crop yields 1961-1981 (1982)

Fauconnier, D. et al.: Response of rapeseed crops to application of potassium sulphate at the end of winter in France. Rape Congress, Paris (1983)
Fuchs, W. H. and Grossmann, F.: Ernährung und Resistenz gegenüber Krankheitserregern und Schädlinge. Handbuch der Pflanzenernährung und Düngung, Ed. *Linser, H.,* Springer Verlag, Vienna - New York, 1006-1007 (1972)
Gaillard, J. P.: Approaches to the fertilization of the "Solo" papaw tree in Cameroon. Fruits *27,* 355-360 (1972)
Garcia, R., Guijarro, R. and Diaz, B.: Changes in the nutritional status of banana due to the effect of potassium on red soils of Cuba; their relations with yield and with the control of fertilizing. Potash Review Subj. 27, Suite 95 (1980)
Gething, P.A.: The Potassium Nitrogen Partnership. IPI Research Topics No. 13 (1986)
Ghosh, A. B.: All Indian Coordinated Project in Long-term Fertilizer Experiments. Ind. Council Agric. Research Ann. Progr. Rept. (1978/1979)
Glas, K.: Sunflower - Culture and Fertilization. IPI Bulletin No. 10 (1987)
Gomes, J. F. M., Purcino, A. A. C. and Lynd, J. Q.: Soil potassium effects influencing growth, nodulation, N_2 fixation and ureide transformation of soybeans grown on a typic Eutrustox. Potash Review Subj. 13, Suite 10 (1986)
Helal, H. M.: Interaction of potassium nutrition and salt tolerance in higher plants. Potash Review Subj. 16, Suite 92 (1982)
Hernando, V.: Soil analysis, leaf analysis and fertilization of citrus. Proc. 14th Coll. Int. Potash Inst. 257-278 (1979)
Hiroce, R.: Uso da analise foliar em citros para adubaçao. Proc. 1 Simposio sobre produtividade de citros; Jaboticabal, Brazil (1984)
Ho, C. T.: Report on response of sweet potato to potash in Taiwan. Potash Review, Subj. 27, Suite 44 (1965)
Holmes, W. and MacLusky, D. S.: The intensive production of herbage for crop drying. V. Effect of continued massive applications of N with and without P and K on yield of grassland herbage. J. Agric. Sci. Camb. 45, 129-140 (1954)
Howeler, R. H.: Potassium nutrition of cassava. Potassium in Agriculture. Proc. Int. Symp. Atlanta, Ga. 819-841 (1985)
Howeler, R. H. and Spain, J. M.: The effects of potassium manuring on some crops in the tropical climate. Potash Review Subj. 16, Suite 83 (1980)
Idris, M. and Sundhu, G. R.: The effect of potash fertilizer on the yield and N_2 fixing efficiency of chickpea *(Cicer arietinum).* Potash Review Subj. 13, Suite 7 (1983)
IRAT: Annual Report (1981)
Juo, A. S. R.: Potassium response in root and tuber crops. Proc. 19th Coll. Int. Potash Inst. 277-288 (1986)
Kang, B. T.: Potassium and magnesium responses of cassava grown in Ultisol in southern Nigeria. Fertilizer Research 5, 403-410 (1984)
Kemmler, G. and Hobt, H.: Potash - a Product of Nature. Kali und Salz AG, Kassel (1986)
Koch, K. and Mengel, K.: The influence of the level of potassium supply to young tobacco plants. J. Sci. Fd. Agric. 25, 465-471 (1974)
Koo, R. C. J. and Reese, R. L.: A comparison of potash sources and rates for citrus. Proc. Fla. State Hortic. Soc. 85, 1-5 (1972)
Lahav, E. and Turner, D. W.: Fertilizing for high yield banana. IPI-Bulletin 7 (1983)
Liang De-yin: The effect of potash fertilizer on plantation crops in China. Potash Review Subj. 27, Suite 107 (1982)
Lin Bao: The effect of potassium fertilizer on wetland rice in China. Potash Review Subj. 9, Suite 65 (1984)
Llanos Company, M.: Experiments on the fertilization of tobacco. Potash Review, Subj. 12, Suite 23 (1984)
Loué, A.: Le sulphate de potasse. Dossier K_2O No. 11 SCPA (1978a)
Loué, A.: The interaction of potassium with other growth factors, particularly with other nutrients. Proc. 11th Congress Int. Potash Inst. 407-434 (1978b)

Mahapatra, I. C., Prasad, R., Krishnan, K. S., Goswami, N. N. and Bapat, S. R.: Response of rice, jowar, maize, bajra, groundnut and castor to fertilizers under rainfed conditions on farmers' fields. Fertilizer News 18, 18–25 (1973)

Mainstone, B. J. and Thong, K. C.: Fertilizer responses over 6 years from planting of monocrop cacao on a Bungor series soil. Internat. Conf. Cocoa and Coconuts, Kuala Lumpur (1978)

Marchal, J., Pinon, A. and Teisson, C.: Effets de la forme d'engrais potassiques sur la qualité de l'ananas en Côte d'Ivoire. Fruits 46, 737–742 (1981)

Mascarenhas, H., Hiroce, R. and Braga, N.: Adubação da soja. Efeito do enxofre e de varios micronutrientes. Bragantia 26, 373–379 (1967)

Merrien, A., Arjaure, G. and Maisonneuve Catherine: Besoins en éléments minéraux (majeurs, mineurs et oligo-éléments) chez le tournesol dans les conditions françaises. Inf. Techniques CETIOM 95 (1986)

Moberley, P. K.: Nutrient requirements of irrigated sugarcane grown on soils of the Hutton form at Pongola. Potash Review, Subj. 27, Suite 105 (1983)

Muthuswamy, P. and Chiranjivi Rao, K.: Influence of potassium and nitrogen fertilization on tuber yield and starch production in cassava varieties. Potash Review, Subj. 27, Suite 91 (1979)

Nambiar, K. K. M. and Ghosh, A. B.: Highlights of research of a long-term fertilizer experiment in India. LTFE. Research Bulletin No. 1. Indian Agricultural Research Institute, New Delhi, 100 pp. (1984)

Naude, C. J.: Fertilization of citrus. Farming in S. Africa 29, p. 34 (1954)

Ng, Siew Kee and Thong, Kar Cheong.: Nutrient requirements for exploiting yield potentials of major plantation tree crops in the tropics. Proc. 19th Coll. Int. Potash Inst. 81–96 (1985)

Nuclear Instit. for Agriculture and Biology (Pakistan): "Ten Years of NIAB", 79–81, NIAB, Faisalabad (1982)

Ollagnier, M.: Interaction entre l'azote et le potassium dans la nutrition des oléagineux tropicaux. Proc. 10th Coll. Int. Potash Inst. 215–231 (1973)

Ollagnier, M. and Mardiana Wahayuni.: Potassium and chlorine nutrition of the hybrid coconut palm. Potash Review Subj. 27, Suite 116 (1986)

Ollagnier, M. and Olivin, J.: Effects of potassium nutrition on the productivity of the oil-palm. Potash Review Subj. 27, Suite 115 (1986)

Orlando, F. J., Zambello, E., and Rodella, A. A.: Calibration of soil potassium and fertilizing recommendations for the sugar cane. Potash Review Subj. 27, Suite 100 (1982)

Osiname, O. A. and Kang, B. T.: The effect of potassium fertilizer on maize yield and calcium, magnesium and potassium status in an oxic paleustalf in S. W. Nigeria. Potash Review Subj. 9, Suite 68 (1986)

Ouvrier, M. and Ochs, R.: Exportations minérales du cocotier hybride Port-Bouët 121. Oléagineux, 33, 437–443 (1978)

Palmer, G. M. and Steven, D. B.: Potatoes fertilizer timing in relation to yield and quality. Potash Review Subj. 11, Suite 24 (1982)

Perrenoud, S.: Fertilizing for high yield potato. IPI Bulletin No. 8 (1983)

Perrenoud, S.: Potassium and Plant Health. IPI Research Topics No. 3 (1989)

Peter, A. von: The role of potassium in world agriculture. Proc. Joint Int. Potash Inst. and FSSA Int. Seminar "The role of potassium in crop production", Pretoria, 13–23 (1980)

Pethiyagoda, U. (ed.): Handbook on coconut cultivation. Coconut Res. Inst. Sri Lanka (1980)

Pieri, C.: Potassium fertilization of pennisetum millet and its effects on the fertility of a sandy soil in Senegal. Potash Review Subj. 27, Suite 101 (1982)

Potash Research Inst. of India: Annual Rept. 1985/86 (1986)

Prummel, J.: Potassium manuring and potato quality. Potash Review Subj. 11, Suite 25 (1981)

Pushparajah, E. and Tajuddin, Ismail: Potassium in rubber cultivation. Phosphorus and Potassium in the Tropics, 293–314, Malaysian Soc. Soil Sci. (1982)

Py, C., Lacoeuilhe, J. J. and Teisson, C.: L'ananas, sa culture, ses produits, 562 pp. (1984)

Quemener, J.: The Measurement of Soil Potassium. IPI Research Topics No. 4 (1979)

Randhawa, N. S. and Velayutham, M.: Research and development programmes for soil testing in India. Fertilizer News 27, 35–64 (1982)

Reddy, K. C. K. et al.: Soil test-based fertilizer prescriptions for yield targets of crops. Extension Bulletin All India Coordinated Research Project on Soil Test Crop Response Correlation Studies, 106 pp. (1986)

Rodriguez-Gomes, M.: Estudios preliminares sobre la nutricion con potasio de los bananales en America central. Fruits 35, 283–294 (1980)

Schroeder, D.: Soils – Facts and Concepts. Int. Potash Inst., 1984

SCPA: Detailed results of field trials (1986)

Sekhon, G. S. and Puri, D. N.: The input-output balance of plant nutrients in some intensive multiple cropping systems in India. Paper presented at the FAO/FIAC TSC meeting, Rome, 1–21 (1985)

Sharma, P. C., Jain, K. N. and Biswas, A. K.: Response to nitrogen, phosphate and potash in mature tea. Proc. 28th Tocklai Biennial Conf. 1977, 31–34, Tocklai, Jorhat (1978)

Shyn, Y. T. and Cheng, H. H.: Effects of phosphorus and potassium levels and plant spacing on the yield and protein content of *Dioscorea alata*. J. Agric. Res. of China, 27, 315–324 (1978)

Siebold, M.: The influence of potash on stem rot in grain maize. Potash Review Subj. 23, Suite 44 (1974)

Singh, L. and Balasubramaniam, V.: Crop responses to potassium on the savanna soils of Nigeria. Fert. Res. 4, 181–190 (1983)

Skogley, E. O.: Potassium in Montana soils and crop requirements. Montana Agr. Exp. Stn., Bozeman, Res. Rept. (1976)

Sonar, K. R.: Fertilizer recommendations based on soil test crop response. Highlights of Research 1978–1984, MPAU, Ruhuri. 39 pp. (1984)

Stangel, P. J.: N-K means high corn profit. Better Crops 49, 8–13 (1965)

Stoch, L. and Fölscher, W. J.: Potassium as a constituent of balanced nutrition with special reference to maize culture. Proc. Joint IPI and FSSA Int. Seminar, Pretoria, 73–82 (1980)

Su, N. R.: Research on fertilization of pineapples in Taiwan. Soc. Soil Sci. Fert. Tech. of Taiwan Spec. Publ. 1 (1969)

Terman, G. L.: Yields and nutrient accumulation by determinate soybeans as affected by applied nutrients. Agron. J. 69, 234–238 (1977)

Tiwari, K. N., Nigam Vandana and Pathak, A. N.: Studies on the potassium nutrition of different crops. Fert. Res. 8, 91–96 (1985)

Thakur, R. S., Chadha, K. L., Samra, J. S. and Rajput, M. S.: Yield, and leaf potassium status as influenced by potassium application in mango *(Mangifera indica L.)*. Potash Review, Subject 27, Suite 108 (1983)

Uexkull, H. R., von: Aspects of fertilizer use in modern high-yield rice culture. IPI Bull. No. 3 (1979)

Uexkull, H. R., von: Potassium nutrition of some tropical plantation crops. Proc. ASA, CSSA, SSSA Symp. "Potassium in Agriculture" Atlanta, Ga., 929–954 (1985)

Uribe-Henao, A. and Mestre-Mestre, A.: Efecto del nitrogeno, el fosforo y el potasio sobre la produccion de cafe. Cenicafe 27, 158–173 (1976)

Usherwood, N. R.: The role of potassium in crop quality. Proc. ASA, CSSA, SSSA Symp. "Potassium in Agriculture", Atlanta, Ga. 1985, 489 (1985)

Vicente-Chandler, A., Pearson, R. W., Abruna, F. and Silva, S.: Potassium fertilization of intensively managed grasses under humid tropical conditions. Agron. J. 78, 450–453 (1962)

Willson, K. C.: Studies on the mineral nutrition of tea. IV. Potassium. Plant and Soil 43, 279–293 (1975)

Winsor, G. W.: Nutrition - Effect of K on fruit quality. In U. K. Tomato Manual ed. *H. G. Kingman.* Grower Books, London (1973)

Yoshi, H., Kaba, S. and Watanabe, B.: On the scale for estimating the degree of damage in rice by stem rot. Annals phytopath. Soc. Japan 8, 3-4 (1949)

Zehler, E., Kreipe, H. and Gething, P. A.: Potassium sulphate and potassium chloride. IPI Research Topics No. 9 (1981)

Zhu, Wei-he and Wen, Y. C.: A study on the response to fertilizer potassium on paddy soils in Guangdong Province. Proc. Academia Sinica Symp. on Paddy Soils, 809-815 (1981)