Potash Review

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Subject 16

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Influence of Potassium Sulphate on the Plant Nutrient Content of Apple Leaves and Fruit

(L'influence du sulfate de potasse sur la composition minérale de la feuille et du fruit du pommier)

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Ed. Lab. coop. de diagnostics foliaires, p. 145–153.

Introduction

The influence of potassium sulphate on the composition of apple leaves and fruit has been studied, using Jonathan apple trees on M IV stocks, growing on alluvial clay.

Plan of the experiments. Fourteen manuring experiments were set up in orchards of Jonathan on M IV stocks during the winter of 1954/55, the trees then being four years old or more. The soil, formed on alluvial river-clays, varied in texture from sandy clay to heavy clay, the percentage of clay particles (smaller than 16μ) varying from 18 to 81. The potash content of the soil was determined by extraction with 0.1 N HCl and with a soil: liquid ratio of 1:10. The figures found for the 0–20 cm layer varied from 0.010 to 0.083% K_2O (of air-dry soil). The subsoil was poor in potash. The heavy soils fix potash in a form available with difficulty. Other soil characteristics varied as follows: pH to KCl (N) of the 0–20 cm layer 4.38–7.45; $CaCO_3$ content 0 to 6.95%; organic matter, 2.0 to 9.0%.

The experiments were continued from 1955 until 1960. Potassium manuring, in the sulfate form, was given at the rates 0, 150, 300 and 450 kg K_2O per hectare (0, 134, 268, 401 lb/acre) annually, with two replicates.

Each year leaf samples were taken in August; these were the third and fourth leaves from the bases of vegetative shoots. The analyses cited are for 'total element' in each case; the figures are reported as the oxides (K_2O, etc.) except for N, and are given as percentages of dry matter for the leaves, but as mg per 100 g of fresh material for the fruits.

The influence of potassium manuring on the nutrient element concentrations in leaves and fruit has been studied, and the changes in these concentrations as a function of potassium manuring over the given range of application rates (regression coefficient = b) have been calculated, per 100 kg K_2O per hectare per annum (90 lb/acre approx.). We have also studied the extent to which the changes in

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composition of leaves and fruit induced by potassium manuring were affected by the levels of these elements in the soil, and in the leaves and fruit themselves; the relations found were statistically verified and formulated by calculating coefficients of multiple correlation. The probabilities that the results are due to chance are shown as: 0 for the non-significant level, and $(^{+})$, $^{+}$, $^{++}$ and $^{+++}$ for P less than 0.1, 0.05, 0.01 and 0.001 respectively.

Results

Effects of potassium manuring on nutrient composition in leaves.

The changes in leaf composition associated with potassium manuring are calculated as the mean effect of 100 kg K_2O per hectare per annum. The mean effects over the years 1958 to 1960 and the regression coefficients (b) are given in table 1.

Emmert (1961) in his review of the literature cites results that are generally similar. Applied potassium reduces the concentrations of N, P, Ca and Mg in the leaves. The fall in nitrogen and phosphorus does not always occur (*Cain*, 1953, *Ljones*, 1954). We ourselves have previously noted a slight lowering of N and P, not statistically significant (*Van der Boon et al.*, 1961). The two following questions come under consideration:

(a) to what extent is the concentration of a given nutrient element in leaf tissue influenced by potassium sulphate?

(b) does the extent of the change depend on the composition of the leaf (and of the soil)?

These questions will be discussed separately for the different elements.

Table 1 Influence of potassium manuring on composition of leaves, 1958–1960. The extents of change (regression coefficients) in nutrient concentrations per 100 kg K_2O per hectare per annum.

Nutrient	% of dry matter by rate of manuring kg K_2O/ha				Effect on nutrient concentration per 100 kg K_2O (= b)	Significance level
	0	150	300	450		
K_2O	1.18	1.34	1.42	1.50	$+0.072^{+++}$	$P < 0.001$
MgO	0.50	0.45	0.43	0.42	-0.016^{++}	$P < 0.01$
CaO	2.90	2.87	2.90	2.85	−0.004	0
N	2.34	2.30	2.32	2.33	+ 0.002	0
P_2O_5	0.54	0.53	0.53	0.53	−0.003	$P = 0.20$
K_2O/MgO	2.8	3.4	3.8	4.0	—	—
MgO/CaO	0.17	0.16	0.15	0.15	-0.006^{++}	$P < 0.01$

The K_2O content of the leaf

On the average for all the experimental material there was scarcely any increase in the potash concentration of leaf tissue in the first year, the figure being only + 0.002% K_2O per 100 kg K_2O/ha/year. In the succeeding years the corresponding coefficients of increase were: 0.039^{++}, 0.063^{+++}, 0.067^{+++}, 0.074^{+++}, and in 1960, 0.076^{+++} (see fig. 1). A maximum seems to have been approached by 1959. The mean increase was then 0.072% K_20 per 100 kg K_2O/ha/year. Studying the relations between the potash contents of leaf and soil under the influence of the fertilizer, it is clear that the effect of the latter during the first year was only slight (Fig. 2). Leaf

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Figures 1, 3, 4, 5: Increase of percentage of K_2O in the leaf with potassium manuring, as a function of time in years (1), soil K_2O (3) and leaf K_2O (4); and increase of MgO with potassium manuring as a function of leaf K_2O (5).

Figure 1

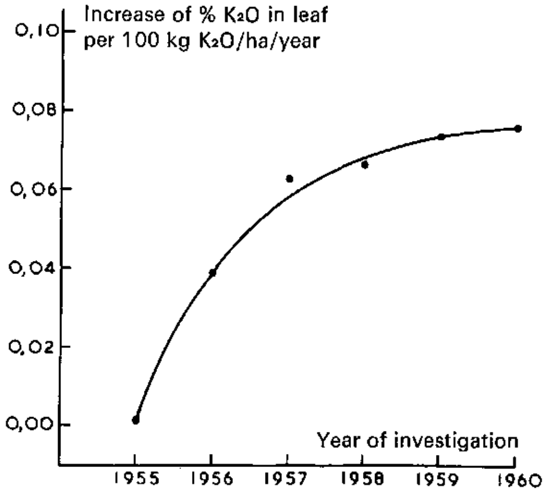


Figure 3

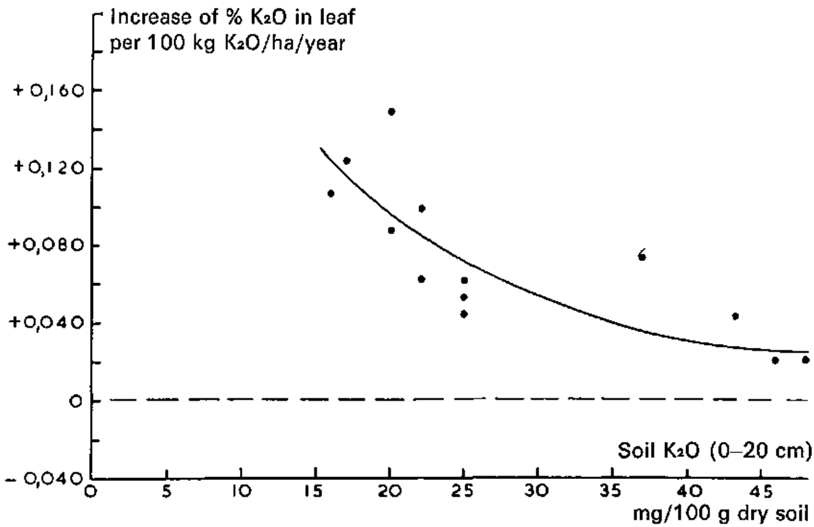


Figure 4

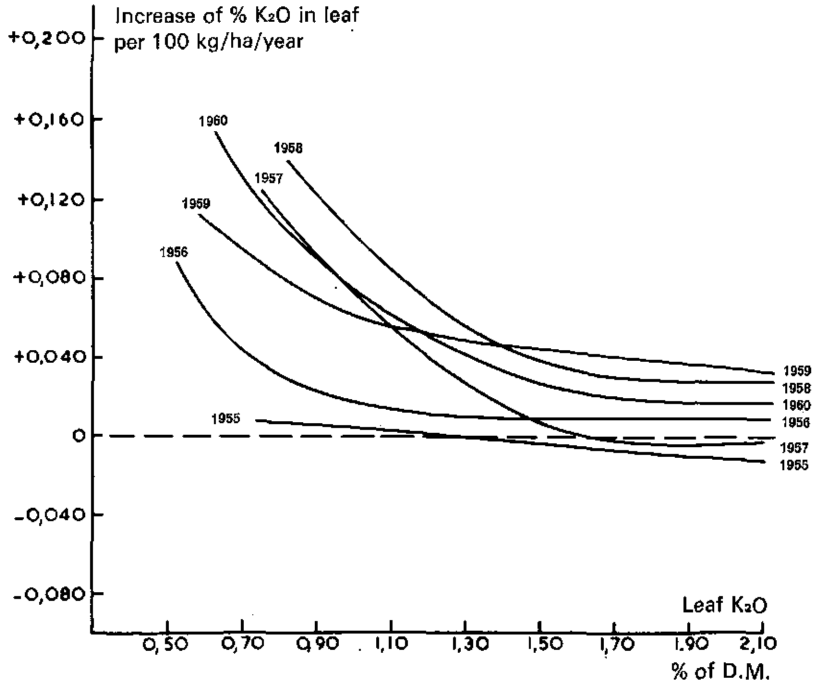
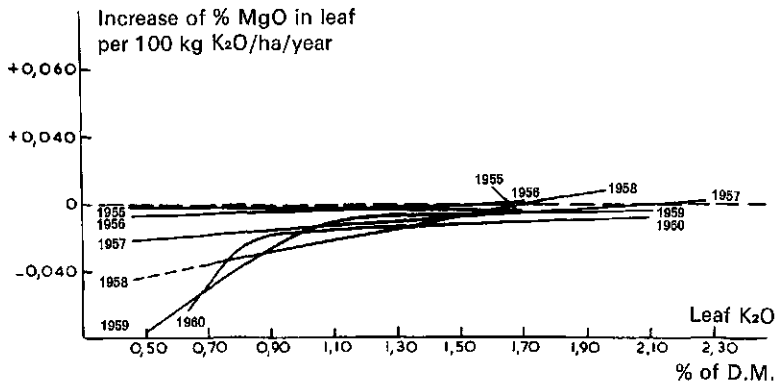


Figure 5



potash for untreated plots shows a close relation to the potash content of the soil. *A dressing of 450 kg K_2O per hectare in the winter of 1954/55 in the orchards low in* potash scarcely increased the potash content of leaves sampled in the following August. The figures for such leaves did not by that time attain the higher levels shown even by unmanured plots on potash-rich soils.

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By 1957 the effect of manuring was already more distinct. In 1958 the relation between the potash content of the leaf and that of the soil was such that the curves for the fertilized plots and the control plots could no longer be separated. This means that after four years of consistent manurial treatment on alluvial clay, the potash contents of leaf and soil had settled into equilibrium with the rates of manuring.

Leaf potash for the trees on light soils turned out to be higher than would have been predicted from the mean relationship between leaf potash and soil potash. The probable reason for this difference is that potash is more easily leached by the rain on the light soils, and can therefore reach the root system more quickly and in larger quantity. Further, the clay soil had a subsoil that was both poorer in potash and more apt to fix the element in a form of low availability to the roots.

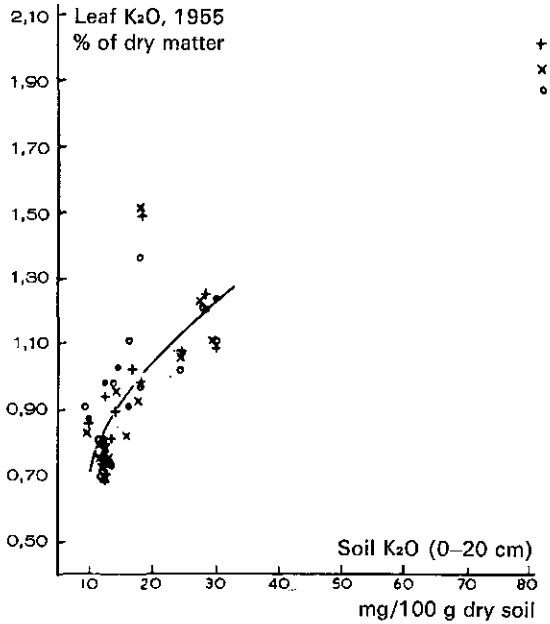
As regards the elevation of leaf potash by the fertilizer, it can be said that the richer the soil in potash, the smaller is this elevation (correlation coefficient between b K_2O of the leaf and K_2O of the soil in 1960 was —0.78^{++}). The findings of *Ljones* (1954) were similar. For a soil K_2O (soluble in dilute HCl) of 0.040%, the elevation of the potash concentration of the leaf was stabilised in 1960 at about 0.020% K_2O per 100 kg K_2O in the annual dressing (Fig. 3). The elevation was greater for soils of lower potash status, and in their case showed itself most strongly in the first years of the experiment. For the years 1958–1960, during which a balance was attained, the regression equation for accumulation of potash in the leaf was: $y = -0.0036 \times$ (K_2O of soil) + 0.1688. The dependent variable (y = b) is the elevation of leaf potash per 100 kg of K_2O applied annually. The equation indicates that (after five years of fertilization), leaf potash is increased by 0.097% per 100 kg K_2O in the dressing, if the 0–20 cm soil layer contains 0.020% of exchangeable K_2O (extractable by 0.1 N HCl); but is increased by only 0.025% per 100 kg K_2O if the soil contains 0.040% K_2O.

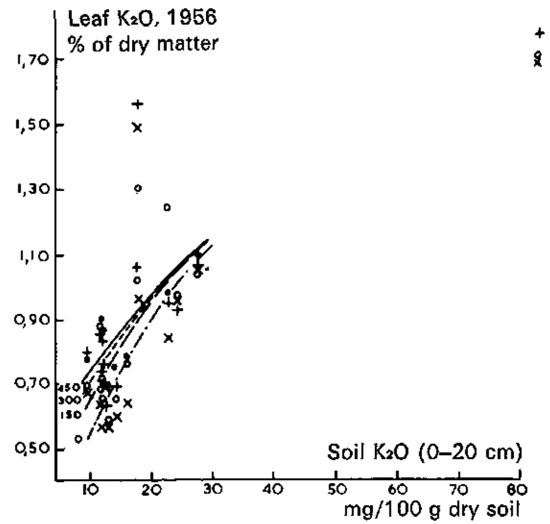
In the light of the above it goes without saying that the relation between the increase of leaf potash by manuring, and the original leaf—K_2O status for the controls was a negative one (Fig. 4). In 1955 the relation was still without statistical significance (r = —0.16). In 1956 the lower levels of leaf potash were subject to special increase and the relation between the increase and the initial stock had already become almost significant (r = —0.49(+). When the leaf contained more than 1.00% of K_2O, the increase due to manuring was only 0.02% K_2O per 100 kg K_2O/ha. In 1957 the effect of manuring was imperceptible at leaf potash levels above 1.60% K_2O. From 1958 leaf potash had been increased everywhere by manuring, although the effect became smaller as the leaf potash figures of the corresponding untreated plots became higher. Thus, a content of 0.70% K_2O was increased by approximately 0.140% K_2O; in contrast, where the content was high it was increased by only 0.025%. The year 1959, very hot and dry, was marked by a flatter yield curve and a low correlation coefficient.

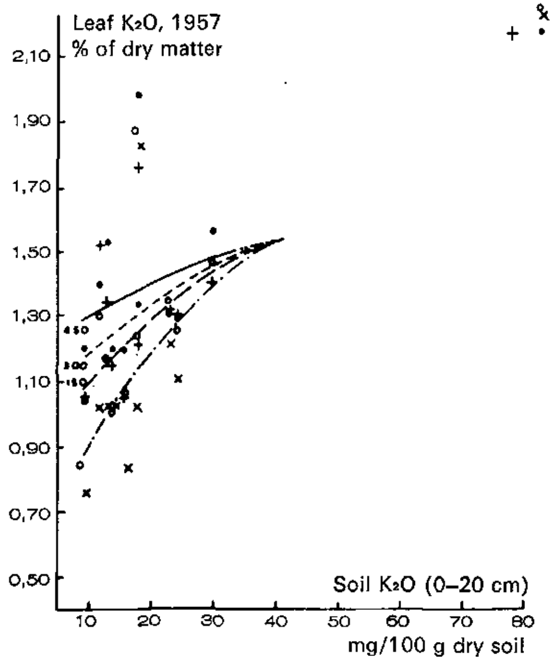
The MgO content of the leaf:

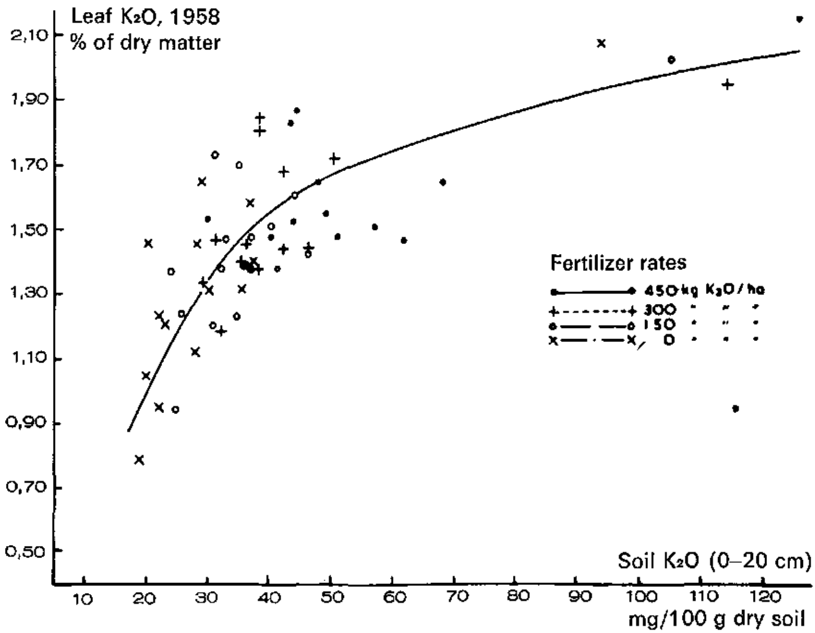
The magnesium level in the apple leaf was depressed by potassium fertilization. The mean diminution over the period 1958–1960 was 0.016% MgO per 100 kg K_2O/ha, the effect being highly significant statistically ($P < 0.01$). Only on experimental plots very rich in potash, and showing symptoms of magnesium deficiency, was the depression not manifested.

Figure 2. Relation between the K_2O contents of leaf and soil, as influenced by annual potassium dressings.






Leaf K₂O, 1957
% of dry matter
2,10
1,90
1,70
1,50
1,30
1,10
0,90
0,70
0,50
450
300
150
Soil K₂O (0–20 cm)
10
20
30
40
50
60
70
80
mg/100 g dry soil


Leaf K₂O, 1958
% of dry matter
2,10
1,90
1,70
1,50
1,30
1,10
0,90
0,70
0,50
Fertilizer rates
450 kg K₂O/ha
300 " " "
150 " " "
0 " " "
Soil K₂O (0–20 cm)
10
20
30
40
50
60
70
80
90
100
110
120
mg/100 g dry soil

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This fall in leaf magnesium was especially apparent in orchards on soils of low potash content (correlation coefficient between $^{r}b_{MgO}$—soil K_2O = +0.77^{++}), that is to say the replacement of magnesium by potassium was most strongly in evidence in such cases.

With soil potash higher than 0.030% K_2O the fall in leaf magnesium was only 0.01% MgO, or less.

In 1956–1958 the fall in the magnesium level due to fertilization was in linear proportion to increasing potash content of leaves. The fall became greater each year, for the low potash levels. In 1959 and 1960 the relationship was no longer linear and the leaf magnesium level was diminished most strongly at potash levels lower than 1.00% K_2O, the correlation coefficient r between b_{MgO} and leaf K_2O,then being +0.82^{++} (Fig. 5).

Depression of leaf magnesium by manuring was greater, the higher the magnesium content of the leaf. This effect became more and more pronounced towards 1957. In 1960 the depression amounted to 0.03% MgO per 100 kg K_2O/ha for a figure of 0.60% MgO in the leaf; but only to 0.006% if the leaf contained 0.40%. The regression equation may be stated as: $y = b_{(leaf\ MgO)}$ = —0.129 × (MgO% in leaf) + 0.046 (correlation coefficient r = —0.68^{+}).

There was a high negative correlation between leaf potassium and leaf magnesium on the control plots (r = —0.83^{++} in 1959). This negative relationship, already met with in many other investigations, is also in accord with the results mentioned above. It is as if potassium fertilization drives magnesium out of the leaves, especially when the potassium status of soil and leaf, low in the first place, are markedly raised by potassium manuring.

The CaO content of the leaf.

The calcium content of the apple leaf has not been clearly influenced by potassium manuring during the six years of experimentation. On the average for the 14 experiments the calcium content fell, during the period 1958–1960, by 0.004% CaO per 100 kg K_2O/ha, but this effect was not statistically significant. The change in calcium status due to fertilizing did not depend on leaf composition in the same manner in each year. With calcium figures higher than 2.50% CaO there was some depression by potassium manuring in 1955 and 1956, r for b_{CaO} and leaf CaO = 0.34 in 1956. This negative correlation no longer appeared in the following years.

Probably the depression of magnesium content was so pronounced that the calcium level was maintained (an interaction of K-Mg and Mg-Ca antagonisms). The higher the pH of the soil, the greater was the fall in leaf calcium; correlation coefficient r for b_{CaO} with pH (KCl) = —0.26.

Relationship between leaf magnesium and leaf calcium

Potassium manuring reduced the ratio of magnesium (MgO) to calcium (CaO) in the leaf, by 0.0057 per 100 kg K_2O/ha/year on the average ($P < 0.01$). The fall in the ration became more pronounced with leaves of increasingly low potassium content according to the equation: b = 0.015 × (leaf K_2O) —0.021; r = +0.78^{++}, and also increased with high magnesium content, b = —0.046 × (leaf MgO) + 0.018; r = —0.82^{++}, and rising calcium content (r = —0.41). There was no effect of manuring on the MgO/CaO ratio with trees having leaf potash higher than 1.45% K_2O, or magnesium lower than 0.38% MgO. These findings accord with the negative correlation between K_2O and MgO (r = —0.90^{++}) and between K_2O and CaO (r = —0.63), and with the positive CaO-MgO correlation for control plots.

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Nutrient element composition of fruit

The composition of the fruit was examined in 1960. The potassium manuring experiments had then run for six years. The results of fruit analysis for ten experiments were available; the mean nutrient concentrations found and the regression coefficients of manuring rate on these are given in table 2.

Table 2 Influence of potassium manuring on nutrient elements in fruit in 1960, and the increase (regression coefficients) in the levels of the various nutrients per 100 kg K_2O/per hectare per year.

Nutrient	mg/100 g of fresh material by rate of application kg K_2O/ha				Effect on content per 100 kg K_2O (b)	Significance level
	0	150	300	450		
K_2O	84.9	89.1	94.3	96.9	+ 3.43++	$P < 0.01$
MgO	7.5	7.6	7.7	7.8	+ 0.09+	$P = 0.05$
CaO	9.7	9.7	9.4	9.1	−0.12	$P < 0.20$
N	48.3	46.8	46.4	47.1	−0.17	0
P_2O_5	26.1	25.6	25.6	25.2	−0.15	$P < 0.20$
Dry matter %	14.2	14.1	14.1	13.9	−0.05	0
K_2O/MgO	11.42	11.76	12.25	12.51	+ 0.33+	$P < 0.02$
K_2O/CaO	9.08	9.43	10.20	11.04	+ 0.45++	$P < 0.01$
MgO/CaO	0.79	0.80	0.84	0.89	+ 0.02	$P < 0.20$

The K_2O content of the fruit

The mean increase of the potash content of the fruit due to manuring was statistically significant: 3.43 mg K_2O per 100 g of fresh materiel, per 100 kg of K_2O annually, with a standard error s = 0.94.

A relation between the potash content of soil and fruit was evident, and was similar to a Mitscherlich curve. Thus, potash concentrations in fruit (per 100 g of fresh material) of 77, 91 and 96 mg K_2O corresponded to soil potash levels (extractable by 0.1 N HCl, from samples representing 0–20 cm layer) of 0.020, 0.040 and 0.060% K_2O respectively. Only one experiment gave results that did not conform to this relationship. No difference was found in this sixth year of the experiments between the curves (fruit K_2O vs. manuring) for manured plots and for controls. Here again, as for leaves, a balance had been attained between the nutrition of the fruit, manuring, and the potash level in the soil.

Fruit with low potash contents corresponded with leaves having less than 1.05% K_2O in the dry matter, above which level the fruit potash figure rose only slightly with increasing potash content of the leaf (Fig. 6).

The regression coefficient, b_{K_2O}, for the fruit varied between 1.22 and 10.22 per 100 kg of K_2O/ha/year. The increase of fruit potash was very pronounced where the leaf had less than 1.00% K_2O in its dry matter. Above this figure, fertilization increased potash in the fruit by some 1.5 to 1.8 mg per 100 kg K_2O/ha/year (Fig. 7).

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Figure 6. Relation between potash content of fruit and leaf.

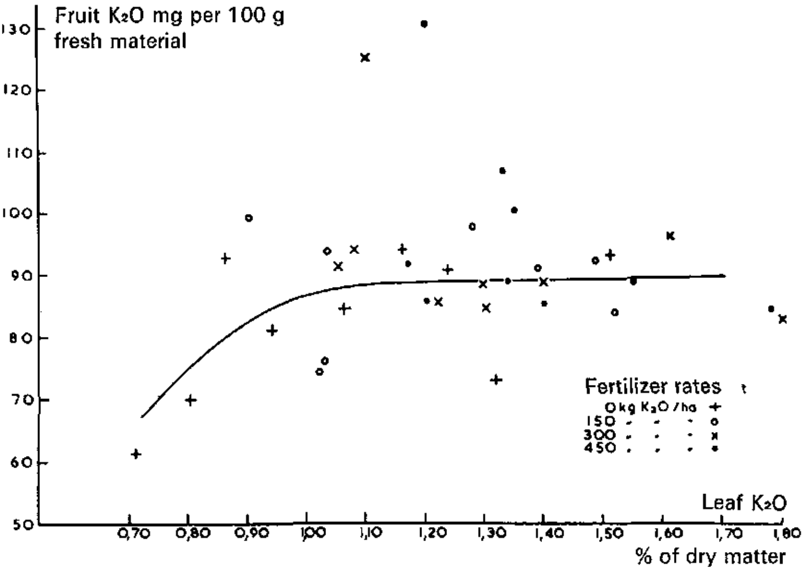

Figure 7. Influence of the potassium sulphate on the fruit K_2O in as function of the leaf potassium.

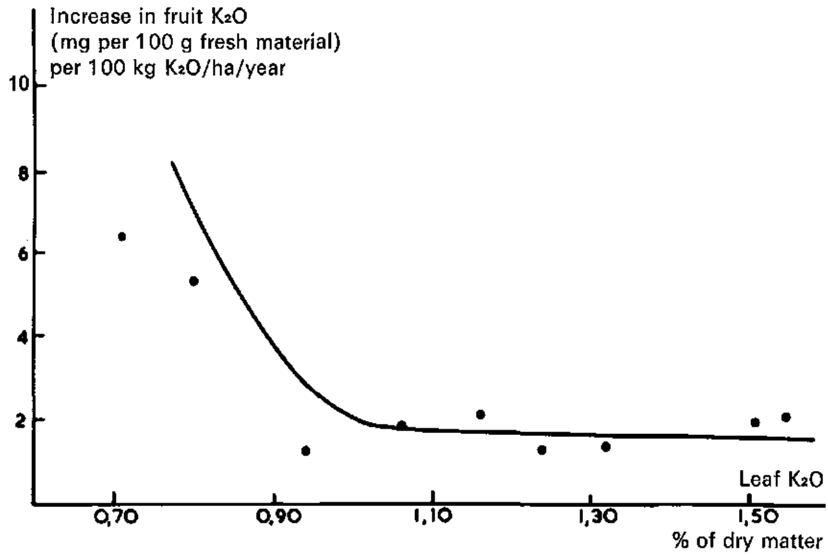

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Figure 8. Influence of the potassium sulphate on the fruit MgO as function of the leaf potassium.

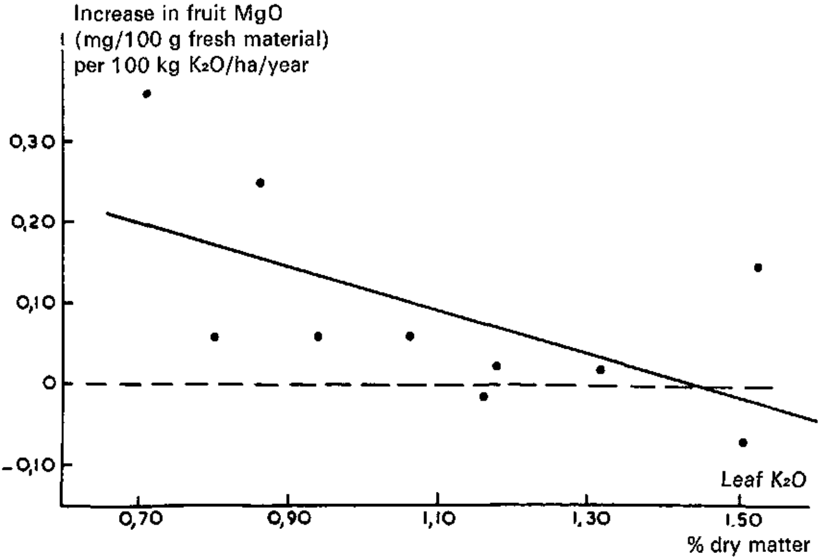
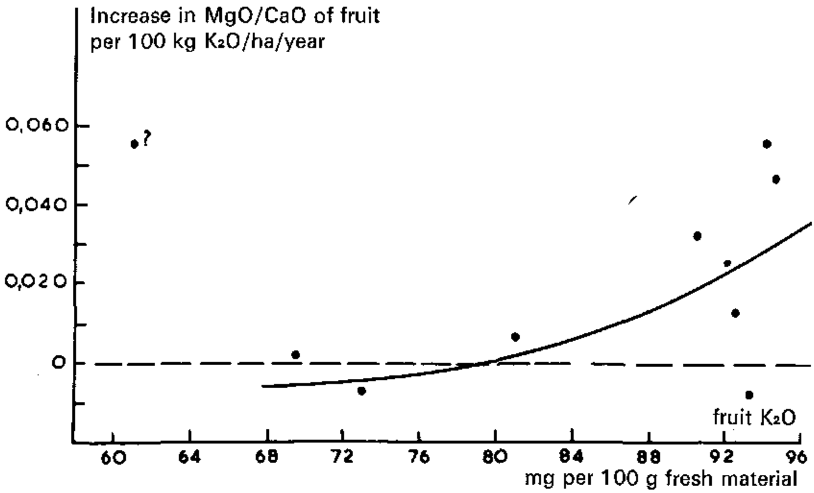


Figure 9. Influence of the potassium sulphate on the MgO/CaO-ratio of fruit as function of the K_2O in fruit.



The MgO content of the fruit

Wilkinson (1958) had previously found that the magnesium content of the fruit rises in consequence of potassium manuring; our results confirm this. The mean increase for the ten experiments was significant: 0.092 ± 0.041. *Wilkinson* put forward the hypothesis that the amount of organic acids in the fruit is increased in consequence of potassium manuring—which has been confirmed by the work of others, *Gruppe* (1958), *Mori and Yamazaki* (1960), *Barden and Thompson* (1962)—and that the fruit accumulates cations such as magnesium to stabilise the pH.

The rise in the magnesium content of the fruit is especially marked when the leaves are low in potash ($r = -0.59$; $P < 0.10$).

According to the regression equation: $b = -0.27 \times$ (leaf K_2O) $+ 0.39$, the magnesium content of the fruit will change no further after the leaf contains 1.48% K_2O or more (Fig. 8). In view of the negative relation between potassium and magnesium in the leaf, it goes without saying that the magnesium content of the fruit increased most strongly through potash fertilization, in the region of high leaf magnesium ($r = +0.33$). Fruit magnesium was only slightly increased when both potassium and magnesium in the fruit were high ($r = -0.37$), and the increase was zero when the magnesium figure was 9.7 mg MgO per 100 g of fresh material.

The CaO content of the fruit

The calcium content of the fruit was reduced by potassium manuring.

The average fall was 0.12 mg CaO per 100 kg K_2O/ha/year, and not significant ($P = 0.20$). A more detailed study of the results shows that the fall in calcium is associated mainly with high levels of CaO in the leaf ($r = -0.62^{(+)}$, $P < 0.10$). It is probable that a high calcium content corresponds to a poor state of potassium nutrition of the plant. Potassium nutrition increases the potash content of the fruit, and under these circumstances this is at the expense of its calcium content.

The relationship between calcium and magnesium in the fruit

The quality of the apple depends not only on the absolute concentrations of nutrient elements in it but also on their proportions one to another. Of particular importance are the ratios (K + Mg)/Ca, K/Ca, and Mg/Ca, especially in connexion with the occurrence of 'bitter pit' (*Schreven et al.*, 1962). We proceed to consider here the influence of potassium manuring on the MgO/CaO ratio in the fruit. The manuring induced an increase in this ratio in 7 out of the 10 experiments. The mean increase, 0.015, was not significant ($P = < 0.20$). Since potassium manuring generally causes the magnesium level in the fruit to rise and that of calcium to fall, a widening of the MgO/CaO ratio is to be expected.

If a tree already well provided with potash is offered more, the magnesium content of the fruit will rise above the existing level. The calcium content will fall. In such cases the MgO/CaO ratio will rise the further, the more potash the fruit contains; correlation coefficient r between $b_{MgO/CaO\ of\ fruit}$ and K in fruit $= +0.64$ (Fig. 9). Similary when MgO/CaO is already high for the fruit, r between $b_{MgO/CaO\ of\ fruit}$ and MgO/Cao of fruit $= 0.90^{+++}_{++}$.

The rise of MgO/CaO in the fruit following potassium manuring was most marked when the corresponding ratio, MgO/CaO, for the leaves was low, r between $b_{MgO/CaO\ of\ fruit}$ and MgO/CaO of leaf $= -0.79^{+}$.

(The results of one experiment, which diverged from the calculated regression lines, have been left out of consideration in the above calculations. Had they been included, the correlation coefficients would have been somewhat smaller.)

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Manuring with potassium sulphate thus lowers the MgO/CaO ratio for the leaf but raises it for the fruit, in which it will still be raised by the manuring even in an orchard well provided with potash. Such was demonstrated in these experiments, under conditions of good potash supply, where MgO/CaO for fruit was higher than 0.7. On control plots there was indeed a small negative correlation between the MgO/CaO ratio of the leaf and that of the fruit. This correlation disappeared, however, on the plots well manured with potassium.

Discussion

The influence of manuring on the composition of the leaves and fruit of the apple tree is a complicated question.

One must ask, in the first place, whether the manuring treatment produces strong increase in the growth of the tree. Badly fed trees will gain a better developed root system if they are given fertilizer and it follows that there will then be a better uptake of nutrients in general (*Cain*, 1953; *Gruppe*, 1958). A tree already well nourished will show hardly any acceleration of growth; rather will a heavy dressing of a given element lead to a reduced uptake of other elements present in the soil, or alter the distribution of these elements in the different parts of the plant (*Cain*, 1953). In the former case, that is to say increased growth, the concentration in the plant of an element not present in the fertilizer may rise, but in the other case—orchards of normal nutrient status—falls of nutrient concentrations may occur (*Mori and Yamazaki*, 1960).

If a pronounced growth increase is left out of consideration—and this accords with the general case in our experiments—the following statement can be made: in a poor nutritive medium, the potassium content of the tree will be strongly influenced by manuring. Where the potassium content of the leaf and fruit was high, the increase in these contents induced by manuring was proportionately slight. Similarly the effect of potassium manuring on the magnesium levels in leaf and fruit was reduced in proportion as their potassium content was high. In the results of *Ijstaas* (1962), likewise the cases of greatest increase of leaf potassium through manuring were associated with marked changes in the magnesium and calcium contents.

The effects attributable to fertilization became striking only as the experiments continued through several years. In the first year, the composition of the leaf changed only very little.

The changes came into operation later to an increasing extent as the soil was enriched with potassium and the potassium level of the leaves rose correspondingly. By the fifth year of experimentation a state of equilibrium was more or less established.

One may also expect an old tree to react more slowly on account of the potash reserves in the wood and bark.

The exchange capacity of the soil, estimated by the percentage of clay $< 16\mu$, exerted an influence. The potash content of the leaves was higher on light soils than the mean relationship between leaf potash and soil potash would have led one to expect. This may have been the consequence of easier leaching of the applied potash less of it being bound by the soil complex—towards the root system. Furthermore the heavy soils fix potassium (in its less available forms) more strongly.

By means of the calculated curves it is possible to predict the potassium content of the leaves of Jonathan apple trees on M IV stocks, as a function of the richness of the soil in potash, and the extent and duration of potassium manuring, on river alluvia under the climatic conditions of the Netherlands.

The influence of potassium manuring on the levels of the other nutrient elements was not the same for all parts of the plant. The magnesium content of the leaves fell but that of the fruit rose. The extent of the change depended, moreover, on the level of potash present beforehand. The MgO/CaO ratio of the leaf fell with potassium manuring. The reduction was smaller, in proportion as the potassium content of the leaf was higher. The MgO/CaO ratio of the fruit increased in consequence of potassium manuring and was very high in association with high potash contents in the fruit.

The levels of other nutrient elements in the soil (and in proportion, in the plant) will also play their part in determining the influence of potassium manuring on the elemental composition of the leaf and fruit. Some elements are more influential in this respect than others. *Van Itallie* (1938) gives the following order: K, Na, Mg, Ca. It turns out, therefore, that the main changes to be expected in consequence of manuring with potash may be expected in the cations.

Potash affected the magnesium content of the leaf more than its calcium content. This effect has been found by many other investigators (*Gruppe, Ljones,* 1963).

Summary

Fourteen manuring experiments have been carried out in orchards of Jonathan apples on M IV stocks, planted on alluvial clay soil. Potassium sulphate was applied annually at four rates.

The changes in the nutrient element composition of leaves taken from the bases of vegetative shoots and of the fruit, associated with potassium fertilization, have been followed over a period of six years.

The mean potassium content of leaves scarcely changed in the first year of the experiment. By the fifth year the increased potassium levels in the plants had more or less reached an equilibrium appropriate to their level of potassium nutrition. At the end of the experiment the potash content of the leaf had been raised on the average by 0.72% K_2O, per 100 kg K_2O applied annually per hectare (90 lb./acre approx.). The increase was, however, more restricted where the potassium content of leaf and soil was fairly high to begin with.

The magnesium content of the leaves was more strongly diminished by the manurial treatments than was their calcium content. This effect on magnesium depended on the potassium content of the leaf, at lower levels of which the effect became proportionately more pronounced.

The magnesium content of the fruit was increased by the potash dressings. The MgO/CaO ratio in the fruit was also raised, specially when the fruit already had a high potash content and consequently also a high MgO/CaO ratio.

The effect of a manurial dressing on the mineral composition of the leaf and fruit of the apple does not depend only on the nutrient element applied, but also on the levels of this element and of the other cations already in the plant.

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