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Improving Returns from Nitrogen Fertilizer

The Potassium-Nitrogen Partnership

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International Potash Institute Basel / Switzerland
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Synopsis

The introductory chapter (1) shows how recent advances have increased the potential of agriculture. In commenting on the pattern of fertilizer usage worldwide it shows how, in some areas, there is a lack of balance which gives cause for concern.

The second chapter indicates how the efficiency of nitrogen fertilizer, i.e. the return in increased crop per unit of N used or, more importantly, per unit cash spent on N fertilizer, depends upon the potassium nutrition of the crop. It quotes many examples showing how attention to the potassium needs of the crop ensures a better return from nitrogen and how, when crops are deficient in K they cannot respond to N fertilizer. It draws attention also to the effects of potassium on crop quality and resistance to disease and to the special significance of potassium for legumes.

Chapter 3 discusses examples of the effect of cropping without replacing the potassium removed from the soil on soil fertility and underlines the need to consider fertilizer policy in the long term and to investigate potassium requirements in long term experiments rather than in annual trials.

The conclusion draws the threads together and emphasizes the importance of the nitrogen-potassium 'partnership' and the need for balanced fertilization.

1. Introduction

1.1. Changing agriculture

Agriculture has developed throughout its long history as knowledge progressed but change recently has been at a staggering rate and in a matter of thirty years or so the whole situation has altered out of all recognition. The result has been to increase potential production manifold.

Two statistics from widely separated countries will illustrate the magnitude of the change in recent times.

- 25 years ago, the average wheat yield on all English farms was about 4 tons per hectare: in 1984 it was 7.7 **t/ha**.
- 25 years ago, the total amount of grain produced in India was about 80 million tonnes: today it is about 125 million.

Agriculture is everywhere coming under the same pressures and is forced to react by producing ever more and more. Though progress may not have been at the same rate all over the world, the same factors are operating in both developed and less developed parts.

The most important factor operating to change agriculture is the sheer need to increase crop yields in order to support the growing population of the world and to supply the higher standards of living which people now demand. This puts pressure on the land which is seen in shortening of fallow periods and more intensive cropping. The land can only supply from its own resources.limited support for crop growth. Return of crop residues directly to the land or through the animal and the most careful conservation of all such residues can at best only maintain the land in its initial state of fertility. If production must be increased, soil fertility must be increased. Fertility can only be increased by importing nutrients in the form of fertilizer; in intensive livestock systems, it can be imported in the form of animal feeds, though this is to the detriment of the fertility of the land producing those feedstuffs. It is inevitable that agricultural production must be increased - failure means starvation.

The chief means of increasing production are:

1. ***Improvement of soil fertility through addition of nutrients in the form of fertilizers. Alongside this, the conservation of fertility by efficient use of farm and other wastes.***
2. ***The use of improved crop varieties. The plant breeders have been most successful in recent years in their quest for higher yield.***
3. ***Pest and disease control. Here also the agricultural scientist has had great success in developing new chemicals, and methods of applying***

them, and has developed biological systems of control which make it possible to control many of the afflictions of crops which reduce yields.

4. *Proper cultural methods - drainage, irrigation, cultivation, rotation, etc. and efficient management.*

Which is the most important of these improvements does not matter greatly. What is true is that in order to succeed, the farmer has to adopt all. It is surely only a matter of common sense that the modern variety of wheat or rice which can, under the right conditions, yield two, three or four times as much as the traditional varieties used by our grandfathers will need two, three or four times as much plant food. Cereal yields in particular have increased to such an extent that, whereas traditionally they were regarded as having minimal needs for potassium, they are now K-demanding. The modern cereal is virtually a new crop.

Wherever farmers have not appreciated the scale of the changes which have taken place, they have not been able to benefit from the new methods. In some countries they did not realize the full benefit of the *'Green Revolution'*, founded on the introduction of high-yielding crop varieties, because they failed to supply the other elements of the package which would ensure success or, maybe, they were unable to obtain the necessary inputs.

1.2. Fertilizer usage

Figure 1.1. shows how consumption of nitrogen, phosphorus and potassium has grown since 1920, before which fertilizer was little used anywhere in the world. A notable feature is that since the late fifties, up to when consumption of P and K was higher than N, nitrogen usage has shot up so that now N consumption is twice as high as P and 2½ times as high as K. What gives greater cause for concern, though, is illustrated in Figure 1.2., which shows the great disparity in N:P:K ratio between different parts of the world. Obviously soil conditions, crops and conditions may vary greatly between areas but it is still worrying that in Asia the N:K ratio approaches 10:1 compared with around 2:1 in Europe and North America.

Fertilizers have a longer history in Europe and North America than in other parts of the world. The early history of fertilizer use in the developed countries up to the first half of the present century showed a steady increase in usage of phosphate and potash, with nitrogen trailing behind. There were two reasons for this: Farming until the second World War was largely based on the maintenance of fertility through livestock fed on leguminous fodder crops and grass-clover leys. Fertilizer nitrogen was expensive and not too plentiful. With the advent of cheap and plentiful N fertilizer and a shift from livestock husbandry to the growing of cash crops and reliance on N to grow grass rather than on legumes in the swards, nitrogen usage increased sharply. The N:K ratio in Europe changed from approximately 1:1.26 in 1950 to 1:0.5 in 1983. One reason why it has been possible to sustain these high rates of N is the long history of reliance on P and K which has built up basic fertility. Even so, there are signs that the swing to nitrogen may have gone too far.

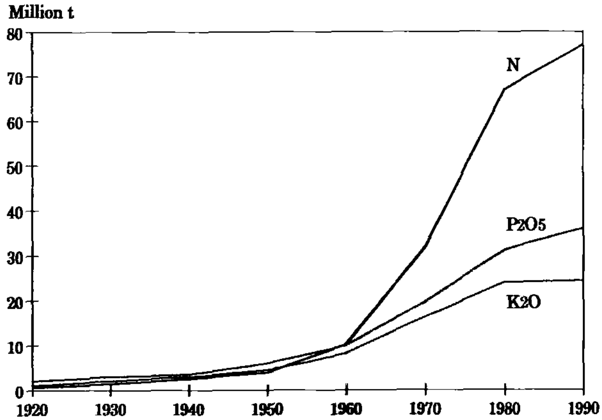


Fig. 1.1. Fertilizer consumption since 1920 in million tons N, P_2O_5 and K_2O

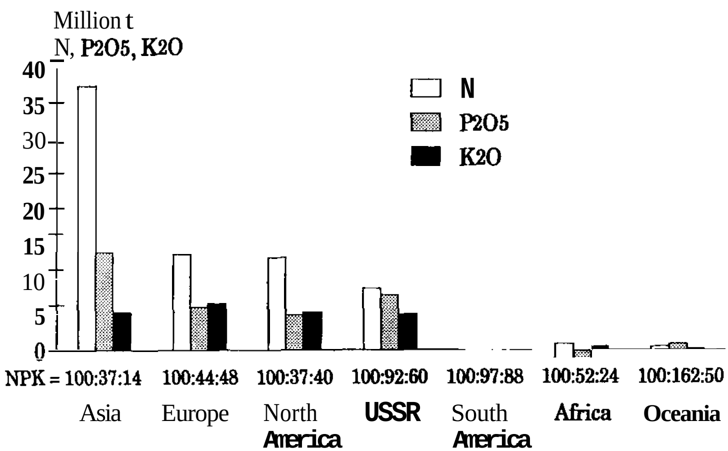
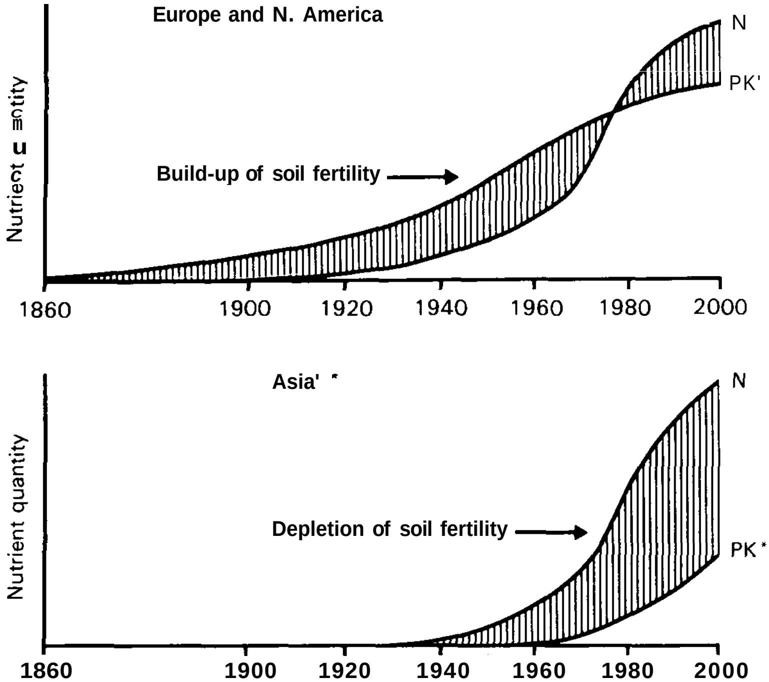


Fig. 1.2. Regional fertilizer consumption 1990191 (FAO)

For the first half of this century, fertilizer usage in the developing countries was very low and increased interest in fertilizers came about after nitrogen had become relatively cheap and plentiful. Farming in these areas did not rely much on legumes and there was no history of phosphate and potash usage.



* P and K followed similar trends and are shown in one line.

** Asia minus Japan

Fig. 1.3. Trends in usage of N in relation to P and K in Europe and North America compared with Asia

Nitrogen, when it was introduced, produced quite spectacular effects on crop yield and it is small wonder that N consumption increased rapidly. Neither is it altogether surprising that the need for P and K was not appreciated - early trials with these fertilizers, and particularly with potash , showed little effect, because the land had not yet been put under strain and the K requirements of the traditional, low-yielding crops were modest and within the soil's capacity to supply.

The contrast in fertilizer use development between Europe and North America on the one hand and Asia, as an example of a developing area on the other, is illustrated in Figure 1.3. (von Uexküll, 1984). The countries with the longer history of fertilizer usage are benefitting from the reserves of fertility built up from applications of P and K in the earlier years when farming systems were more conservative. The newer countries, which have jumped on the 'nitrogen bandwagon' without the preceding basic fertility build-up are depleting their soils of fertility. The depletion process is being speeded up by the pressure of population increase calling for more intensive use of the land and by the introduction of varieties of higher yield potential.

1.3. Balance

In the old days before there were any fertilizers on the market, farmers relied on farmyard manure to maintain soil fertility and to improve their crops. In the nature of things farmyard manure is balanced because it originates from crop and animal residues and contains plant nutrients in roughly the same proportions as those in which they are found in crops and so may be expected to reflect the crops' needs. Balance is an underlying principle of good husbandry.

In the first half of the nineteenth century Justus von Liebig, basing his approach to the feeding of crops on analyzing plants to find out what they contained, and which it might be presumed they needed, tried out the effects of applying the substances he found in plant ash. As a result of this work he published in 1841 the "Law of the Minimum" which stated that the amount of plant growth is regulated by the factor present in minimum amount. The practical effect of this law is that if two factors (in the case of the sugar beet experiment referred to in chapter 2, nitrogen and potassium) are limiting growth, adding only one of them may have little effect, but the effect of adding both together is spectacular. The idea of interaction was implicit in this law and nothing has happened since 1841 to suggest that the law has any defect.

When fertilizers came on the scene, because they - particularly the nitrogen fertilizers - can produce spectacular effects on plant growth, the risk arose that insufficient attention would be paid to balance. Indeed, in the early days fertilizer somethimes got a bad name and was compared unfavourably with the good old-fashioned muck.

Though the need for balance in the feeding of crops has been known for so many years it is not always observed in practice by farmers and extension workers, the more so in parts of the world where fertilizers have only recently been introduced. The effects of nitrogen are easily seen; crops look more vigorous and yield better, but if the farmer uses only nitrogen he may do well the first time but the second time he uses it the results are not quite so good and if he persists in this one-sided policy the results get poorer year after year until the final state is worse than the first, and his neighbours, who have stuck to the old-fashioned ways, are doing better than the innovator. Of course there is no need for this to happen. A little thought shows that the crops are taking from the soil substances other than nitrogen and supplies of these have to be replenished if things are to remain in ***balance.*** Just as 'man cannot live by bread alone', so the plant cannot live by nitrogen alone. Like man, the plant has to have a complete diet.

It would be difficult to find a better illustration of the dangers implicit in unbalanced fertilizer usage than that given by Lin Bao (1984). Fertilizer experiments on the rice crop have been carried out in China for a great many years. In 1958, 29% of 62 field experiments in the ***National Network of Fertilizer Experiments Scheme*** responded to potassium: in 1982 63% of 260 experiments responded. The average response to N expressed as kg grain per kg N was 16,5 in 1958: In 1982 it was only 10.1! At the same time, the overall average response to potassium increased from 3.8 to 5.8 kg grain per kg K_2O. Using 1984 world prices of US$ 0.50 per kg N as urea, $ 0.25 per kg K_2O and $0.185 per kg padi, unit expenditure on N in the 1958 situation would have given a return of 6.1 units in value of crop, while the comparable figure for 1982 would be only 3.7. The efficiency of nitrogen fertilizer is only 60% of what it was originally!

The principle of balance is well-known to scientists from the results of their experiments and to farmers from their ingrained notions of husbandry, practical experience in watching their crops or even perhaps folklore, but it is not always strictly observed in practice. The desire for a quick profit or, maybe, untimely advice from an over-zealous fertilizer salesman can put the uncritical farmer on the broad way that leads on to destruction. We shall point to the strait gate and the narrow way which leads to success. In the context of farming, it is not so hard to find.

The main points emerging from this preliminary discussion are:

- that there are indications that fertilizer usage in some areas is unbalanced;
- that the plants needs a ***complete*** or ***balanced*** ration of nutrients;
- that the ill-effect of unbalanced feeding are cumulative, due to exhaustion in the longer term of soil reserves of one or another nutrient.

2. Interactions

More than a hundred years ago, in 1871, Sir John Lawes of Rothamsted started an experiment on sugar beet, at that time a crop new to England. The crop was grown for three years in succession on plots receiving annually various combinations of fertilizers. Sugar yields given by selected treatments of this experiment are shown in Table 2.1.

The effect of applying potash in addition to phosphate was to increase the response to the high rate of nitrogen from only 2.6 t/ha to over **4.3** t/ha and to give a yield from the fertilizer treatment appreciably in excess of that obtained by using the traditional (35 t/ha) dressing of farmyard manure. This spectacular effect of potash came about partly through improving the yield of roots but in large measure also because potash counteracted the tendency for sugar content to be lowered by high rates of nitrogenous fertilizer. Nowadays we use the term 'interaction' to describe this type of phenomenon and this means that the effect of applying two nutrients together is greater, rarely less (negative interaction), than the sum of the separate effects of the two nutrients when applied on their own. This text deals with the effects of potassium on the response of crops to nitrogen fertilizers and is essentially about ***interactions.***

Table 2.1. Average sugar yields (t/ha) 1871 to 1873 (Hall, 1905)

Mineral fertilizer	Nitrogenous fertilizer		
	Nil	96 kg/ha N*	206 kg/ha N**
Superphosphate only	2.09	4.31	4.70
Superphosphate + Sulphate of potash	2.06	4.92	6.39

* As ammonium salts
** As ammonium salts + rapeseed cake

2.1. Measuring interactions in experiments

Fertilizer experiments in the field set out to measure the effect of applying in combination several rates of two or more nutrients. The aim is to find the best combination of nutrient types and rates for the area in which the experiment is done. When sufficient consistent results are available they can be used as a basis for making fertilizer recommendations. Of course the number of treatment combinations that can be tested in an experiment depends on the space available and on the availability of other resources. There is always a conflict between carrying out a small number of very detailed experiments or a large number of much simpler trials to cover the farming conditions over an area as a whole. While the case for the latter approach is most understandable, particularly when there is little accumulated experience upon which to base recommendations, the averaging of large numbers of such results in order to obtain a general guide often conceals as much as it reveals. This may not matter in the early stages following the introduction of fertilizers into a country. After all, some fertilizer is better than none and even if the recommendations are not such as to achieve optimum results, they will be sufficiently good to make it possible for most farmers to increase their crops well above what they have been able to grow in the past.

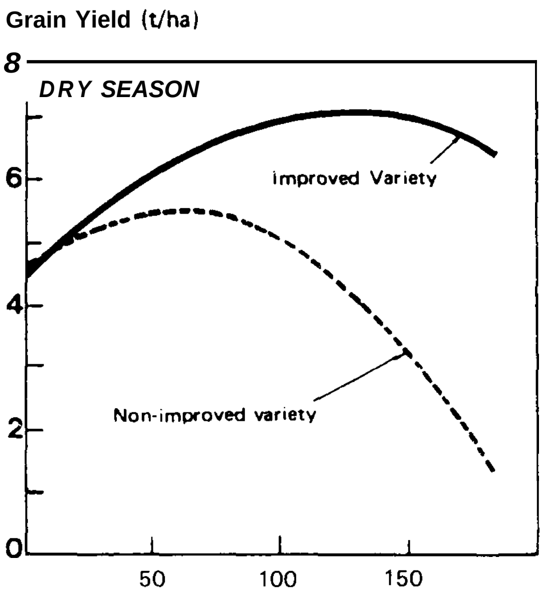


Fig. 2.1. Typical response curves. Response of two varieties of rice to increasing nitrogen (von Uexkiill, 1976)

Until fairly recently field experiments tested at the most three rates of fertilizer and, if for instance the three main nutrients (NPK) were under test, this, without allowing for the safeguard of replication, required 27 plots.

Results from this kind of experiment seemed to indicate that crops responded to increasing nutrient in the way illustrated in Figure 2.1. However, this shape of the response curve arose largely because it was convenient for concise statement of results to assume that the response took a curved shape. Recently, more complex designs have been used for experiments and this has made it possible to test a much larger range of application rates (as many as eight or nine) and yet keep the size of the trial within bounds. This has shown that it is more usual for response to fertilizer to follow a straight line (or two or more intersecting straight lines), yield rising with increasing fertilizer up to a plateau when, if more fertilizer is applied yield increases no further (Boyd *et al.*, 1976).

The reason for yield reaching a plateau may be limiting supplies of another nutrient, and if this is supplied yield will continue to increase linearly until another plateau is reached because something else, which may be supply of a third nutrient or some other factor (*e.g.* sunlight, water or genetic potential of the test crop) becomes limiting. This is precisely the state of affairs described in Liebig's Law of the Minimum and is illustrated in Figure 2.2. showing in schematic from results of a fertilizer trial with N and K on potatoes.

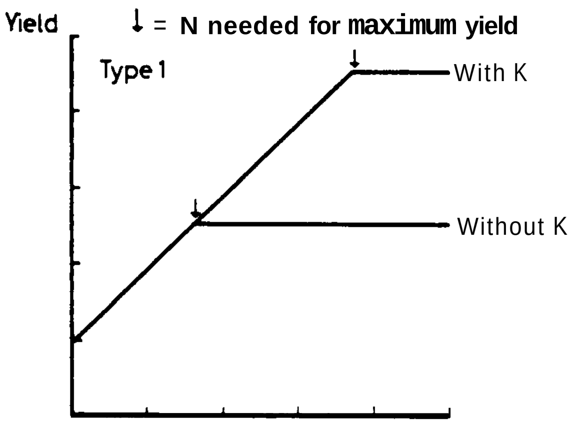


Fig. 2.2. Interaction. When K limit is corrected, crop responds to more N up to 2nd plateau (Cooke and Gething, 1978)

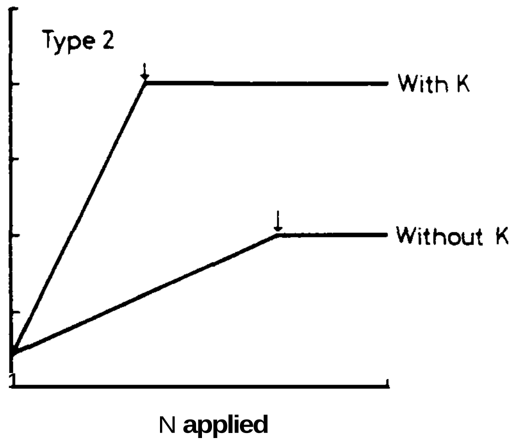


Fig. **2.3.** Interaction. Adding K changes form of N response (Cooke and Gething, 1978)

There seems to be another type of interaction. In the example above for potatoes, the gradient of the response to increasing N fertilizer was the same whether with or without K. In the other type (Figure 2.3.), applying K raised the plateau in a manner similar to the first example but it also changed the way in which the crop responded to N by making the gradient steeper. The result is a double bonus from potash: the plateau yield is raised and the plateau is reached at a lower level of N. The second bonus for the farmer is a considerable saving in nitrogen fertilizer. In discussing these aspects, Boyd (1976a) wrote: 'Indeed, with barley and potatoes adding more K fertilizer can so increase the efficiency of N use as to double yield while halving N requirement.'

In the above examples, there was no response to K in the absence of N. It is perhaps more usual for there to be separate responses to the two nutrients, giving rise to the type of response patterns illustrated in Figure 2.4.

This discussion may seem a little academic; it may not apparently matter a great deal to the practical man what shape the response curve takes but it does contribute to the understanding of the way in which crops respond to fertilizers. Also, if the graphical representation of the response is erroneous, this may result in serious miscalculation of the optimum rate, setting it higher than would be indicated by intersecting straight lines. In practice, response curves are often not straight lines and this seems to be due to the interference of other factors like, for instance, disease, the severity of which can be aggravated by unnecessarily high rates of fertilizer, especially N. In such cases, the response overturns and yield actually declines as fertilizer is increased above the optimum rate in a manner similar to that illustrated in Figure 2.1.

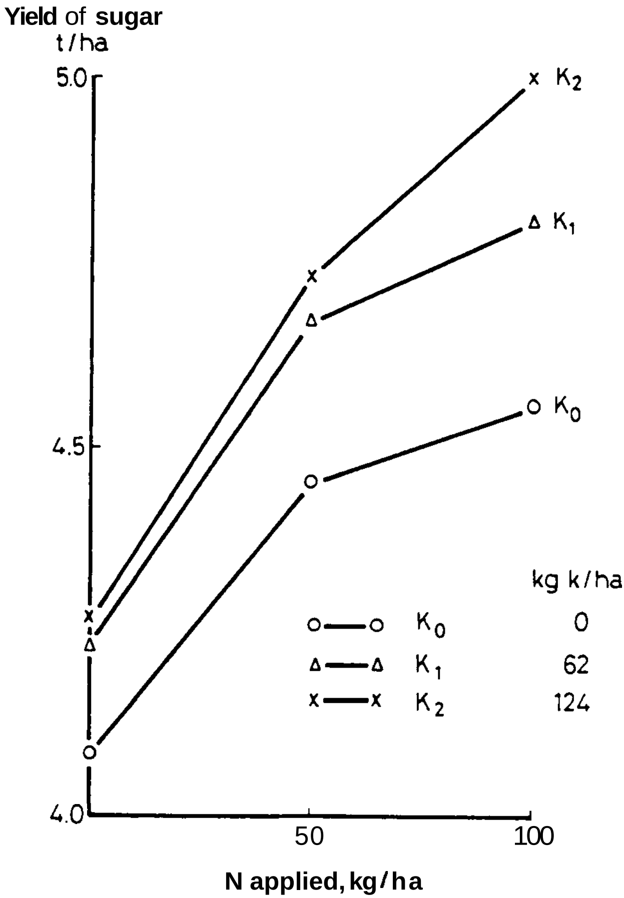


Fig. 2.4. Response patterns showing additive effects of N and K and interaction (Cooke and Gething, 1978)

When we are concerned with three fertilizers, *e.g.* N, P and K the picture becomes more complicated as each may affect the behaviour in response to either or both the others, *i.e.* P and K may each improve the N response (positive two-factor interactions) while there may be a further bonus in the mutual interaction of all three nutrients - NK>(N+K), N>(N+P), NPK> (N+K+P+NK+NP). Here, however, we shall confine ourselves to the simple two-factor interaction NK (or N×K).

2.2. Examples of N×K interactions

2.2.1. Temperate arable crops and grass

The *Agronomy Department* of the *French Potash Industry (SCPA)* studied the interaction of nitrogen and potassium in series of experiments on their experimental farm at Aspach and on practical farms throughout France. The results were reviewed by Loué (1978). The experiments covered a whole range of crops grown in rotation, including potato, wheat, barley, maize, sugar beet, grass and grass-clover mixtures. The strongest interactions were shown by the more potassium demanding crops, *i.e.* potatoes and sugar beet and also maize; those experienced with wheat and barley were much smaller. It is important to note that in the rotation experiments at Aspach, the so-called K_0 treatment, which received no K fertilizer, was not potassium-starved since it received dressings of farmyard manure, calculated to supply 42 kg/ha K per annum. The results are summarized in Tables 2.2. (Aspach) and 2.3. (Experiments on commercial farms).

The yields in Table 2.2. are means derived from the 20 seasons for which the experiment ran; there was a good deal of variation from year to year. The interactions are illustrated in Figure 2.5. which show the computed response curves, the shaded area representing the interaction between the extreme rates of N and K.

Results from experiments on French commercial farms are given in Table 2.3 where the mean calculated optimum rates of N and K are given together with the interaction at those levels.

Table 2.4 shows the responses to nitrogen (N at 440 kg/ha - N at 100 kg/ha) at different rates of potassium in another experiment at Aspach in which cocksfoot was cut for silage. The figures are means over 10 years. As in the British grassland experiments cited in a later section (see 3.1) the interaction effect increased with the passage of time.

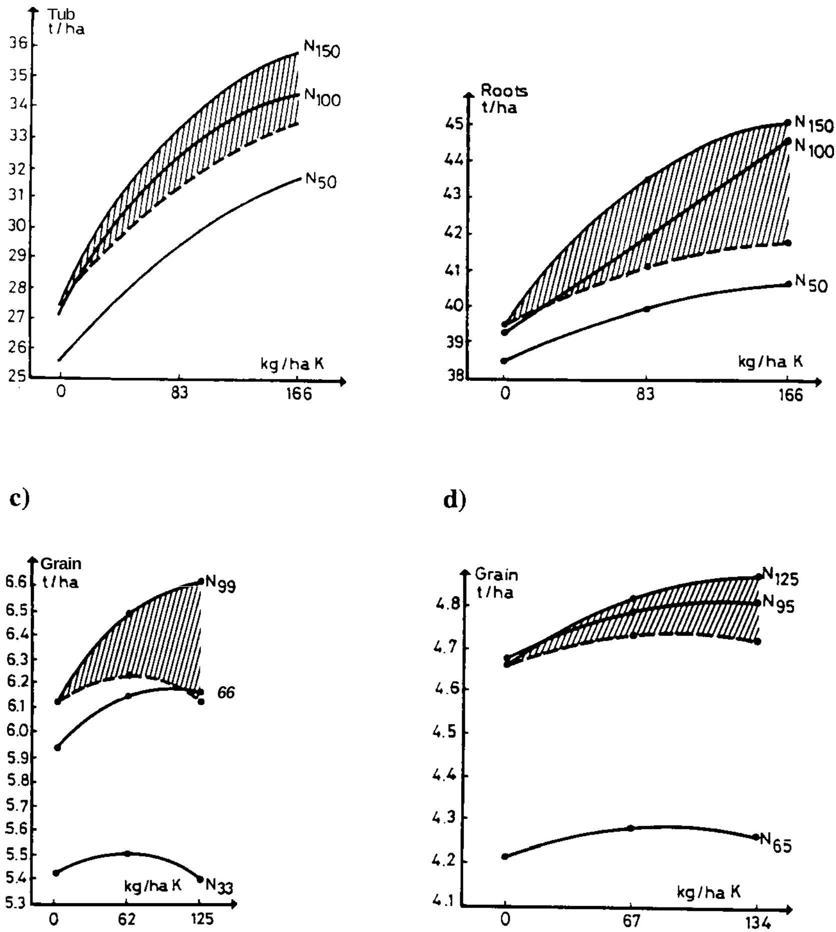


Fig. 2.5. N×K interaction in French experiments a) potatoes (17 crops), b) sugar beet (18 crops), c) maize (9 crops), d) wheat (13 crops)

Table 2.2. Main effects and interactions in a long-term experiment at Aspach

Crop	Fertilizer applied (kg/ha)			Yield (t/ha)	Effects (t/ha)		
	N_1	N_3	K_2*	at N_1K_0	N_3-N_1	K_2-K_0	N×K**
Potatoes	50	150	167	25.6	3.3	7.4	2.30
Sugar beet	50	150	167	38.5	3.0	4.4	3.60
Maize	33	99	125	5.5	0.95	0.22	0.26
Wheat	65	125	133	4.25	0.52	0.13	0.08
Barley	30	70	133	3.33	0.59	0.23	nil

* kg/ha K to crop, control received K only from FYM

** Int. = $(N_3K_2\text{-}N_1K_2) - (N_3K_0\text{-}N_1K_0)$

Table 2.3. Calculated optimum rates of N and K and interactions at these levels. Experiments on French farms

Crop	Optimum rates (kg/ha)		N×K interaction (t/ha)	Number of experiments
	N	K		
Potatoes	168	224	3.40	11
Sugar beet	142	213	5.20	16
Maize	127	132	0.60	56
Wheat	104	95	0.36	65
Barley	88	94	0.36	24

Table 2.4. Effect of N on yield (t/ha DM) of cocksfoot receiving various rates of K

	K (kg/ha)			
	0	125	250	375
N_{440} - N_{100}	0.95	2.17	3.15	4.55

These results are in general agreement with results obtained elsewhere, mainly in the U.K.: on potatoes by Boyd (1961), Inkson and Reith (1966), Simpson and Crooks (1961), Widdowson and Penny (1961); on sugar beet by Draycott (1972), Gallagher (1967), Mcdonnell (1966), Tinker (1965), Widdowson and Penny (1967).

It may be remarked that in these SCPA experiments and in others to which reference is made above, the yields, particularly for cereals, are rather low by modern standards as are the rates of N and K tested. In several cases in the French experiments, the calculated optimum fertilizer rates fell outside the range actually tested in the experimental dressings, indicating that higher rates of fertilizer might have been profitable. Cereal yields in Europe, especially of wheat, have increased very much in recent years, mainly as a result of plant breeding and better disease control, supported by correct fertilizer treatment.

The new crop varieties are very responsive to N, indeed they need generous N fertilizer treatment in order to realize their potential, and rates now generally used by farmers are much higher than they were a few years ago. It is to be expected that N×K interaction effects would be greater at these higher yield levels and it is certainly true that the higher yields now commonly obtained must impose a greater strain on soil reserves of potassium. Statistics of fertilizer usage by farmers in Europe show that, as yields have increased and as more nitrogen fertilizer has been used to obtain these high yields, potash application to cereals has also increased, a tendency which is most marked in those countries like the U.K. where potash usage on cerals in the past has been conservative in comparison with, for example, Germany, Belgium and the Netherlands where there has for many years been something of a 'potash tradition'. It must seem that farmers in countries which have long been familiar with fertilizers are quite well aware of the need to adjust fertilizer nutrient input in line with changing circumstances.

There is not very much recent experimental evidence on interactions in the developed parts of the world. There are historical reasons for this. These countries have been applying regularly phosphate and potash for 80 years or more with the result that it is rare to obtain large responses to these two nutrients, and the policy with regard to P and K manuring is increasingly to cater for the long term needs, supplying K, mainly applied to the more responsive crops like potatoes and beet, to cover the needs of the crop rotation as a whole. P and K requirements in these areas are now quite well known and there is a general assumption, not entirely without foundation, that if the general advisory recommendations are followed, no problems should arise with either P or K supply to crops. Further, on the basis of current fertilizer and produce prices, the cost of ***insuring*** a crop against the loss of yield , which is the penalty when P and K decline, is low.

It is not at all easy to forecast the need for nitrogen. There will be consider-able yield loss if too little N is used. There will also, at the least, be a waste of fertilizer if too much N is applied, and, at the worst, yield may even decline. Unlike P and K, surplus N does not remain in the soil to benefit future crops. Hence priorities in agronomic research have shifted towards attempts to identify N requirement more closely and towards the control of disease. In such experiments it is usual to apply comparatively generous rates of P and K overall in order to avoid yield limitation by a lack of these and to investigate N response in greater detail, using a wide range of rates, and to investigate the interactions of N with disease control measures and other cultural factors. The fashion is for large and complex experiments which attempt to identify the factors which limit the yields obtained on practical farms. Though national average yields of wheat in the U.K. increased from about 4 t/ha in1970 to over 7.5 t/ha in 1984, these were still well below the known potential of some 15 t/ha and also below what is regularly achieved on some farms and on experiment stations - in excess of 10 t.

*2.2.2. **Tropical arable crops***

Rice

Most traditional wet rice soils are comparatively well supplied with K and there are usually sizeable additions through the water used for irrigation. Thus, in traditional rice growing it is unusual to find large responses to K fertilizer. However, there have been in the last thirty years great advances in plant breeding and much better varieties of far higher yield potential are now available. Further, the increasing pressure of population and other economic circumstances in the rice growing areas have made it necessary to intensify the growing of this crop. The higher yields obtained now through the use of N fertilizer, do impose a strain on potash supplies as is made clear in results of a long term trial in the Philippines shown in Figure 2.6. Here, there was no appreciable response to K in the first year though complete fertilizer (NPK) increased yield by 3 t/ha (an effect due entirely to N), neither was there any response to P. By the 7th year, because the higher yields obtained with N had increased the uptake of P and K from the soil to the extent that supplies of these were now marginal, there was a response of over half a ton to K and of a ton to P. Yield on the N only plots declined throughout the period, while it remained steady on the complete fertilizer plots.

The results reproduced in Table 2.5 which relate to the mean of all three sites on which the experiment was conducted are perhaps even more telling. Yield on the N only treatment declined by over 20% (increased removal of P and K); while yield was always low on the no fertilizer treatment it did not decline (only moderate removal of P and K). To maintain yield, complete (NPK) fertilizer was needed: there was in the ninth crop a very strong N×P× K interaction.

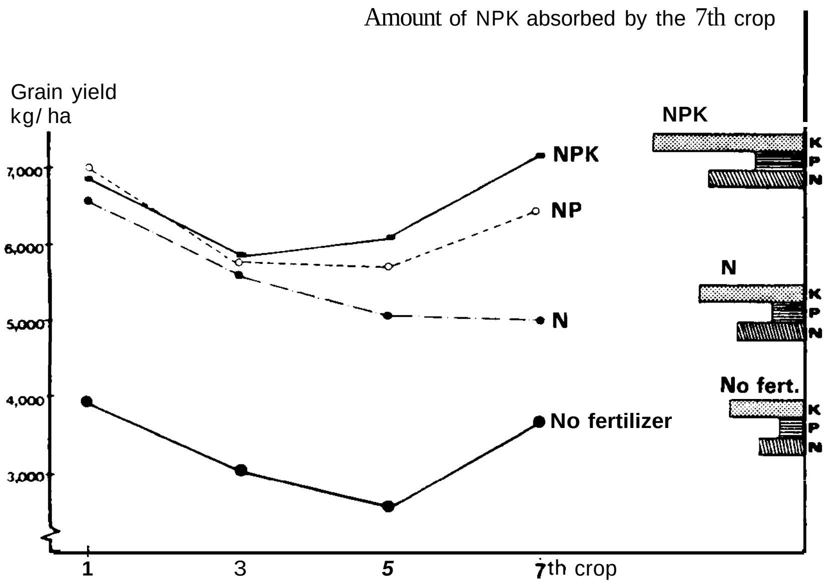


Fig. 2.6. Rice yields in a long-term fertilizer trial in the Philippines. Mean of high yielding varieties (von Uexkiill, 1976).

Fertilizer response by rice has been extensively investigated in India. An example of results obtained (Mondal *et* al.) showing positive N×K interaction is given in Table 2.6. The range of K dressings tested was large, the highest (133 kg/ha K) having been supra-optimal.

Table 2.5. Long-term rice experiment in the Philippines. Little K effect in the first crop, but very large in the ninth crop (von Uexküll, 1976)

Treatment			Yield (kg/ha grain)	
N	P	K	1st crop	9th crop
0	0	0	3200	3260
140	0	0	6130	4800
140	60	0	6460	5330
140	0	60	6020	5400
140	60	60	6840	6730

Table 2.6. N×K interactions in dry and wet season rice crops in India. The effect of increasing N dressing (yield at 160 kglha - yield at 40 kglha). Mean of 2 years (kg/ha grain)

	Overall	K fertilizer applied (kglha K)			
	mean yield	33	66	99	133
Dry season	5970	1431	2230	2651	2301
Wet season	4280	616	774	1056	1028

Table 2.7. Response to 60 kgha N (t/ha grain)

Province	kg/ha K applied		
	0	46	93
Guandong (control 30 kg/ha N)	0.48	0.55	0.78
Zhejiang (control 60 kg/ha N)	-0.35	0.16	0.37

Table 2.8. Response of rice grown in multiple cropping system to extra N as affected by K fertilizer

	t/ha grain		
	No K	46 kg/ha K	92 kg/ha K
Mean yield	3.82	5.65	6.18
$N_2 - N_1$	-0.28	+0.33	+0.41

N_2 = 60 kglha N
N_1 = 120 kg/ha N

A particularly interesting case of interaction is reported by Ismunadji and Partohadjono (1979) from Indonesia. Applying 120 kg/ha N without potassium fertilizer actually depressed yield but when K was also given, the yield was almost doubled. This was due to the effect of potassium in reducing disease - see 2.3.

The need to apply potassium to support nitrogen fertilizer has also been mentioned by Velly (1973) in Madagascar and Haque *et al.* (1983) in Bangladesh. In the latter case there was variation in the effect of potash between sites, presumably due to differences in soil K status.

The report from China (Lin Bao, 1984), which comments on the change in fertilizer response pattern over the period 1958 to 1982 resulting from farmers using generous dressings of nitrogen without taking care to replace the potassium removed by the heavier crops grown, also gives results obtained in experiments in S. China in 1982 (Table 2.7). There was also a sizeable three factor (N×P×K) interaction: in Zhejiang for example the increase in yield from applying K in addition to N was 0.33 t/ha but the increase from applying K in addition to N+P was 0.65 t/ha.

One more result from South China is of special interest (Li and Zhan, 1985) since it applies to intensive conditions with multiple (mixed) cropping. The data summarized in Table 2.8 show, in addition to a very large 'straight' effect of potassium fertilizer increasing yield by 2 or more t/ha, an appreciable N×K interaction - raising the N level under conditions of potassium shortage reduced the yield, but, when potassium was also applied, it increased yield.

This Chinese experience is an 'object lesson' of the need for balanced fertilizer dressings. N used without P and K is effective in the early stages but after some time the N response falls off or may even become negative. The large N×K interactions underline the need for potassium to ensure that N fertilizer produces its full effect.

It is also found in China that potassium fertilizer is very effective in the nursery bed - seedlings recover more easily from transplanting - and nursery application alone may increase final crop yield by 3-5%.

Maize

Maize is widely grown in the tropics and similar interaction effects to those recorded in the temperate zone are to be expected. V. Burkersroda (1965) found a large positive interaction in yield in experiments in Zimbabwe, the results of which are summarized in Figure 2.10. It is striking that when the rate of nitrogen was increased on a K deficient soil, the yield declined to a totally unacceptable level unless K was applied, while if sufficient K was used increasing the N rate from 44 to 132 kg/ha increased the grain yield by over 2 t/ha.

Heathcote (1972, 1973) in the savannah country of N. Nigeria found large positive N×K interactions in long-term experiments. Positive interactions were also recorded with sorghum in the same series of experiments. Where there was no statistically significant interaction, the highest yields were still obtained from the NK treatment. In this connection, it is worth noting that the error of an interaction effect, which is measured as a difference between two differences, is about twice the magnitude of the error of a main treatment. It is therefore more difficult to establish 'statistical significance' for these effects and in tropical areas the inherent errors associated with the site are often high, so that many interaction effects are likely to go undetected.

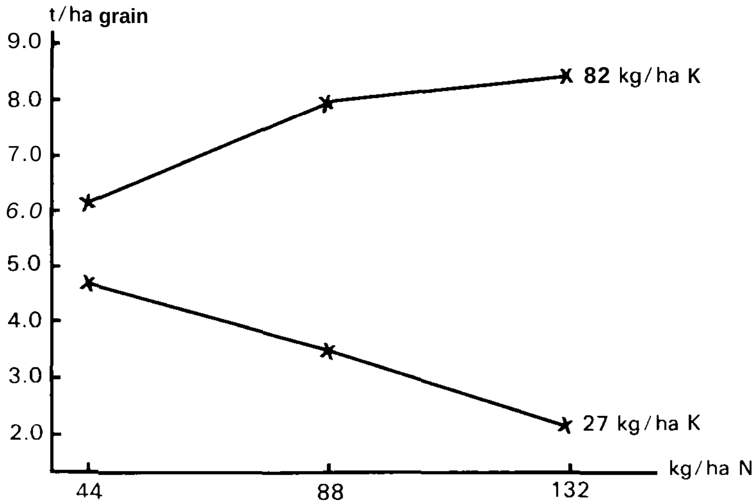


Fig. 2.7. N×K interaction in yield of hybrid maize in Zimbabwe (N rates: 44, 88, 132 kg/ha N; K rates: 27, 55, 82 kg/ha K).

Cassava

This is the most important food crop over a large part of Africa. It is also grown in other parts for export to the manufacturers of compound animal feeding stuffs in Europe and the USA. Traditionally it has been grown as the last crop preceding the reversion to fallow and not meriting any special consideration. The majority of fertilizer experiments with this crop have shown it to be not particularly responsive to nitrogen but generally moderately responsive to potassium. In a factorial trial with 4 rates of each potassium and nitrogen, Muthuswamy and Chiranjivi Rao (1979) concluded that the optimum rates of fertilizer were 50 kglha N plus 250 kglha K (N was applied in the experiment at rates up to 150 kg/ha). At this level of N, the Nx K interactions were listed in Table 2.9.

Howeler and Spain (1980) summarized results obtained from potassium fertilizer experiments with various crops at *CIAT*. They remark on the few reports of response to nitrogen; N apparently increases leaf growth at the expense of the root. It was found at Carimagua that the crop did not respond to N unless K was also applied. 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). The response to 100 kg/ha N (negligible in the absence of K) was 5 t/ha in the presence of 120 kg/ha K, *i.e.* a total yield increase of over 10 t/ha. This combination was found to give the best return among all the combinations tested.

Table 2.9. Increase in yield of cassava (t/ha fresh tubers) due to applying 50 kg/ha N

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

In the developing countries of the tropics, investigation of fertilizer response by principal and minor food crops has not reached a very advanced stage. Fertilizer research in the field has generally been confined to attempts to identify the main nutrient deficiencies over areas of the country with the object of being able to make practical recommendations for crop treatment which are likely to be of immediate practical benefit to the farmers. Very many experiments have been done, notably through the offices of the FAO fertilizer projects, but the experimental designs used have been simple and were not capable of identifying interaction effects. Suffice it to say here that the same general principles apply as do in the temperate areas, namely that:

- Continuous cropping without the intervention of fallow crops or natural fallows puts a strain on potassium reserves.
- Generally speaking, the root crops (*e.g.* cassava, yam, taro) in which very large amounts of carbohydrate are stored, are particularly responsive to K.

An important point emerging from the discussion above is that the availability of the new varieties of higher yield potential coupled with the use of much nitrogen to realize that potential, has brought about a radical change. For instance, to take the case of rice, and the same applies to other food crops, a crop yielding 7 t/ha or more is quite a different proposition from the traditional variety yielding only about 2.5 t/ha when grown under good conditions. The new varieties, if they are to give their full potential need, at the peak of development, to take up nutrients at a much higher rate than do the traditional types. This being the case, rice falls into the same 'K category' as the K demanding root crop! Add to this the possibility of growing more than one crop a year plus catch-cropping imposing a further strain, and it is easy to understand how the farmer who does not appreciate the need to look after the potassium status of his soil can soon end up in serious trouble. The change is similar to the change in wheat growing in Europe.

2.2.3. Plantation crops

Because they have a long commercial history in the tropics, much more attention has been given to these crops than to food crops and therefore we have much more detailed knowledge of their fertilizer requirements. Not only have there been tangible cash rewards from fertilizer use but the sophistication of those in charge of plantations has been higher than that of the average subsistence farmer, so that new ideas are more readily taken up. Further, the financial resources needed to support agronomic research have been more adequate than those of government and other agencies charged with the responsibility for improvement in food produciton and general welfare.

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 (1983). The need for potassium has only been realized relatively recently.

Whether rubber responds to potassium depends on soil K status and the Rubber Research Institute (Malaysia) workers have developed a system to predict K fertilizer requirement using a combination of soil and leaf analysis. 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.

An example of $N \times K$ interaction in rubber yield is given in Table 2.10. Here we see the effect of decline in soil K content with time and consequent decline in the efficiency of N fertilizer unless the K supply is corrected.

Table 2.10. Effect of N and K fertilizers on rubber yield. Adapted from Pushparajah and Tajuddin Ismail (1983)

	Yield increase (g dry rubber/tree/year) due to N fertilizer					
	Year 1	Year2	Year3	Year4	Year5	Year6
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

In the same report there is mention of positive N×K interaction in the growth of rubber seedlings in the nursery, the increase in dry weight of seedlings due to applying N being increased by some 20 percent by applying potassium. Onuwaje and Uzu (1982) have reported a positive N×K interaction in the rubber nursery as indicated by girth measurements.

Another Malaysian report (Anon., 1983; Table 2.11) also mentions N×K interaction.

It is interesting that the various clones react differently to N and to the N× K interaction. With Tj 1, N without K decreased yield.

Table 2.11. Relative yield of dry rubber (no fertilizer = 100)

Fertilizer treatment	Clone		
	Tj 1	RRIM 509	PB 49
N	75	106	109
K	108	104	105
NK	119	134	121

Oil palm

Ollagnier and Ochs (1973) reviewed the nitrogen potassium interaction in tropical oil crops, identifying differing kinds of behaviour. Some results they cite are'summarised in Table 2.12 which shows the response to N at differing K levels. The rates of N and K fertilizers differed between experiments; the data are derived from the extreme rates of N and K applied. Especially where leguminous covers are used, response to N is often slight (even negative) in the absence of K but greatly improved when K is also given. In the examples quoted the value of the NK interaction ($N_0K_0 + N_2K_2 - N_2K_0 - N_0K_2$) ranged from 2.6 (Kluang, soil well supplied with K) to 6.2 t/ha (La Me). Potassium is the most important nutrient (spectacular response at La Mé). Often, the best profit was obtained from potassium fertilizer (or K + Mg) the return from N being sometimes marginal though there were positive N×K interactions.

Table 2.12. Effect of N on yield of bunches at increasing rates of K (t/ha bunches) (adapted from Ollagnier and Ochs, 1973)

Site	Chemara, Malaysia		Kluang, Malaysia		La Mé, Ivory Cost	
	K_0	K_2	K_0	K_2	K_0	K_2
N_0	30.6	30.6	18.7	18.7	71.9	95.8
N_2	27.9	40.0	18.6	20.9	62.0	98.8
Eff. of N	-2.7	3.4	-0.1	2.9	-9.3	3.0

Coconut

The behaviour of this crop in response to fertilizers is similar to that of oil palm and Ollagnier and Ochs *(ibid)* quote examples of the same types of interactions. The picture is further complicated by the fact that on most of the soils on which this crop is grown (coastal sands) it responds to chloride, suggesting that some responses to potassium chloride may have been due to the chloride rather than the potassium and that occasional lack of response to potassium sulphate may have been due to Cl shortage.

A striking example of interaction with coconut in Mozambique is illustrated in Figure 2.8. There was quite a marked response to nitrogen which, applied at 0.4 kg/tree, increased yield of copra by about 40%.

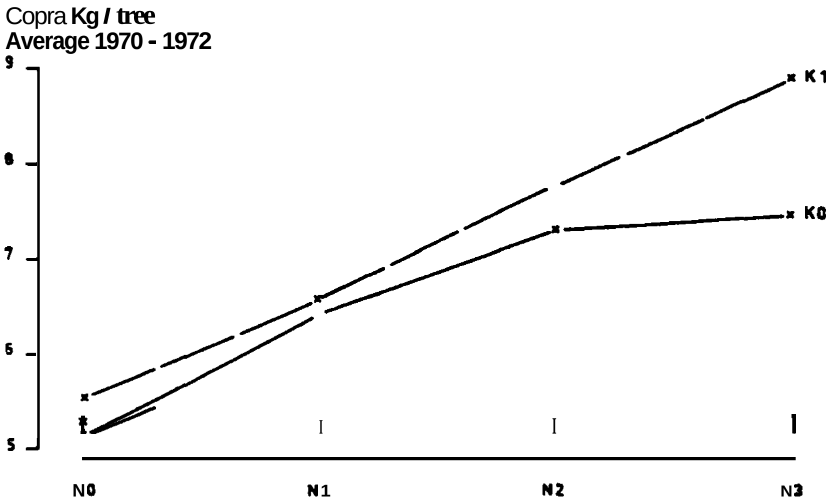


Fig. **2.8.** **N×K** interaction in coconuts in Mozambique. Adapted from Ollagnier and Ochs **(1973).**

Applying N above that rate did not increase yield further unless K was also given. Using K without N did not increase yield, but at 0.6 kg/tree N, it increased yield by some 1.5 kg/tree.

Many interactions can be explained by ion antagonisms. For both oil palm and coconut it is important to pay attention to all the cations. Antagonism between K and Mg can explain why potassium may sometimes depress yield on soils low in Mg; antagonism between NH_4 and K may contribute to the N×K interaction. It will also be interesting to see the effect of replacing ammonium sulphate by ammonium nitrate (S in the former). It might be expected that improved cultivars would be more responsive to N. Certainly one would expect the need for K fertilizer to increase with the introduction of higher yielding planting material and improving culture.

Tea

Yield of tea is increased by nitrogen as would be expected since the harvest is the product of vegetative growth. The nutritional requirements of tea have been investigated in some detail by Willson (1976) in Kenya. He found that response to nitrogen was frequently limited by lack of potassium and that, under these conditions, applying K fertilizer results in large positive interactions. He found that soil analysis was a poor indicator of the K requirement of the crop and that response could be expected when soil pH was 4.9 or lower (no response above pH 5.2) and when *K* content of the third leaf was 1.57% or less in dry matter. Figure 2.9, adapted from this paper shows the type of interaction which occurs when limiting K supply prevents the tea from responding to nitrogen fertilizer.

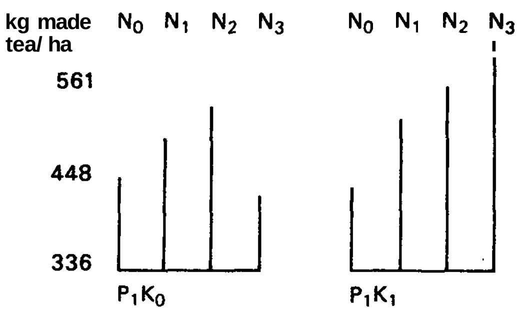


Fig. 2.9. **Effect** of potassium in improving N response by tea (Willson, 1976).

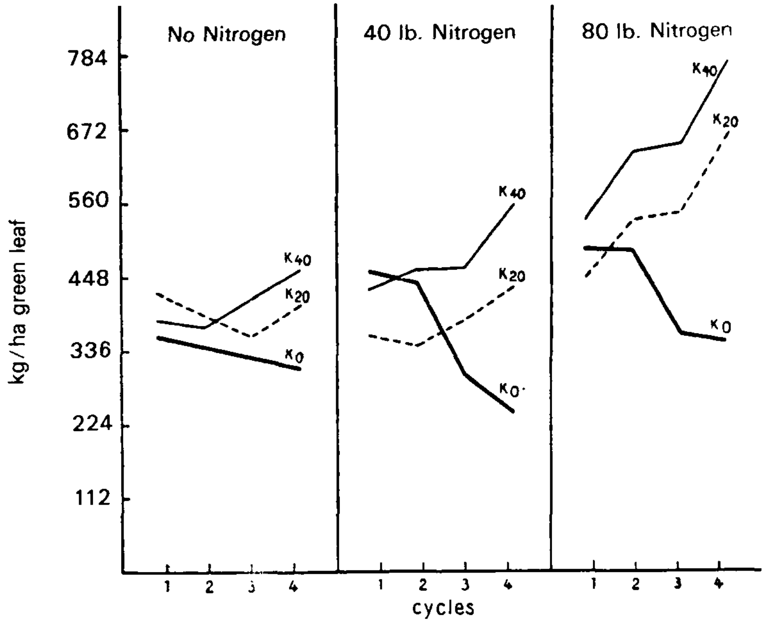


Fig. 2.10. N×K interaction in tea. In K-depleted tea garden N increased yield only when K deficiency was corrected (Kanwar, 1974).

Indian experience with the manuring of tea was discussed by Kanwar (1974). In a long-term experiment at Toklai, it was found that after 25 years or so the yield started to decline, indeed yields from the 135 kg/ha N plots were considerably lower than those from plots receiving 45 kg/ha. It was then found that applying *56* kgha K restored the yield on plots receiving heavy N dressings. The results illustrated in Figure 2.10 show that in old tea gardens where soil potassium has declined, nitrogen fertilizer alone has little effect on yield; it is only effective when the K deficiency is made good.

Sugarcane

Like other crops where large amounts of carbohydrate reserves are laid down the sugar cane is most responsive to potassium. The N×K interaction is well demonstrated in results of a South African experiment on a low potassium soil (64 ppm exch. K) which are shown in Table 2.13 (Stewart, 1969).

The results of this experiment suggest that the appropriate N:K ratio for cane fertilizer is about 1:1.

Table 2.13. Yields (t/ha sucrose) from combinations of N and K fertilizers

kglha K	kglha N				
	0	112	224	336	448
0	12.1	10.8	10.1	9.7	8.9
93	13.9	19.2	18.4	15.3	14.9
186	12.9	20.2	18.2	18.6	20.0
279	15.6	18.2	17.0	20.5	18.3
372	12.9	19.5	19.9	21.3	15.7

Tobacco

The generally beneficial effect of potassium fertilizer on tobacco, particularly as regards quality attributes, is well documented. Chouteau (1964) in a pot experiment testing 2 rates of N applied in combination with 3 rates of K found a large positive N×K interaction in mean leaf weight (Table 2.14).

Table 2.14. Effect of N and K fertilizers on mean leaf weight (g DM)

g N/plot	K applied (g/plant)								
	lower leaves			middle leaves			upper leaves		
2.5	[illegible]	4.3	5.0	5.8	[illegible]	[illegible]	8.0	7.5	[illegible]
5.0	5.3	5.1	5.8	8.0	8.4	10.2	11.3	10.3	13.1

There was quite an appreciable interaction in the weight of middle and upper leaves but no such interaction on the lower leaves. There was a tendency for increasing N to reduce combustibility and increasing K counteracted this tendency in the lower and middle leaves hut not in the upper.

2.2.4. Fruit

Apples

A long-term experiment at the East Malling Research Station/England was planted in 1931 and continued, with some intervening changes to treatments until 1962. An account of this work was given by Greenham (1965). In the early stages, potassium deficiency on trees receiving no K was so severe that it was necessary to apply K over the whole area, while the original comparison of 0 vs 94 kg/ha K as sulphate was continued. The overall K treatment was discontinued from 1953. The potassium comparison was combined with 0 vs. increasing rates (as the trees aged) of nitrogen fertilizer.

Response to nitrogen in terms of total crop up to 1947 was greatly improved by potassium, the extent of the interaction depending upon rootstock and variety. In yields of Cox recorded 1953-1956, there was no real response to nitrogen unless potassium had been applied:

Response to N (kg fruit/tree)	
Without K	With K
0.9	12.7

The greater part of the response to K would be due to the cumulative effects of K applied earlier in the experiment on tree growth, rather than to that applied in the current seasons.

Soft Fruit

N×K interactions on soft fruit were found by Bould (1964, 1965) in sand culture experiments with strawberries and raspberries carried out to determine critical levels of nutrients in leaves. In strawberry, increasing the N content of the nutrient solution from 2.5 to 10 me/l increased yield by 19.2 g per pot at the lowest level of K (0.75 me/l) but by 34.2 at the highest level (3 me/l). In the case of raspberry, the interaction was even greater:

Response to extra N (g fruit/pot)	
Low K	High K
89	538

2.3. Potassium and crop quality

An important aspect of the nitrogen potassium interaction is in the effects that potassium has on quality. Heavy nitrogen dressings often lower quality while potassium acts in the opposite direction. A case in point is in the old sugar beet result quoted at the beginning of this chapter. Although potassium increased the yield of roots, at least half the increase in sugar yield given by the high N+K treatment was because, although the heavy nitrogen dressing reduced the sugar percentage, it was restored by applying potassium along with the nitrogen. Of course, the object of growing sugar beet is to produce sugar, not roots, so that it is more logical to express yields in terms of sugar yield, and where this is done in publications no particular point is made about the effect of K in improving sugar content.

Another well known effect of heavy N dressings to beet is to increase the so called 'noxious nitrogen' content of the juice, which lowers the refining percentage, in other words the recovery of sugar. Potassium acts in a contrary direction by reducing the noxious nitrogen.

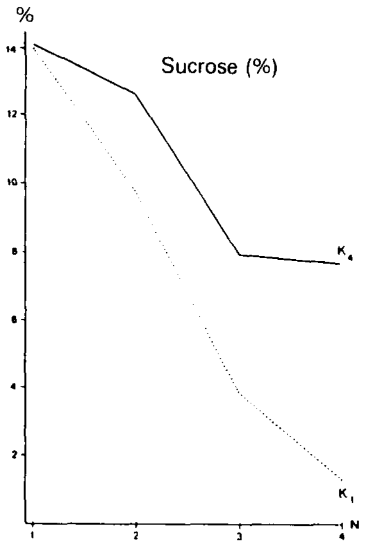


Fig. 2.11. Effect of N:K ratio on % sugar in roots.

Fig. 2.12. Effect of N:K ratio on % sugar recovery.

Koechl (1977) investigated these effects in detail in solution culture and the end results of his findings are summarized in Figures 2.11 and 2.12. The effect of increasing nitrogen was to increase the juice content of non-sugar substances and to reduce the sugar content of 137 day-old seedlings while applying potassium had the opposite effect, thus counteracting the effect of N. Figure 2.11 shows the effect of N×K interaction on percentage sugar content in seedlings and Figure 2.12 the sum of the effects on sugar content and juice purity on the percentage recovery of sugar in the factory, an effect which has to be added to any effect potassium may have had on root yield.

There are similar effects in grass (Nowakowski, 1969, 1972). Adequate K was necessary for maximum sugar and fructosan content. Generous nitrogen treatment increased the total N content of the grass, but a high proportion of this total N was in the form of partly elaborated compounds, undesirable from a nutritional point of view; not as protein. Further, the content of soluble carbohydrates was lowered. Potassium applied with the nitrogen counteracted these undesirable effects (Table 2.15).

The same tendency for potassium to counteract the unfavourable effects of generous nitrogen treatment on quality of crops has been reported for many different crops.

Table 2.15. Effect of potassium in the presence of high **N** on protein and non-protein N contents of ryegrass

Treatment	Protein N	Sol. organic N	NO_3N
N_3+K_0	77.8	12.84	7.79
N_2+K_1	85.9	11.76	1.30
N_3+K_2	89.1	9.30	0.94
N_3+K_3	92.0	7.53	tr.

The effects of **K** in increasing starch content of potatoes, resulting in positive N×K interactions for starch content and starch yield are well known. Muthuswamy and Chiranjivi Rao (1979) report a similar effect on cassava (Table 2.16).

Table 2.16. Effect of K and N on tuber and starch yield of cassava

	t/ha fresh tubers		t/ha starch	
	No	N_{50}	No	N_{50}
K_0	28.8	32.4	4.63	6.30
K_{100}	32.3	43.1	5.73	7.09
K_{300}	32.8	46.9	5.96	8.94

It will be noted that the interaction in terms of starch yield is greater than it is for tuber yield due to potassium increasing both tuber yield and starch content.

Loué (1978) reports that, in a field experiment, increasing the rate of nitrogen from 95 to 205 kg/ha reduced the oil content of rapeseed from 53.8% to 52.7%; when 234 kg/ha K was applied, the comparable figures were 54.7 and 54.4%.

Forster (1977) in pot experiments found that increasing N fertilizer reduced the oil content of rapeseed but that K fertilizer counteracted this effect so that, in terms of oil yield there was a very large N×K interaction (Table 2.17). The content of glucosinolates, which should be low in animal feeds, was increased at the high rate of N, but K fertilizer counteracted the effect.

Traditionally, potash has a reputation for improving the quality of crops, a reputation which is well-deserved. We have confined ourselves here to a few examples of established N×K interaction without attempting to catalogue the many examples in the literature of the straight effects of K on crop quality. In general these interaction effects arise from the property which potassium has of counteracting unfavourable effects of high rates of N on quality. Generally speaking, generous use of nitrogen tends to soften growth while potassium has the opposite effect. Thus potassium has a beneficial effect in improving the storage properties of perishable vegetables and their ability to withstand damage in handling and transport.

Table 2.17. Effect of N and K on rapeseed oil yield and glucosinolate content

	N_1K_1	N_2K_1	N_1K_3	N_2K_3
g oil/pot	13.9	17.8	11.4	29.6 (mean 3 cvs.)
µmole/g glucosinolate	104	163	114	138 (cv. Lesira)

2.4. Potassium and plant health

The effect of heavy nitrogen dressing in producing soft growth has consequences for the susceptibility of plants to disease. Again potassium acts in the opposite direction, increasing resistance to, or tolerance of, disease. An example of this effect is in the Indonesian rice experiments quoted above Ismunadji and Partohardjono (1979). There were large positive N×K interaction effects on yield of grain and this was very largely due to effects on disease incidence (Table 2.18).

Table 2.18. Effects of N and K fertilizers on rice and disease (1975176 wet season)

Treatment	at Jakenan		at Cihea	
	kg/ha grain	Stem rot index	kg/ha grain	Sheath blight
120- 0- 0	1194	69.2	2095	58.8
120-60- 60	3402	4.4	3511	55.0
120-60-120	3138	1.8	4042	48.0

The function of potassium in increasing crop resistance to disease and pests has been extensively reviewed by Perrenoud (1977). We confine ourselves here to quoting the examples of N×K interaction effects illustrated in Figures 2.13-2.16.

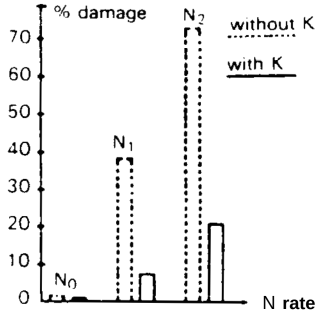


Fig. 2.13. N×K interaction and stem rot of rice (Yoshi *et* al., 1940).

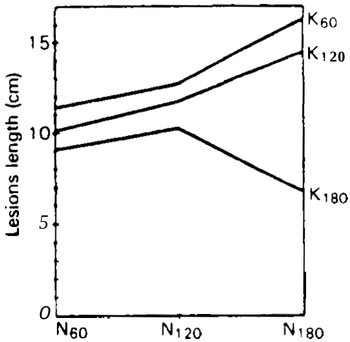


Fig. 2.14. N×K and bacterial leaf blight of rice (Davadath and Padnanathan, (1970).

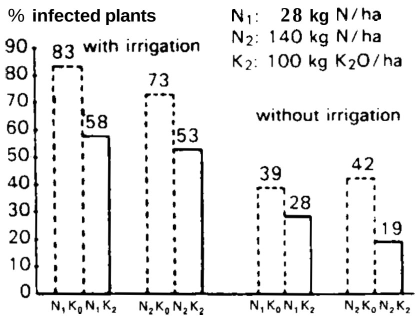


Fig. 2.15. N×K interaction and leaf blight of cotton (Miller, 1969).

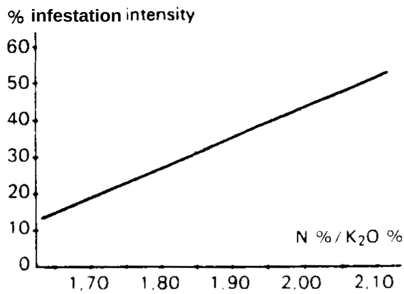


Fig. 2.16. N×K interaction and leaf spot of apple (Lefter and Pascu, 1970).

2.5. Potassium and legumes

Traditionally, temperate agriculture relied much on leguminous plants to supply the nitrogen requirements of crops whether by growing arable leguminous fodders for livestock feeding, which left residues of nitrogen for the benefit of succeeding crops in the soil, or by grazing stock on grass-legume swards. Today, with readily available supplies of N fertilizer, there is less reliance on legumes. Grazed swards are more easily controlled by the judicious use of N fertilizer, hence there is a tendency to all-grass swards. Nevertheless there is still a strong case for the legume, since the nitrogen it fixes comes free of charge while N fertilizer costs money. The case for the legume is even stronger in other parts of the world, where the cost of N fertilizer is relatively higher and where temperatures and solar radiation are higher with consequent higher rates of N-fixation by the legumes.

The potassium supply is particularly important for legumes and we have here a special case of the N×K interaction, in which increasing the K supply leads to large economies in N fertilizer. In the mixed grass-clover sward, when nitrogen is applied, its main effect is to increase the growth of grasses. This it does to such an extent that the clover in the mixture is less able to compete and tends to die out. However, if the potassium status of the soil is sufficiently high, the clover is better able to compete. Some of the N×K interaction exhibited in mixed sward fertilizer experiments (*e.g.* those referred to in 3.1) is due to this effect.

Potassium has a direct effect in stimulating the bacteria in the nodules attached to the roots of legumes, which are responsible for fixing atmospheric N. Two examples of this effect are given here (Tables 2.19 and 2.20). The first refers to solution culture experiments with broad bean (Vicia *faba*). Increasing the potassium supply increased both the number and size of nodules and the combined effect of this was greatly to increase the amount of atmospheric N fixed.

Table 2.19. Effect of K supply on nitrogen fixation by broad beans (Haghparast-Tanha, 1975)

	K concentration in solution (me/l)		
	0.5	1.5	4.5
Labelled N_2 absorbed by plants via root nodules (µmg N/12 hr)	580	853	1130
Nodules / plant	233	250	251
Fresh weight / nodule (mg)	6.5	7.2	8.4

Table 2.20 summarizes results from a trial in Japan on two swards - alfalfa with orchard grass, and Ladino clover with orchard grass which were cut three times a year. Over 15 years, the dry matter yield was increased by over 85%. The increase in N fixation brought about by the high potassium treatment amounted to about 0.5 kg N for each kg K used.

It appears uncertain to what mechanisms the stimulating effect of K on N fixation is due, whether by improving translocation of assimilates to the root (Mengel *et al.*, 1974; Barta, 1982), increased nodule enzyme activity or direct effect on nodule mass (Duke *et al.*, 1980). Gomes *et al.* (1983) found in soya beans that the level of K needed for effective N fixation is higher than that required for maximum growth. Whatever the mechanism involved, there is no doubt about the final result.

Table 2.20. Effect of K supply on dry matter yield and N fixation by mixed swards (Kemmler *et al.*, 1977)

Sward	Alfalfa-grass		Ladino-grass	
K (kg/ha/year)	0	250	0	250
Annual yield (t/ha DM)	17.5	41.3	19.1	41.0
kg/ha N in forage	54.8	192.5	61.8	179.7

3. Running down soil potassium

3.1. K removal by intensive cropping

The nitrogen potassium interaction has important implications for soil fertility. Attention was drawn in the introduction to the effect of using fertilizer without attention to the need to maintain balance. The use of nitrogen alone may increase crop yield but because the yield is increased, the removal from the soil of nutrients other than nitrogen is increased and, as time passes, the soil becomes impoverished of that nutrient to the extent that deficiency levels are reached and crop growth is constrained. Increasing yields by using N fertilizer increases the removal of potassium from the soil which means that in the course of time the K supply becomes limiting and it is necessary to replenish soil stocks if yield is to be maintained.

A telling example of the effect of such unbalanced crop feeding is to be found in a series of grassland experiments carried out in Scotland some 25 years ago (Reith *et al.*, 1961). At 6 sites, a grass-clover sward was cut 5 times per year. Combinations of the following total amounts of fertilizer were applied each year: 0, 98, 195 and 390 kgha N; 0, 24 and 48 kgha P; 0, 156 and 312 kg/ha K. The N was given in 5 equal dressings in early spring and after the first 4 cuts. There was some difference in behaviour between the various sites according to the type of soil (heavy or light) and its K status at the beginning of the experiment but the results shown in Figure 3.1 are typical.

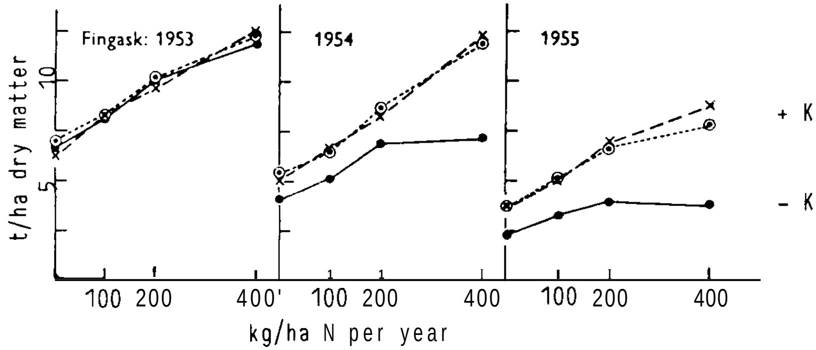


Fig. 3.1. N×K interaction in Scottish grassland experiment. Effect of increasing N fertilizer on annual herbage dry matter yield at K_0 (•—•), K, (0 — 0) and K_2 (x—x). K_0=no potassium, K,=156 kgha K, K_2=312 kg/ha K.

Potassium fertilizer did not affect the yield in the first year and there was a satisfactory response to N. In the second year, there were small effects of K in the absence of N and at the intermediate rates, but a large effect at the highest rate of N. In the third year the response to K increased as the rate of N used increased throughout the range, more particularly from 195 to 390 kg/ha N, exhibiting a strong positive N×K interaction. The reason for this is not difficult to find. In the first year there was sufficient K in the soil to supply the sward's needs even at the highest rate of N, but the high rate of N, by increasing the yield of cut grass, greatly increased the removal of K from the soil with the result that in the second year the grass was unable to make use of more than 195 kgha N. By the third year, the accumulated K removals at the lower rates of N were also sufficient to lower soil K to a critical level and the interaction effect was noticeable at these lower rates of N. In line with these effects it is interesting to see the effect of treatment on soil K level as measured in soil samples taken at the end of the experiment. Applying N without K reduced the available soil K while applying the higher rate of K easily maintained soil K at the highest rate of N and increased it when no N was used.

It is worth mentioning another series of similar experiments (Gething, 1964) in which, after effects similar to those described above had been noted over the first 3 years, the phosphorus + potassium (PK) treatment on one set of plots was maintained for a further 2 years, while treatments on some of the other sets were reversed (Figure 3.2).

Yields relative to those obtained on the set of plots receiving PK throughout the 5 years.

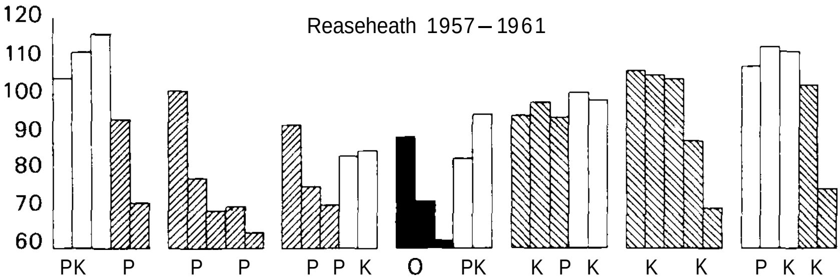


Fig. 3.2. Effect of reversing treatments in grassland experiment. Restoring the potassium restores the yield.

Applying K to the plots previously K-starved restored yield to much the same level as that on plots receiving **K** throughout. The result of omitting K on those plots to which it was applied previously was that yield declined rapidly as in the first phase. It is interesting that while P had little effect in the first 3 years it had an effect as large as that of **K** in the last two years (compare the two right hand sets in the figure).

Grass removes much K from the soil and the same applies to any crop which is grown for its leaves, hence the above described experiments produced spectacular effects. In the case of crops where only the grain is removed from the field and the residues are returned to the soil, the removal of K is not so marked but, even then, in the longer term the effects of K starvation will surely show up eventually.

3.2. The importance of soil potassium

The importance of maintaining soil potassium at a good level cannot be over-emphasized. Work at Rothamsted showed in a very clear way that the residues of potassium applied as fertilizer in the past still benefit crops grown at the present day and, furthermore, that it is not practicable completely to imitate the effect of these potassium residues by applying new fertilizer. A test crop of potatoes was grown in the 1950s on land which had received either no potash or normal dressings over the period 1856-1901. If no fresh K was applied the old residues were worth some 10 t/ha potatoes (telling evidence of the value of reserves of soil K), but, however much fresh K fertilizer was used on the potatoes (within the range of rates tested) the yield on plots without K residues never came up to the yield which was possible on plots with reserves (Johnston *et al.*, 1970).

One is entitled to enquire whether such results are really applicable to practical farming conditions since the plots without residues had not received any K fertilizer or farmyard manure for 100 years or more and could be regarded as completely exhausted. Here it is of interest to quote a recent result obtained on a soil which was by no means exhausted of K. This was a heavy boulder clay soil of a type on which it is generally thought K fertilizer can be omitted except for the most K demanding crops. Furthermore, the soil was high in exchangeable K as indicated by soil analysis. In both 1981 and 1982 500 kg/ha K was applied to two wheat crops (total 1000 kg/ha). Wheat showed a fair response to these heavy dressings, about half a ton total for the two crops. In 1983 a potato test crop, to which 0, 60, 120 and 180 kg/ha K were applied, was grown. The yields obtained are shown in Figure 3.3.

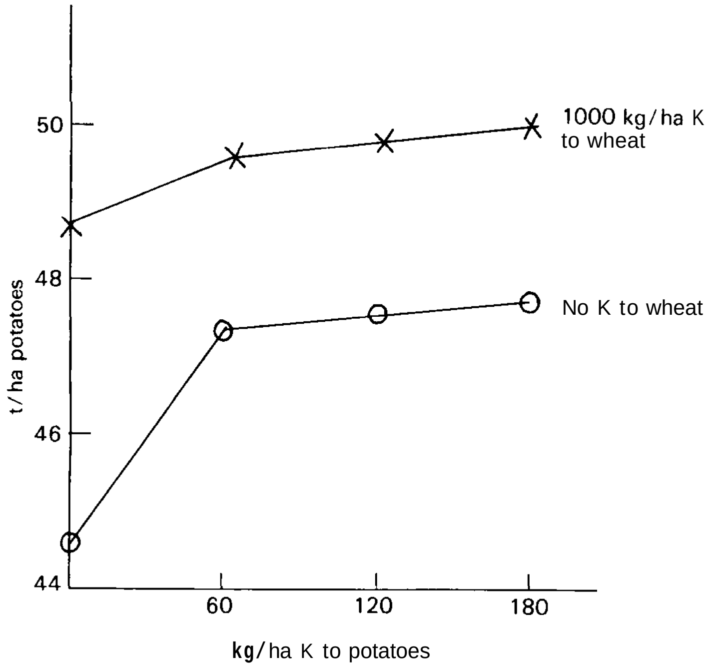


Fig. 3.3. Value of reserves of soil K for potatoes on a soil reputedly not responsive to potassium and high in exchangeable K (Ridgman, 1986).

There is a striking similarity to the Rothamsted results and no sign that yield on land without the residues from the heavy dressings to wheat would ever attain the level with residues no matter how much fresh K was given for potatoes (Ridgman, 1986).

3.3. Long *vs.* short term experiments

If we consider these examples of the effects of running down soil K, and many other examples with different crops and from different parts of the world could be quoted, we are immediately struck by the fact that it is not likely that we can obtain guidance good enough for practical use in fertilizer advice from short term experiments on isolated crops. With potassium, things are never static and what we do in one year will affect what happens and what we should do in the next. Because potassium is taken up by crops in such large amount each crop taken leaves the soil that much worse off for potassium and, though there may be no response to K in the first year of a trial, the longer the trial is continued the more likely it is that response will in due course appear. Additionally, crop growth and hence response to fertilizers is very much at the mercy of the weather, so that it is always wise to check results over a number of years.

The effects of nitrogen fertilizers are more or less ephemeral. Fertilizer N not taken up by the crop does not contribute sensibly to permanent soil fertility; losses by leaching and denitrification take their toll. Nitrogen response is affected by the weather so there is still a case for repetition in case the result obtained in a particular year should prove to be just a 'flash in the pan' but there is not the same need for long-term work that there is with phosphorus and potassium, the residues of which are available for the benefit of future crops. Also, in the case of the latter, the debts incurred by the ungenerous farmer must in due course be paid by future crops and future generations. What we are really saying here is that investigation of potassium needs should be directed towards finding out the potassium requirement for the whole rotation and beyond.

4. Conclusion

This text does not attempt an exhaustive review of the connection between potassium and nitrogen in plant physiology and crop production. Its aim is essentially practical. For the practical man, farmer or adviser, we have given in chapter 2 a number of selected examples of clear interaction effects, drawn from research results from all over the world. Most of the examples come from the temperate climate, and these have been discussed in the greater detail, simply because fertilizer response has been investigated more thoroughly in this part of the world. However, there is information from other parts of the world, including the tropics. Experimental results here show the same trends, namely that, in order to obtain the best results from nitrogen fertilizer, soil potassium supply must be kept at a sufficiently high level. Many more examples could have been quoted but those mentioned are sufficient to illustrate the principles clearly.

Potassium performs many functions in plant metabolism, promoting photosynthesis, conserving water, speeding up the transport of the products of metabolism between different parts of the plant. If these were the only important processes in which potassium was concerned we should still expect the K supply to the plant to affect the way in which nitrogen works (*i.e.* its efficiency): if growth is limited by supply of one element, it cannot respond to the other (Law of the Minimum). But there is evidence of a more direct connection between the two elements (Lips et al., 1970) in that the potassium ion acts as a carrier for nitrate from the root to the leaf, where proteins are synthesized. There may also be a connection in that the potassium ion, being very mobile, promotes the uptake of nitrate by the root.

For the practical man, farmer or adviser, it is of interest to have some idea of what the mechanisms may be in the plant that give the connection between nitrogen and potassium such significance, but he can be content to leave the fine detail to the physiologist and biochemist. It is clear to him that nitrogen and potassium each have their separate effects on crop yield, and, as the results discussed above so clearly show, there is a special connection between the two.

There are soils which contain abundant potassium, and on these one does not expect a response to potassium fertilizer except by the most potassium demanding crops. The majority of soils are not so rich and, though they may grow moderate crops of the traditional varieties, they will not support the much greater growth of which the improved crop varieties are capable when supported by nitrogen fertilizer. High yields of modern crops require large dressings of nitrogen. If these are to be effective, they have to be supported by larger amounts of potassium. Fertilizers must be balanced.

We have discussed how, if the fertilizer policy is unbalanced, there is a serious risk of running into problems of potassium shortage. The larger the crops that are grown, the greater is the risk. The rundown of soil potassium can be avoided to some extent by taking care to return all crop residues to the field and in the obvious interests of economy this should be done.

The insidious danger of decline in soil potassium should be guarded against. **A** rough idea of what is happening can be got by keeping a balance sheet, entering into the account on one side the amounts of K put on as fertilizer and on the other side, estimates of the amounts removed from the soil. Table 4.1, giving nutrient contents of total crop at harvest could be of help. In many cases, the marketed portion of the crop contains the minor share of the total of potassium taken up. For instance, in cereals, if the straw is removed and sold off the farm, K removal is three times as high as when the grain only is sold and the straw is left in the field, burned or ploughed in, or returned in due course as farmyard manure. Such a balance sheet can be a useful guide but it is advisable to check the state of affairs by commissioning a soil analysis at intervals, say once in the course of the rotation.

Table 4.1. Potassium taken up by crops (kg/ha)

Crop	Yield (t/ha)	uptake	
		K	K_2O
Rice	6	130	155
Wheat	5	110	130
Maize	6	100	120
Sorghum	4	80	100
Beans/peas	2	100	120
Soybean	3	140	170
Pigeon pea	1.5	45	55
Groundnut	2	90	110
Rapeseed	3	125	150
Sunflower	3	200	240
Potato	40	260	310
Sugar beet	20	225	270
Cassava	40	300	350
Sweet potato	40	320	380
Yam	35	155	190
Cotton (lint)	1	130	160
Tobacco (dry leaf)	2	200	240
Grass	10	200	240

The above are the amounts of potassium contained in the above-ground parts + underground harvested portion where appropriate.

As agriculture is intensified, and this is an inevitable necessity in all parts of the world as population increases and economic pressures harden, crop yields rise and so do potassium removals. High yields of modern crop varieties require large dressings of nitrogen. If these are to be effective they have to be supported by larger amounts of potassium. We have shown how the advances in plant breeding and in agricultural technology have changed the nature of some crops. Those which were formerly regarded as needing little support from K now have potassium requirements equalling or nearing those of the traditional potash-hungry crops. The whole situation has changed.

While the above remarks apply principally to the more developed agricultures of the temperate zone, the pressures are mounting also in the less advanced parts of the world, where the food situation is the most urgent. Increasing pressure means that in due course the farmer must quit his traditional methods and move into the more intensive modern world.

In the arguments put forward here, we have tied together two themes:

- Nitrogen and potassium work *together* in crop production. Nitrogen alone may produce the 'quick buck' for a short time, if the soil is rich in K. If the soil is not well supplied, nitrogen cannot produce the results. Either the yield will plateau off at a comparatively low level because at that level the potassium supply runs out, or the whole pattern of response to N will be damaged with the dual drawback that crop yield is limited to well below the potential *and* nitrogen is so inefficiently used that more of it will be needed to reach even that modest yield than would be required for a much higher yield had the farmer only thought to see that the potassium supply had also been made good. There is a double benefit from the N×K interaction.
- The need to farm with a view to the long term. Crops do not come from thin air alone. They consume food; the bigger the crops the more they consume. Potassium is taken up in large amounts, the bigger the crops, the bigger the drain on soil reserves which cannot last forever. The deficit must be made good.

There is perhaps no better way to draw these two points together than to invite comparison of the figures illustrating nitrogen × potassium interaction and those illustrating the effects of running down soil potassium. There is a remarkable parallel.

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