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A five-year fertilizer trial with apples on a sandy soil; the effect on magnesium deficiency, foliage and fruit composition, and keeping quality

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Summary

A fertilizer trial was laid down in an orchard of Jonathan and Cox's Orange Pippin M IV on a light sandy soil. Three levels of nitrogen and potassium and two of calcium and magnesium formed 36 combinations divided into two replicates.

There was much magnesium deficiency in the foliage which was increased by dressing with potassium and diminished by magnesium. No effect or constant effect was found for nitrogen and calcium. The best relationship with magnesium deficiency was found with the K/Mg-ratio in soil, foliage and fruit. No magnesium deficiency will occur when the K_2O/MgO-ratio is less than 0.6 in the soil and less than 6 in the foliage. The MgO-content of the soil should be at least 110 dpm and 0.30 % in the foliage.

Dressing with potassium lowered the magnesium content of the foliage more than the calcium content; fertilization with magnesium reduced calcium more than potassium in the foliage. The first mechanism is much more powerful than the second. Dressing had less effect on the nutrient content of the fruit. Dressing with potassium increased the potassium and magnesium content in the fruit. A low level of calcium in the foliage was correlated with a high level of potassium and magnesium in the fruit.

Magnesium dressing raised the yield and potassium decreased it. The quality of Jonathan fruit was little influenced by the various dressings. Magnesium produced larger apples but a poorer keeping quality. After correction for apple size the unfavourable effect was eliminated. In the last year of the experiment potassium resulted in much breakdown in late-picked apples.

Bitter pit of Cox's Orange Pippin was significantly increased by potassium and magnesium dressings and lowered by calcium. Spraying with calcium lactate confirmed the beneficial effect of this element on bitter pit.

Bitter pit was connected with a high potassium content and a high potassium/calcium- and a low calcium/magnesium-ratio in the foliage and a low level of calcium. Regression formulae predicted no bitter pit for calcium-oxide levels higher than 1.9 %, a CaO/MgO-ratio higher than 11 and a K_2O/CaO-ratio of less than 0.8.

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1. Introduction

Most Dutch orchards are established on clay soils. During recent years there has also been a rapid expansion of fruit-growing on sandy soils, but several drawbacks arose such as a relatively short life of the trees, much magnesium deficiency in the foliage and poor keeping quality of the fruit.
As little was known about the optimal nutrition of fruit trees on sandy soils, a fertilizer trial was carried out with nitrogen, potassium, magnesium and calcium. A study was made of the influence of the variation in dressing on the health of the trees and the storage quality of the fruit by means of field observations and storage trials. Changes in the nutritional status of the soil and the trees were assessed by soil and plant analysis.

2. Material and methods

2.1. Description of the experimental field

The fertilizer trial was carried out on a reclaimed sandy soil of poor water-retaining characteristics. To improve soil retentivity the following measures were taken.

1. Before planting, the humic upper layer of the soil (c. 20 cm) was ploughed up to a depth of 40—50 cm in order to reduce evaporation.
2. 20,000 kg of town refuse/ha was given annually before 1954 to restore the water retentivity of the topsoil.
3. In addition sprinkle irrigation was applied in the last three years of the experiment. From 1960 frost damage in the spring was also prevented with the use of the same equipment.

Jonathan, Cox's Orange Pippin and Ellison's Orange on root-stock M IV were planted out in December 1947. In 1954 and 1955 the yields of the trees were recorded to assess the variability of the field. The fertilizer trial was begun in the winter of 1955/1956.
The soil has been sampled in 1954, the results of the soil analysis being given in TABLE 1. The orchard was clean-cultivated in spring. Green manure, *e.g.* lupine, serradella, which is able to fix nitrogen from the air, together with turnips, *etc.*, were sown in July and August. Before the trial started a 2 % solution of epsom salt was sprayed several times during the growing season to counteract magnesium deficiency. This measure was discontinued during the experiment.

TABLE 1. Soil-analysis figures of the upper layer of 0—20 cm depth (soil-solution ratio 1 : 10; percentages of air-dry soil)

pH-1 N KCl	Organ. matter (%)	P_2O_5 in mg/100 g air-dry soil soluble in		K_2O (%) exchangeable in	MgO (%) exchangeable in
		water at 50°C	1 % citr. acid	0.1 N HCl	0.5 N NaCl
5.3	2.6	1.1	38	0.0175	0.0054

2.2. The fertilizer experiment

A factorial experiment with 3 N—, 3 K—, 2 Ca— and 2 Mg— ratings was started in 1956 and ended in 1960. The nitrogen and potassium rates remained the same each year. Since the magnesium deficiency of the trees on the experimental field became increasingly serious, the amount of magnesium fertilizer was stepped up. Calcium in the form of calcium carbonate was only given in 1955. As a result the pH-KCl increased from 5.3 to 5.6. In our opinion a higher pH was not desirable. Calcium nutrition of the trees was continued with gypsum. TABLE 2 gives a review of the amounts of the various dressings throughout experimental period.

TABLE 2. Scheme of dressings in 1956—1960

Nutrient (kg/ha)	Ratings			Years
	0	1	2	
N, nitrochalk	0	80	160	1956-1960
K_2O, potassium sulphate	0	200	400	1956-1960
MgO, epsom salt ($MgSO_4 . 7 H_2O$)	0	128		1956, 1957
	0	192		1958
	0	384		1959, 1960
CaO, calcium carbonate	0	800		1956
gypsum	0	310		1958
gypsum	0	155		1959, 1960

The dressings were given in December (chalk, gypsum, sulphate of potash, epsom salt) or at the end of February or beginning of March (nitro-chalk).
The 36 combinations of dressing were laid down in two replicates with partial confounding (LI, 1944). The number of trees per plot were: 4 Jonathan, 2 Cox's Orange Pippin and 2 Ellison's Orange.

2.3. Observations during the experiment

The soil was analysed in 1954, 1955, 1957 and 1958. In 1958 three layers of the soil (0—20, 20—40 and 40—60 cm) were sampled. Routine soil analysis (DE VRIES and DECHERING, 1960) was used to study the effect of the dressings.
The third and fourth leaf from the base of the young shoots were sampled every August: The leaves were analysed for total N, P, K, Ca and Mg.
In the storage trials, thirty fruits per treatment were taken from trees with as far as possible the same yield/volume ratio. Sections of the fruits without skin and core were analysed for the above-mentioned elements.
Marks were allotted each year for the rate of growth and magnesium deficiency. Fruit yields were recorded.
Fruit of Cox's Orange Pippin and Jonathan were stored in 1958 and 1960. The apples were taken from the southern side of the trees having as far as possible the same fruit/foliage ratio. Two to four boxes of 15 kg outwardly healthy apples were stored per treatment. The number of the fruits per box was counted in order to determine the mean weight of apples per treatment. Cox's Orange Pippins were picked in a single operation and the fruits stored at 4°—5° C. Jonathans were harvested in three stages with an interval of a week. The apples of this variety were stored at 2°—3° C. Owing to frost damage a complete storage trial was not possible in 1959.

3. Results

3.1. Influence of fertilization on soil fertility

The results of soil analyses carried out in 1954, 1955, 1957 and 1958 are as follows: Nitrochalk lowered the potassium and magnesium contents of the upper layer (0—20 cm) of the soil. This effect may be explained by the greater uptake of these nutrients by the tree. It is also possible that exchange took place between calcium from nitrochalk and these elements on the absorbing complex of the soil, and that K and Mg were washed out to a deeper layer.

When potash was omitted the K_2O-content decreased 0.002 % per annuum, being 0.008 % on the unfertilized plots in 1958. A dressing of 200 kg K_2O/ha more or less maintained the K_2O-content of the upper layer, which was about 0.015 %. The dose of 400 kg K_2O/ha increased the K_2O-HCl content to 0.018 % K_2O in 1958. With increasing rates of potassium the content of exchangeable magnesium decreased. In 1957 the amount of MgO-NaCl on plots dressed with 0, 200 and 400 kg K_2O/ha was 69, 62 and 59 p.p.m. respectively. This decline in the MgO-content can also be explained by increased uptake of the tree or by exchange reactions in the soil.

When magnesium fertilizer is omitted the magnesium content of the soil decreased from 54 p.p.m. in 1955 to 46 p.p.m. in 1957 and 34 p.p.m. in 1958, the annual decline being 7 p.p.m. MgO-NaCl in the upper layer. With a total dressing of 450 kg MgO over the period 1955—1958 the MgO-percentage of the soil increased from 54 to 94 p.p.m. Thus a dressing of 100 kg MgO/ha/year increased the MgO-content of the soil by 9 p.p.m.

As mentioned above the pH of the soil was increased by calcium carbonate. Gypsum dressings did not change the pH but lowered the K_2O- and MgO-percentages of the soil. The decrease, however, was only statistically significant in the case of potassium.

The potash dressing had a greater effect on the K_2O-content of the subsoil than that of the epsom salt on the MgO-content (TABLE 3). Potash increased the K_2O-content of the 20—40 cm layer as much as the content of the 0—20 cm layer. On the other hand, the magnesium dressing enriched the upper layer in particular. This may be the reason why magnesium deficiency of the apple tree caused by excess potassium cannot be quickly remedied by dressing with magnesium sulphate.

The pH of the layer 20—40 cm showed a small increase of 0.05 pH-unit from calcium carbonate. No effect was noted in the deeper layer.

TABLE 3. Effect of potassium and magnesium dressing on the subsoil as compared with the topsoil

Depth of layer	K_2O-HCl $^1/_{1000}$ %			MgO-NaCl $^1/_{10000}$ %	
	ratings in kg K_2O/ha			ratings in kg MgO/ha	
	0	200	400	0	128 (192)
0—20 cm	8	14	18	34	93
20—40 cm	7	12	16	21	43
40—60 cm	6	9	10	16	30

3.1.1. *Conclusion*

Manuring with a certain nutrient not only changed its own content in the soil but also the percentages of other elements. The potash content in the upper layer of the soil decreased as a result of nitrochalk and gypsum and the magnesium percentage as a result of nitrochalk, sulphate of potash and to a lesser degree gypsum. This phenomenon may be explained by a changed uptake of the tree or by exchange reactions in the soil.

The subsoil was most enriched by potash and secondly by magnesium. Calcium carbonate increased the pH of the upper layer but did not influence the pH of the deeper layeyrs. Gypsum caused no change in pH.

3.2. Influence of the various dressings on the mineral composition of foliage and fruit

3.2.1. *The average mineral composition of foliage and fruit*

The results of the leaf and fruit analyses of this experimental field are tabulated in TABLE 4. The potash contents were very high, but the calcium and magnesium contents appeared to be fairly low. We consider the following percentages in the foliage of apples as normal: 1.5—1.8 % K_2O, 2.0—2.2 % CaO, 0.4—0.5 % MgO, 2.3—2.5 % N.

Compared to Cox's Orange Pippin, Jonathan had a lower K_2O-content and a higher MgO- and especially a higher CaO-content of the foliage under the same conditions of dressing and soil.

The ratio between the basic nutrient elements in foliage and fruit is not the same. Taking nitrogen as the basis of calculation, 2.5 times more phosphorus, 3—4 times more potassium, 1—3 times more magnesium, but 2—3 times less calcium are found in the fruit.

The unbalanced amounts of K, Mg and Ca in the foliage and the fruits from this experimental field are likely to cause an unbalance in the plant, resulting in a poor quality of the crop. As is known a high $\frac{K}{Mg}$-ratio causes Mg-deficiency symptoms in the foliage. According to GARMAN and MATHIS (1956) and other investigators high $\frac{K}{Ca}$- or $\frac{K + Mg}{Ca}$-ratios in foliage and fruits will result in a high susceptibility to bitter pit.

TABLE 4. Mean of nutrient elements in foliage and fruit

	In foliage (% dry matter)	In fruit (mg/100 g fresh)	When N = 100 in foliage (%)	When N = 100 in fruit (%)
Jonathan 1958				
N	2.36	38.2	100	100
P_2O_5	0.38	15.8	16	41
K_2O	2.54	129.0	108	338
CaO	1.42	7.3	60	28
MgO	0.21	6.7	9	26
Jonathan 1960				
N	2.25	34.8	100	100
P_2O_5	0.36	14.7	16	42
K_2O	2.59	145.7	115	419
CaO	1.59	6.8	71	20
MgO	0.38	6.2	17	18
Cox's Orange Pippin 1960				
N	2.36	39.8	100	100
P_2O_5	0.37	15.5	16	39
K_2O	2.83	173.0	120	437
CaO	1.14	4.9	48	12
MgO	0.35	6.8	15	17

TABLE 5. Influence of dressing on chemical composition of foliage and fruit of Jonathan

Dressing	Correlation coefficients x 100															
	foliage															
	N		P_2O_5		K_2O		CaO		MgO		K_2O/MgO		K_2O/CaO		CaO/MgO	
Jonathan																
N	+21	+44	—15	+05	—06	+03	+23	+23	—00	—17	—08	+16	—20	—16	+08	+28
K	—31	—00	—03	—07	+91**	+91**	—67**	—64**	—59**	—56**	+66**	+70**	+86**	+91**	+25	+20
Ca	—29	—21	+03	—19	—12	—06	+03	+28	—19	—07	+11	+04	—07	—21	+21	+19
Mg	+37*	+01	—30	—19	—22	—26	—16	—56**	+66**	+82**	—54**	—67**	+01	+19	—78**	—92**
Cox's Orange Pippin																
N	+68**		+29		+00		+34		—03		—01		—30		+14	
K	—04		—02		+81**		—28		—49**		+59**		+70**		+21	
Ca	—05		—18		—12		+05		—01		—11		—12		—03	
Mg	+08		—38*		—37*		—71**		+75**		—74**		+36*		—88**	

Statistical evaluation: 0 not significant; * significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$

3.2.2. *Influence of fertilization on the mineral composition of foliage and fruit*

In TABLE 5 the influence of the dressings on the mineral contents in apple foliage and fruit are expressed as correlation coefficients (see also FIGS. 1, 2, 3 for the influence of dressing on the mineral composition of Jonathan foliage and fruit).

Potassium and magnesium appeared to exert most effect on the composition of foliage and fruit:

Potassium increased the K_2O-content of the leaf and decreased the CaO- and MgO-content. The decrease of the leaf magnesium caused by potassium was more pronounced on the plots with a magnesium dressing (K $\times$ Mg-interaction, in 1960 significant). LJONES (1954) found a depressing effect of K-dressing on the Mg-content of the foliage in September but not in June. GRUPPE (1958) showed that high levels of potassium in sand culture increased the calcium content of the shoots and lowered this content in the foliage, probably preventing transport to the foliage. The total quantity of calcium taken up and the calcium content of the whole plant was highest for the dressing with the K/Mg-ratio which gave the best growth.

The K_2O-content of the fruit was increased by a potassium dressing, and this also increased its MgO-level. This was found for Jonathan in 1958 and 1960 and for Cox's Orange Pippin in 1958. Thus a potassium dressing differs in its effect on the magnesium content in the foliage and the fruit. The same was seen in more recent experiments (VAN DER BOON, 1964). WILKINSON (1958) also found, that an increase of potassium in the fruit is accompanied by an increase of magnesium. The distribution of magnesium over foliage and fruit is therefore changed by increasing the supply of potassium. According to WILKINSON fruits with a high potassium content may draw magnesium from the foliage on account of their higher acidity which is dependent on the potassium level.

The calcium content of the Jonathan fruit decreased when potassium was added to the plots with magnesium (an almost significant K $\times$ Mg-interaction in 1960, $P = 0.10$).

Since the quality of the fruit, especially bitter pit, depends on the potassium, calcium and magnesium ratios, these were also calculated. It is evident that the K_2O/MgO- and the K_2O/CaO-ratios are closely correlated to the potash dressing. The and Cox's Orange Pippin in 1958 and 1960

Correlation coefficients																	
fruit																	
dry matter		N		P_2O_5		K_2O		CaO		MgO		K_2O/MgO		K_2O/CaO		CaO/MgO	
+12	+13	—04	+07	—02	—10	—02	+02	+30	+09	—23	+00	+16	+02	—22	—00	+37*	+08
—24	—14	+21	+36*	—00	+31	+47**	+83**	+08	—00	+29	+17	+20	+52**	+03	+44*	+01	—04
+15	+32	—03	—13	+08	+09	—09	+01	—14	+19	—06	—23	—02	+21	+05	—25	—12	+18
+57**	+10	+13	+37*	+08	+40*	+12	+21	—06	—27	+20	+67**	—08	—45**	+14	+33	—11	—44*
—16	+13	+14	—10	+24	—15	+07	—20	—00	—03	+26	—17	—16	—01	+02	—04	—13	+08
—42	—26	—33	—10	—45*	—12	+64**	+35	—11	+04	+44*	—12	+22	+72**	+49*	+45*	—33	+09
+47*	—14	+20	—51**	+43	—42*	+20	—25	—01	—01	+01	—13	+18	—16	+12	—15	+01	+07
+61**	+22	+32	—09	+38	—33	+33	—16	+33	+22	+47*	+35	—12	—30	—09	—28	+05	+04

FIG. 1. Influence of dressing on K_2O-level in foliage and fruit of Jonathan

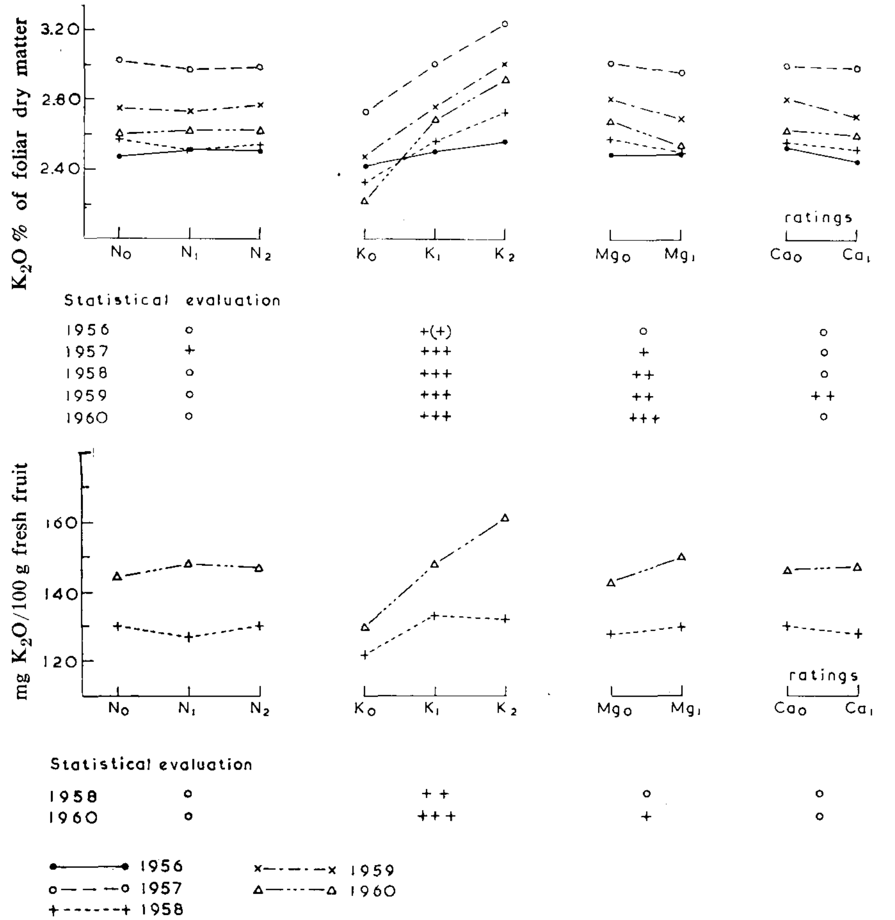
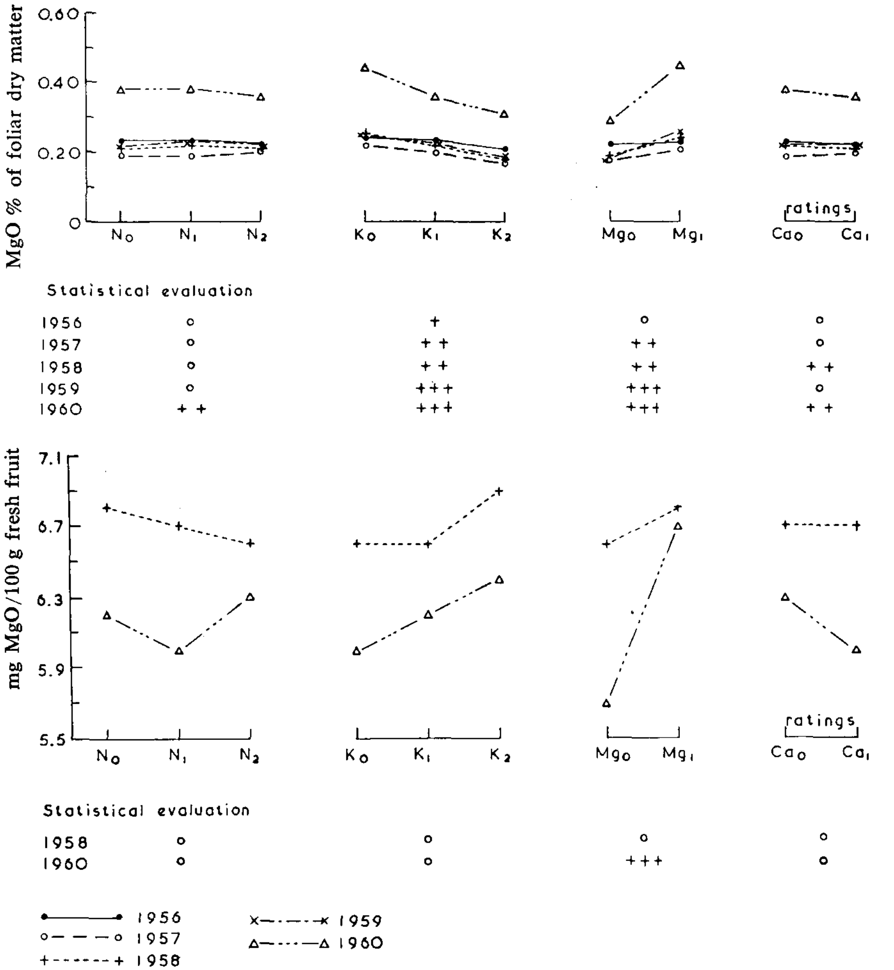


FIG. 2. Influence of dressing on MgO-level in foliage and fruit of Jonathan

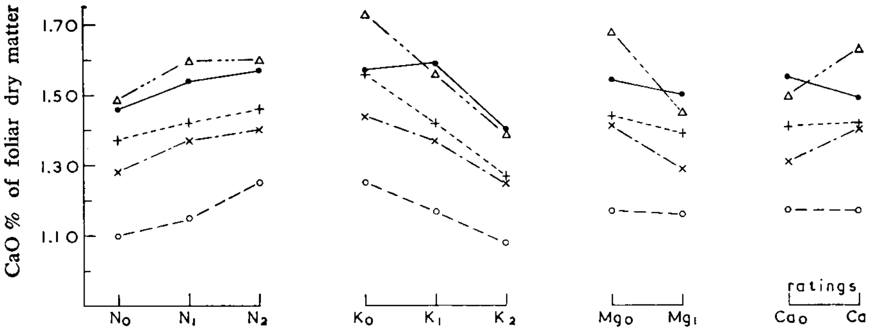


positive correlation between the CaO/MgO-ratio in the foliage and K dressing is of greater interest. Potassium decreased the calcium content less than the magnesium content. The effect of K on the CaO/MgO-ratio in the fruit was not evident in this trial. More recent experiments (VAN DER BOON, 1964) showed that the CaO/MgO-ratio decreased.

The *magnesium dressing* often showed a significant influence on the nutrient contents of foliage and fruit. More magnesium increased the magnesium content of the foliage and decreased the potassium and calcium content. Since the K_2O/CaO-ratio in the leaf was raised, potassium must have decreased less than calcium.

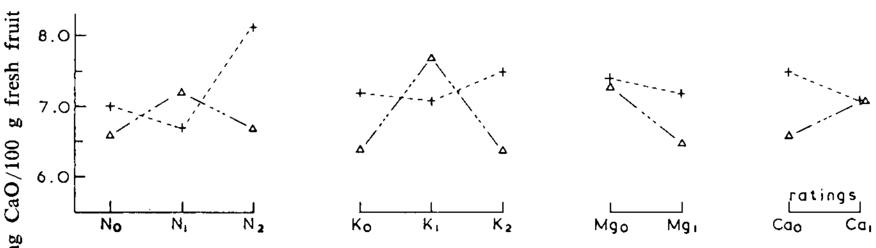
The dry-matter content of the fruit in 1958 was higher for the plots dressed with magnesium. Since the healthier leaves have better powers of assimilation more carbo-

FIG. 3. Influence of dressing on CaO-level in foliage and fruit of Jonathan



Statistical evaluation

1956	o	+	o	o
1957	+ +	+ +	o	o
1958	o	+ +	o	o
1959	+++	+++	+++	+++
1960	+ +	+++	+++	+ +



Statistical evaluation

1958	o	o	o	o
1960	o	+ +	(+)	•

•——• 1956
o— — —o 1957
+------+ 1958
x—·—·x 1959
Δ—···—Δ 1960

hydrates are stored in the fruit. Magnesium dressings resulted in an increase of the Mg-content of the fruit. As a result of this treatment no distinct influence was noticed on the $\frac{K_2O}{MgO}$-, $\frac{CaO}{MgO}$- and $\frac{K_2O}{CaO}$-ratios in the fruit.

Nitrochalk increased the nitrogen content of the foliage, but had no clear effect on that of the fruit. As was expected, the calcium content of the foliage was increased (VAN DER BOON and POUWER, 1960). No effect on the K_2O- or MgO-content was noted.

Calcium carbonate and gypsum only led to minor changes in the foliar composition, the nitrogen, potassium and magnesium contents of the foliage being slightly decreased and the calcium content increased. The correlation coefficients were not significant.

In LJONES' experiment (1954) the potash content was depressed by hydrated lime and especially by dolomite.
LJONES (1963) also made an extensive study of the influence of fertilization on the chemical composition of the foliage. He distinguishes "primary" and "secondary" effects. The "primary" effect is the influence of a given dressing on its content in the foliage. The "secondary" effects are the effects on the contents of other elements in the foliage, these usually being less severe than the former. In agreement with our own experiments, he found the primary effect of calcium to be least when the influence of K-, Mg- and Ca-ratings were compared. He found that nitrogen caused a decrease of foliar potassium where growth was vigorous ("dilution effect") and little effect, as in our experiment, where there was little or no change in growth. Calcium and magnesium dressings decreased the foliar potassium in several of his experiments. On the other hand potassium dressings considerably decreased the calcium content of the foliage, especially in years of high calcium level. In some of his experiments potassium had a relatively greater depressive effect on foliar magnesium than on calcium. The influence of nitrogen on foliar magnesium was not conclusive.

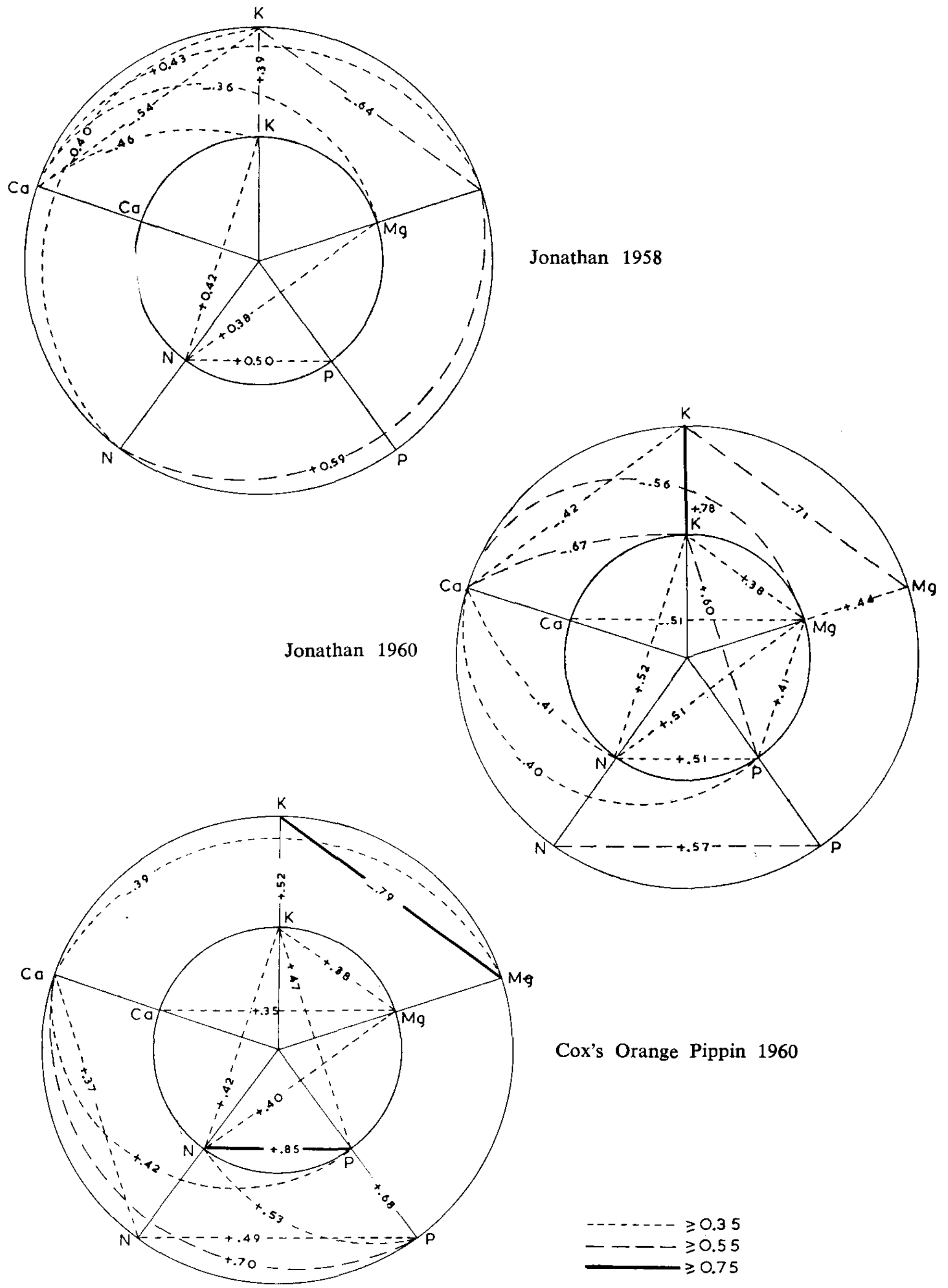
3.2.3. *Relationships between nutrients in foliage and fruit*

The correlations between the nutrient elements in foliage and fruit are also specified in FIG. 4. The data relates to two varieties and the two years 1958 and 1960.

3.2.3.1. *Correlations between nutrients in the foliage.* The foliage showed a significant negative correlation between the K_2O-content and the MgO- and CaO-contents (average correlation coefficients resp. —0.67** and —0.42**). But a significant positive correlation was seen with the CaO/MgO-ratio (corr. coeff. +0.46**). This means that the depressive effect of potassium on magnesium in the foliage is greater than that of potassium on calcium.
However, the MgO-content of the foliage appeared to be significantly negatively correlated with the K_2O/CaO-ratio (corr. coeff. —0.39*(*)). From this it may be concluded that magnesium will decrease the K_2O-content of the foliage more than the CaO-content.
According to VAN ITALLIE (1938) the depressive effect of an increase of a certain cation on other cations in the foliage decreases as follows: K> Na> Mg> Ca. In 1954, before the experiment was started, foliar calcium and magnesium were positively correlated, but in 1960 a negative correlation was found. The heavy epsom-salt dressing had an adverse effect on the calcium content of the foliage. LJONES (1954) found the following correlations in his experiment with potassium dressing: – K : Ca = —0.65, K : Mg = —0.49 and Ca : Mg = +0.35.

3.2.3.2. *Correlations between nutrients in the fruit.* The correlation coefficients between the nutrient elements in the fruit were not high and sometimes did not even have the same sign for the two varieties in the two experimental years 1958 and 1960. Only the following correlations are worth noting: – In the four series the potassium and magnesium contents in the fruits are positively correlated. This agrees with the influence found for potassium dressing on the magnesium content of the fruit. In 1958 the correlation coefficients were +0.48* and +0.22 for Cox's Orange Pippin and Jonathan respectively and in 1960 +0.38* and +0.38*.
In all four cases there were positive correlations between nitrogen and phosphorus

FIG. 4. Correlation between nutrient elements in foliage (outer circle) and fruit (inner circle); significant correlation coefficients



contents in the fruit (corr. coeff. +0.62***) and also, although to a less extent between nitrogen and potassium (corr. coeff. +0.42***) and between nitrogen and magnesium (corr. coeff. +0.40***). GARMAN and MATHIS (1956) found more potassium and magnesium in the fruit after dressing with nitrogen.

3.2.3.3. *Correlations between nutrients in foliage and fruit.* The data for Cox's Orange Pippin in 1958 and Jonathan in 1958 and 1960 were studied for the relationships between the levels of the nutrient elements in foliage and fruit. The correlations for the corresponding element in foliage and fruit are high for potassium (+0.56) and low for calcium. Occasionally the correlations between the ratios of the elements in foliage and fruit were higher than those for separate elements. The correlations between the calcium content of the fruit and the nutrient percentages for the other elements in the foliage were likewise all low. In two of the three cases a high negative correlation was found between the calcium percentage of the foliage and the potassium content of the fruit (—0.67**, —0.46** and —0.05). A negative correlation with the magnesium level in the fruit (—0.56**, —0.36** and —0.21) was also noted, which would imply that high levels of K and Mg in the fruit, which impaired the quality, went together with low calcium levels in the foliage.
MULDER (1950) assumed that low levels for foliar phosphorus will occur in orchards suffering from severe magnesium deficiency. VAN STUIVENBERG and POUWER (1952) could not confirm this relation. In our experiments the same amount of phosphorus was given to all plots every year, and magnesium in two levels. There was a small negative correlation between magnesium and phosphorus in the foliage (corr. coeff. —0.19), but a positive one in the fruit (+0.30*). There was a slight negative correlation between the phosphorus content in the foliage and the magnesium in the fruit (corr. coeff. —0.19).

3.2.4. *Conclusion*

The foliage and fruit on this experimental field showed high potassium and low calcium and magnesium levels.
Dressing with potassium had a notable influence on the chemical composition of the foliage. The potassium content increased, but the calcium and particularly the magnesium contents decreased. The CaO/MgO-ratio in the foliage also rose. There was an increase in both the potassium and magnesium percentage in the fruit.
Fertilization with magnesium increased the MgO-content and lowered the potassium, and especially the calcium content of the foliage. Both the magnesium content and the percentage of dry matter increased in the fruit.
Nitrochalk increased the N- and Ca-content of the foliage, but had only a slight effect on the composition of the fruit.
Calcium carbonate and gypsum caused no noticeable change in the composition of foliage and fruit.
On the whole these influences were confirmed by a calculation of the interrelationships of the nutrient contents in foliage and fruit. It should be observed that the heavy epsom-salt dressings during the experiment changed the positive correlation between foliar calcium and magnesium content to a negative one.
The correlations between K, Ca and Mg in the fruit were lower than those in the foliage. Corresponding to the influence of dressing, K and Mg were positively correlated in the fruit and negatively in the foliage.

There was a distinctly positive correlation between the K-content of the foliage and fruit. No clear relationship was found between calcium in the foliage and fruit. High levels of K and Mg in the fruit were found at low Ca-levels in the foliage.

3.3. Magnesium deficiency

3.3.1. *Difference between varieties*

Magnesium deficiency very often occurs in the Netherlands on sandy and marine soils, both being rich in exchangeable potassium and the latter also in calcium carbonate (MULDER, 1950). Failure to bud of the shoots on the base and the middle is the most harmful long-term effect.
Cox's Orange Pippin showed more magnesium deficiency than Jonathan under the same conditions. This agrees with the differences in the chemical composition of the foliage. Cox's Orange Pippin had a higher K-content and a lower Mg-content in the foliage than Jonathan (TABLE 4). BÜNEMANN (1959, 1960) found the same differences between these two varieties.

3.3.2. *Influence of the various dressings on magnesium deficiency*

The trees on these sandy soils even showed symptoms of magnesium deficiency on plots to which no potassium had been given. Potassium sulphate greatly enhanced the deficiency and magnesium sulphate decreased it, but not to a sufficient extent during the first years. FIG. 5 shows the influence of the various dressings on Mg-deficiency for Jonathan, and TABLE 6 gives a survey of the results obtained for both varieties in 1960.

TABLE 6. Effect of N-, K-, Mg- and Ca-fertilization on magnesium deficiency

Ratings	Vigour markings on 11th August 1960 [1]							
	Jonathan				Cox's Orange Pippin			
0	N: 1.0	K: 0.5	Mg: 1.8	Ca: 1.2	N: 2.5	K: 1.6	Mg: 3.3	Ca: 2.3
1	1.1	1.1	0.4	1.1	2.4	2.3	1.7	2.6
2	1.2	1.8			2.5	3.5		
Statistical evaluation:	0	***	***	0	0	**	**	0

[1] Code of markings: 0 = all leaves healthy.
3 = leaves on base of shoots with brown necrotic spots and margins.
5 = 1 to 2 leaves on base of shoots had fallen off; higher leaves on shoots with necrotic spots and margins.

There was a statistically significant K $\times$ Mg-interaction on magnesium deficiency, in 1958 for Jonathan only, and in 1959 and 1960 for both varieties.
TABLE 7 shows the influence of the K $\times$ Mg-interaction on the degree of magnesium deficiency of Jonathan in 1958 and 1960. In 1958 potassium dressing increased the deficiency, especially when no magnesium had been given. In 1960, after three years of increased dressing of magnesium, the unfavourable effect of potassium on Mg-deficiency was no longer noted on the latter plots.
Nitrochalk had no constant effect on Mg-deficiency. In 1957 the symptoms in Jonathan decreased with increasing nitrogen dressings. The crop was small that year, but also in 1959 when however a beneficial effect of nitrogen was absent. It was only in 1958 that an N $\times$ K-interaction occurred: nitrogen increased magnesium deficiency slightly at low potash levels, but decreased the deficiency at high levels.

FIG. 5. Influence of dressing on magnesium deficiency of Jonathan

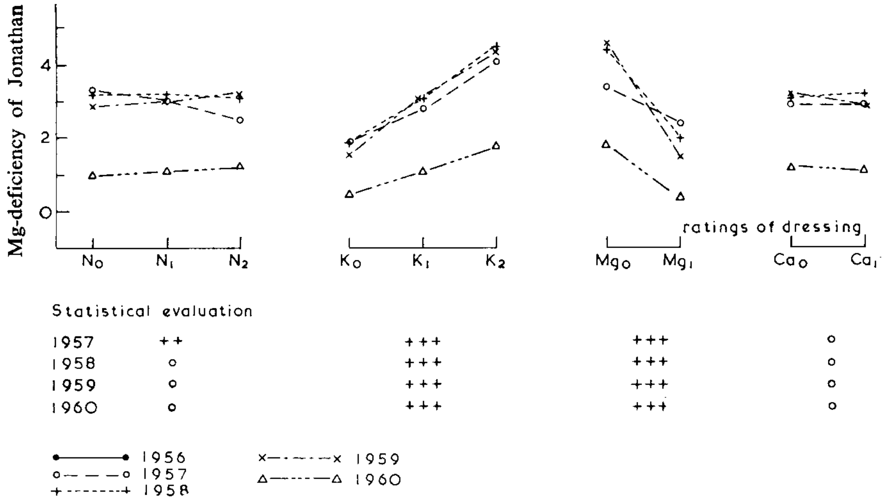


TABLE 7. Scores for magnesium deficiency of Jonathan in 1958 and 1960; effect of K × Mg-interaction

K_2O in kg/ha	MgO in kg/ha			
	1958		1960	
	0	192	0	384
0	2.7	1.1	0.5	0.4
200	4.3	2.0	1.7	0.5
400	6.0	2.9	3.1	0.4

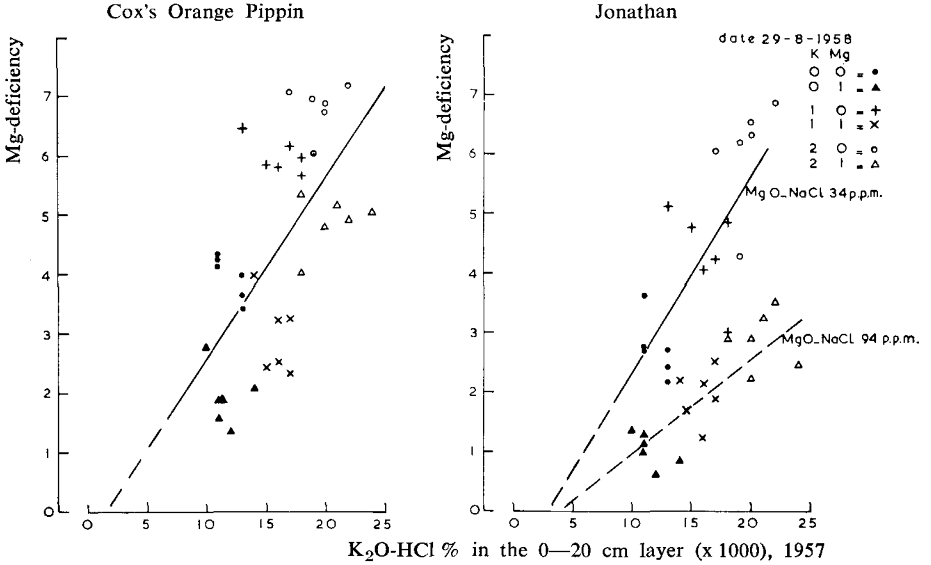
Calcium given in the form of calcium carbonate and gypsum had no effect. LJONES (1954) found that hydrated lime postponed the first appearance of magnesium deficiency in June, but by September no further beneficial effect was visible.

3.3.3. *Relationship between magnesium deficiency and the chemical composition of the soil and the tree (foliage and fruits)*

The various dressings changed the chemical composition of the soil and the nutritional status of the tree. Plotting the markings for magnesium deficiency against the chemical composition of the soil and the foliage gives some idea of the relationships between these factors.

3.3.3.1. *Relationships with the chemical composition of the soil.* The Mg-deficiency increases with increasing amounts of soil potash. For Jonathan this relationship clearly depends on the Mg-status of the soil, but this interaction was not so apparent for Cox's Orange Pippin (FIG. 6). The regression line predicts no Mg-deficiency when the K_2O-HCl content of this sandy soil is less than 0.005 %. LJONES (1963) also states that determination of soil potassium only gives no reliable information about foliage-

FIG. 6. Markings for magnesium deficiency and potassium content of the soil (0—20 cm layer)



0 = no Mg-deficiency; 10 = very serious Mg-deficiency (serious fall of foliage)

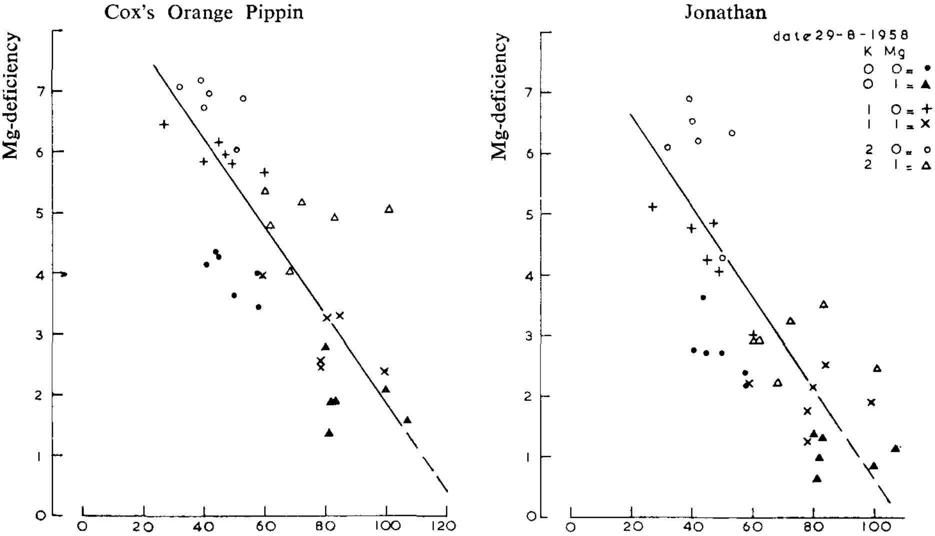
magnesium status and the risk of magnesium deficiency, although this deficiency is often induced by high potassium levels. A soil analysis of magnesium is required as well.

When the deficiency markings are plotted against the soil-analysis figures for magnesium, extrapolation of the regression line shows that a MgO-content on an air-dry basis of 110—120 p.p.m. is sufficient to prevent Mg-deficiency (FIG. 7). GRUPPE (1958) states that all orchards showed magnesium deficiency when the soil contained less than 50 p.p.m. of exchangeable magnesium; both healthy and diseased trees occurred at a level of 50—120 p.p.m. of exchangeable MgO, and only healthy trees were found above this range.

The best relationship is found with the K_2O/MgO-ratio in the soil (FIG. 8). No Mg-deficiency is to be expected when this ratio is less than 0.6. This figure is considerably lower than that given by BUTIJN (1961) and GRUPPE (1958). BUTIJN states that the K_2O/MgO-ratio may be higher without risk of Mg-deficiency according as the soil contains less calcium. His maximum permissible ratio is higher than 1.8 on soils having a pH of less than 6. GRUPPE (1958) gives 1.8—2.3 as critical levels. The disagreement with our results may be due to the special qualities of the light sandy soil of which practically all the magnesium is dissolved and exchanged in the soil analysis. There is no $CaMg(CO_3)_2$ of which the magnesium availability is under discussion. Moreover the subsoil here is very poor in magnesium.

3.3.3.2. *Relationship with the chemical composition of foliage and fruit.* TABLE 8 shows the correlation coefficients between Mg-deficiency and the percentages of K_2O,

FIG. 7. Markings for magnesium deficiency and magnesium content of the soil in the 0—20 cm layer



p.p.m. MgO-Na Cl in the 0—20 cm layer, 1957

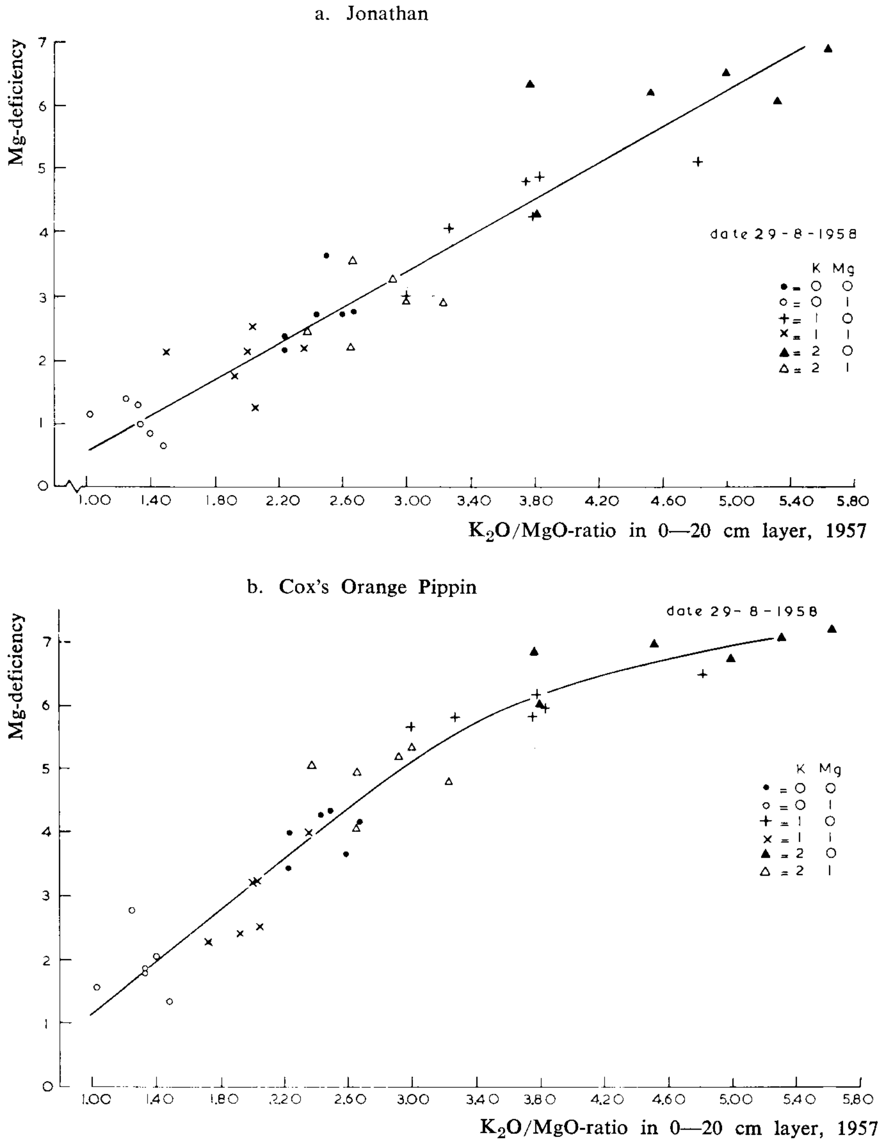
o = no Mg-deficiency; 1 o = very serious Mg-deficiency (serious fall of foliage)

TABLE 8. Magnesium deficiency in the foliage and the chemical composition of foliage and fruit (correlation coefficients)

	Magnesium deficiency		
	Cox's Or. Pippin	Jonathan	
	1960	1958	1960
Foliage			
K_2O	+0.68***	+0.74***	+0.69***
CaO	+0.32	—0.34*	—0.05
MgO	—0.59***	—0.93***	—0.72***
K_2O/MgO	+0.72***	+0.91***	+0.86***
K_2O/CaO	+0.12	+0.57***	+0.38*
CaO/MgO	+0.62***	+0.83***	+0.67***
Fruit			
K_2O	+0.24*	+0.13	+0.36*
MgO	—0.40**	+0.12	—0.39*
K_2O/MgO	+0.57	+0.05	+0.66***

MgO and CaO and the respective ratios in the foliage and between Mg-deficiency and the K_2O- and MgO-content and the K_2O/MgO-ratio in the fruit.
Despite the high correlation with the K_2O-content in the foliage, no simple linear relationship was found with Mg-deficiency. This also appeared to depend on the Mg content of the foliage (FIG. 9).
On the other hand, a linear correlation was found with both the Mg-content and

FIG. 8. Markings for magnesium deficiency and K_2O/MgO-ratio of the soil in the 0—20 cm layer; a. Jonathan, b. Cox's Orange Pippin



the K_2O/MgO-ratios in the foliage (FIGS. 10 and 11). As was found for the soil the best relationship was noted with the K_2O/MgO-ratio in the foliage, thus providing confirmation of VAN STUIVENBERG and POUWER's theory (1952). Magnesium deficiency does not occur when the K_2O/MgO-ratio is less than 6, or less certain when the

FIG. 9. Magnesium deficiency and potassium content of foliage; two levels of Mg-dressing

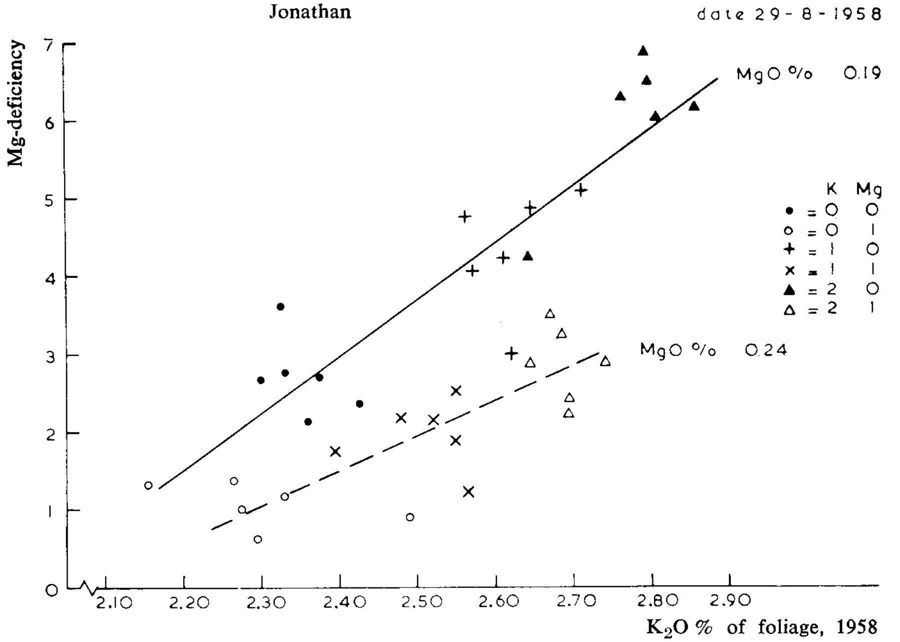


FIG. 10. Magnesium deficiency and magnesium content of foliage

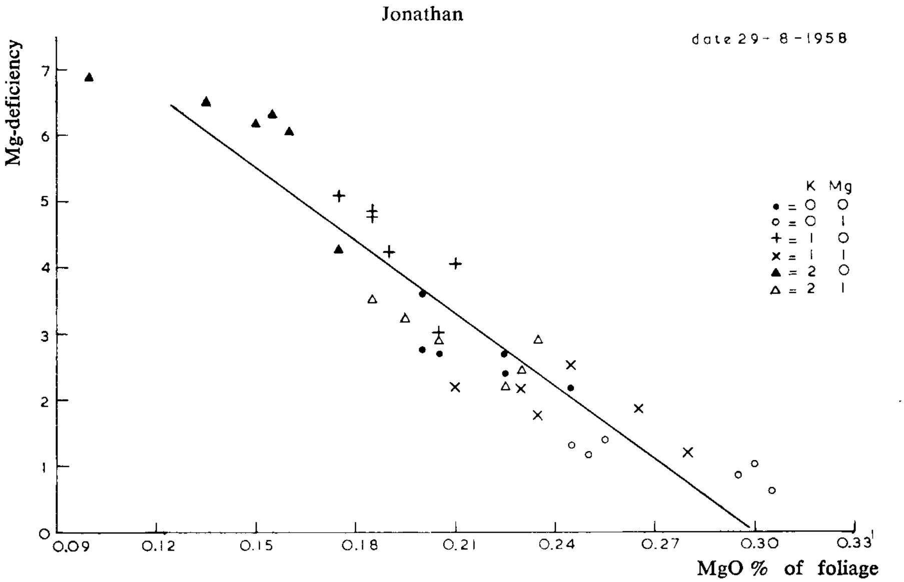
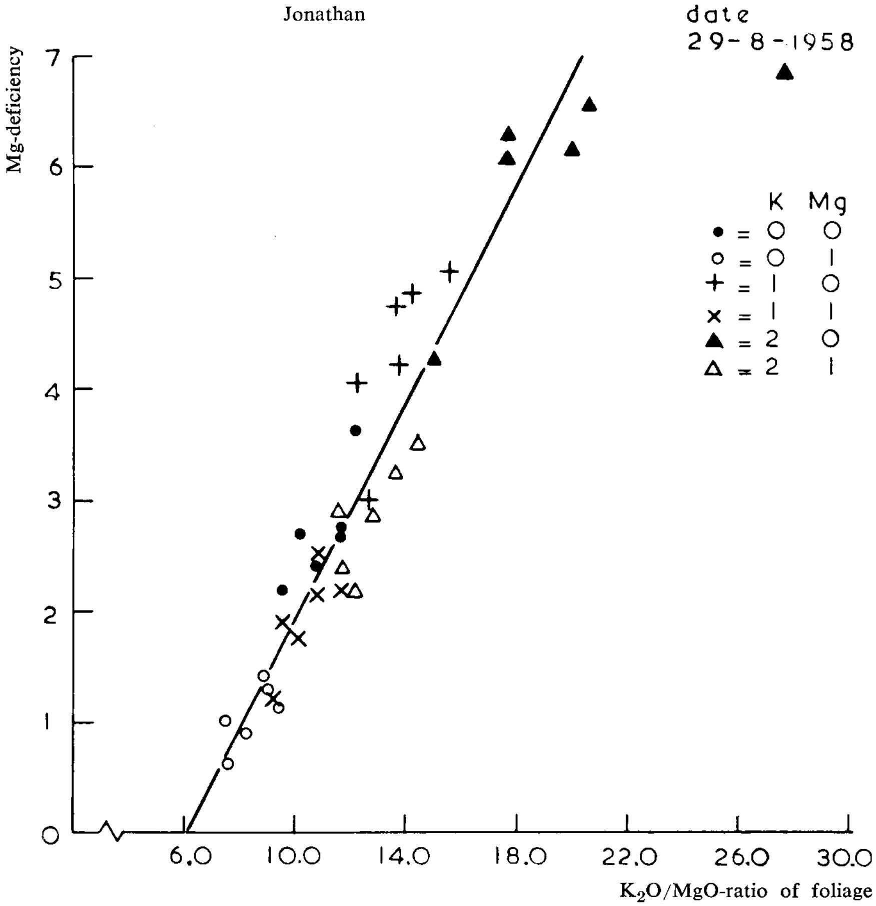


FIG. 11. Magnesium deficiency and K_2O/MgO-ratio in foliage



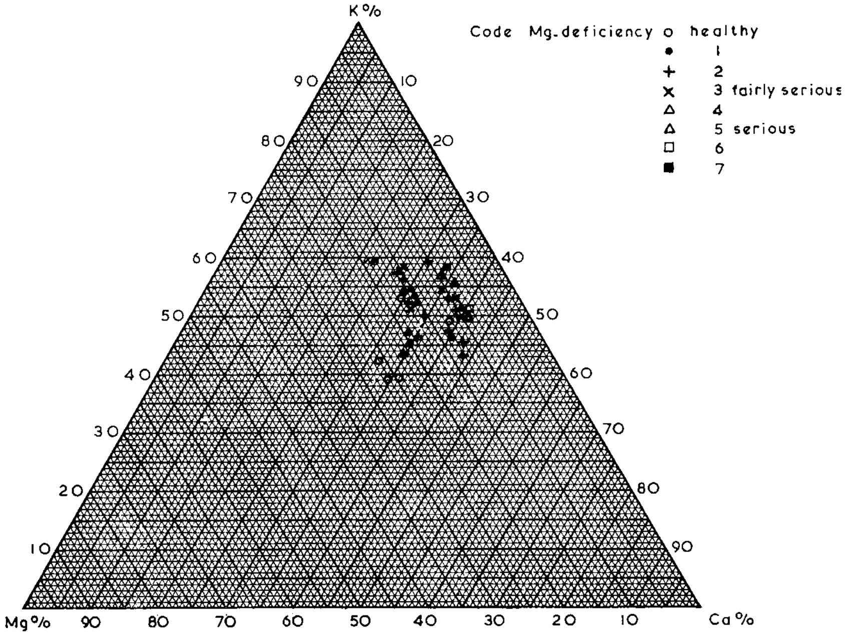
MgO-level is above 0.30—0.35 %, and the K_2O-percentage below 2.20. LJONES (1954) cites from literature a threshold value of 0.40 MgO %. He finds the same value in his own experiments but only reliable as a characteristic in on-years for foliage sampled in September. Magnesium deficiency appeared with a value of 1.25—1.45 K_2O % in the foliage sampled in September. It increased markedly for K_2O-levels higher than 1.75 and MgO-levels lower than 0.36 %.

According to GRUPPE (1958) the basal leaves of the shoots showed symptoms of magnesium deficiency when the K_2O/MgO-ratio exceeded 9.3. BUTIJN (1961) found a K_2O/MgO-ratio of 5.9 for Cox's Orange Pippin and a maximum permissible ratio of 5.2 for Jonathan.

The positive correlation of magnesium deficiency with the CaO/MgO-ratio in TABLE 8 may suggest that calcium also has a considerable effect. This, however, is probably due to the interdependence of the separate elements K, Mg and Ca, as Ca dressings had no effect on the degree of Mg-deficiency (FIG. 5). The triangle diagram, in which K, Ca and Mg are converted to equivalents and expressed as percentages of

the sum of the three elements, also shows critical levels for K and Mg, but not for Ca (FIG. 12).
This positive correlation with CaO/MgO means that high levels of potassium, inducing magnesium deficiency, prevents magnesium uptake by the foliage more than calcium uptake. Nor does BUTIJN (1961) state that a calcium dressing has any effect on magnesium deficiency. However, he found less magnesium deficiency for an unfavourable K/Mg-ratio in the foliage when the calcium content in the foliage was high.
No significant correlations were found in 1958 between Mg-deficiency and the chemical components of the fruit of Jonathan. Significant correlations were found with the MgO-content and the K_2O/MgO-ratio, in both varieties in 1960 the latter being the highest (see TABLE 8).

FIG. 12. K, Mg and Ca as aeq. in the foliage of Cox's Orange Pippin in 1960; degree of Mg-deficiency



3.3.4. *Conclusion*

Cox's Orange Pippin suffered more from magnesium deficiency than did Jonathan.
Dressing with 384 kg MgO/ha in the form of epsom salt in 1959 and 1960 caused a marked decrease in the harmful effect of potash on the appearance of magnesium deficiency.
Magnesium deficiency was most closely related to the K/Mg-ratio both in soil and foliage. No Mg-deficiency symptoms will occur when the K_2O/MgO-ratio in the soil is less than 0.6 or less than 6 in the leaf.
The MgO-content of the light sandy soil should be at least 110—120 p.p.m. and 0.30—0.35 % in the foliage.

Nitrochalk had no consistent effect on magnesium deficiency; calcium carbonate and gypsum had no effect.

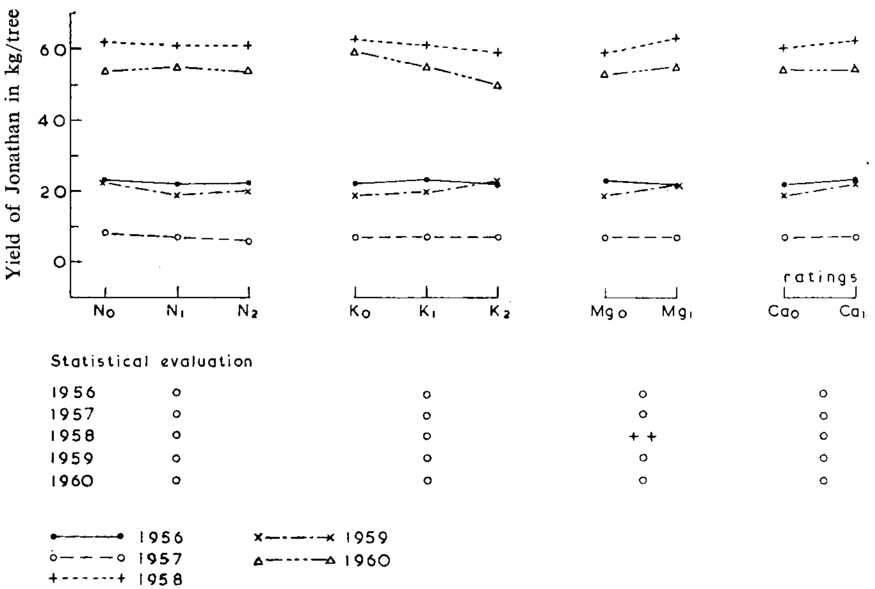
3.4. The crop

3.4.1. *Influence of the various dressings on the yield of apples*

On the whole the various dressings exerted a fairly small effect on the yield of apples .The differences were mostly non-significant, probably as a result of the great variability of the trees.

It was only in 1958 that a very significant increase was observed with Jonathan as a result of dressing with *epsom salt* (FIG. 13). Comparison of mean yields of Cox's Orange Pippin and Jonathan over 1957—1960 also showed an increase of 6 % for both varieties as a consequence of MgO-dressings. Although the differences were statistically not significant, this effect must be regarded as real. It is to be attributed to the beneficial effect of magnesium on the health of the foliage.

FIG. 13. Influence of dressing on yield of Jonathan



Potassium, especially the highest level, showed a tendency to decrease the yield of the apples. The mean yields for the three ratings of dressing over 1957—1960 were 36.6, 35.7 and 34.6 kg Jonathan per tree, and 23.5, 24.0 and 22.0 kg Cox's Orange Pippin. It was striking that no significant K/Mg-interaction was found for the crop, in contrast with the influence of K/Mg-dressings on magnesium deficiency.

In practice, the view is held that the yield will be largest when the trees are bordering on magnesium deficiency. The results of LJONES (1954) agree with this theory, as in his experiments the yield was enhanced by potassium, despite increasing magnesium deficiency. GRUPPE (1958) obtained maximum growth and production of dry matter of Cox's Orange Renette in sand culture with a moderate potassium excess

(6 m val K/2 m val Mg). The foliage showed magnesium-deficiency symptoms and had partly fallen off. Hence a slight Mg-deficiency may be permitted in orchards without damage to growth or yield, but a further increase in the K-supply without a simultaneous increase in the Mg-dressing may be harmful in the future. As in our experiments the potassium dressings usually resulted in a decrease of yield, the critical threshold must have been exceeded.

Surprisingly enough the yield on this light soil was not depressed by the omission of a nitrogen dressing for five years. In fact the nitrogen content of the foliage was lower on the plots without nitrochalk, but the level was evidently high enough, *viz.* 2.19 % N for Jonathan in 1960, to prevent symptoms of N-deficiency and a depression of the crop. The nitrogen supply in the trees may have been high enough to withstand a long period of starvation, or mineralisation of organic matter in the soil or green manure may have liberated sufficient nitrogen.

Calcium had a varying, small influence on yield. Jonathan always responded with an increase, but Cox's Orange Pippin only twice, and even significantly in 1959.

3.4.2. *Correlation between yield and magnesium deficiency of the tree, and between yield and chemical composition of foliage and soil*

It was only in 1958 that the yield of Jonathan showed a significant negative correlation with the degree of magnesium deficiency. In this year the relationship between yield and chemical composition of the foliage was also closer than in 1960. However, the correlation coefficients were not high, although significant with respect to the MgO-content and the K_2O/MgO-ratio of foliage and soil. The variance in the yield could only be very partially accounted for by these factors (c. 20 %). For the data of Jonathan in 1958 it was calculated how much a factor would have to change to increase or decrease the yield by 10 % (TABLE 9). The mean of the factors gives an idea when a reduction or increase in yield is to be expected when, for instance, the potassium dressing is increased still further. It was found undesirable for the foliar-potassium level to exceed 2.5 % K_2O and the magnesium to be less than 0.22 % MgO. The plots with the lowest dose of potash and the highest yield had a

TABLE 9. Correlation coefficients and regression equations for yield of Jonathan in 1958 with magnesium-deficiency markings and K- and Mg-content in soil and foliage

	Yield of Jonathan in 1958 in kg/tree					
	Mean of x-factor	Correlation coefficient	Regression coefficient	Standard deviation regr. coeff.	Stat. evaluation	10 % increase/decrease of yield due to change in content of
Mg-deficiency markings	3.2	—0.41	—1.56	±0.61	*	3.9
K_2O-content of soil 0—20 cm (0.001 %)	16	—0.17	—0.30	±0.30	0	20
MgO-content of soil 0—20 cm (p.p.m.)	63	+0.44	+0.14	±0.05	**	44
K_2O/MgO-ratio of soil 0—20 cm (p.p.m.)	2.83	—0.43	—2.40	±0.87	**	2.5
K_2O-percentage foliage	2.54	—0.30	—10.9	±6	0	0.56
MgO-percentage foliage	0.22	+0.44	64	±23	**	0.10
K_2O/MgO-ratio in foliage (p.p.m.)	12.8	—0.40	—0.65	±0.26	*	9.5

mean K_2O-level of 2.2—2.3 % for Jonathan and 2.5—2.7 % for Cox's Orange Pippin. The linear curve between yield and potash levels in the foliage suggested that these values were still too high on the zero plots. From the relationship with the Mg-deficiency markings we may conclude the yield will be depressed when the foliage on the base of the shoots show brown necrotic spots and begin to fall off.
Yield depression may be expected when the K_2O/MgO-ratio is 12 or more. The linear relationship between yield and this ratio indicates that even lower ratios are harmful. The low calcium content of 1.42 % CaO must also have had a bad effect on the yield.

3.4.3. *Variation in yield within and between years and the chemical composition of the foliage*

The mean yield of the entire experimental field of each year was correlated to the mean content of some nutrient elements of the foliage. The number of years with known yields were seven for Jonathan and six for Cox's Orange Pippin. The rank-correlation coefficients were calculated by the KENDALL (1948) method. These correlation coefficients were compared with the correlation coefficients between the separate yields and the same nutrient contents of the plots during the year (TABLE 10).

TABLE 10. Correlation coefficients between mean yields for each year and between yields of the plots separately during each year, and the mineral composition of the foliage

		K_2O	MgO	CaO	K_2O/MgO	K_2O/CaO
Jonathan						
Between years	1954—1961	—0.40	+0.24	+0.62(*)	—0.33	—0.33
Within years:	1954	—0.68**	+0.49	+0.43		
	1958	—0.30	+0.45*	+0.35*	—0.40*	—0.36*
	1960	—0.31	+0.33	+0.26	—0.34	—0.37*
Cox's Orange Pippin						
Between years	1954—1960	—0.48	+0.07	+0.21	—0.20	—0.60
Within years:	1954	—0.46	+0.54	+0.42		
	1960	—0.30	+0.31	+0.21	—0.31	—0.34

It may be concluded from the correlation coefficients calculated between years that heavy crops are to be connected with high calcium contents and low potassium contents and with low ratios of K/Mg and K/Ca. The same can be deduced from the correlations between yields and nutrients per plot within the year, although the positive correlation with magnesium is higher. This means that within seasons and between seasons the same mechanisms seem to control the relationship between yield and composition of the foliage. When too much potassium had been applied the yield decreased, the magnesium and calcium content fell, and the foliar-potassium level increased. If the yield was high in a given year, the foliar-potassium content was reduced, probably because a great deal of potassium had been transported to the fruit. It is known that the foliage of the spurs may show potassium-deficiency symptoms in an on-year. On the other hand, the magnesium and calcium contents of the foliage are higher in an on-year, either because more potassium is transported to the fruit, than magnesium and calcium, or because the lower potassium content does not prevent the supply of these elements to the foliage. LJONES (1954, 1963) also found a lower foliar-potassium and a higher foliar-calcium content in an on-year.

3.4.4. *Conclusion*

The increase in yield resulting from a magnesium dressing was 6 % whereas potassium decreased it. Magnesium deficiency must have been harmful for the tree, and certainly in the long run. The magnesium content cannot be less than 0.22 % MgO without adversely affecting the yield. A level of 2.2—2.3 % K_2O in the foliage for Jonathan and 2.5—2.7 % for Cox's Orange Pippin should not be exceeded. The K_2O-, MgO- and CaO-content of the foliage changed with on- and off-years in the same way as the modifications found in the correlations between yield and these nutrient contents within each year.

3.5. Keeping quality of the apples

3.5.1. *Influence of dressing and picking time on breakdown of Jonathan*

The keeping quality of Jonathan was investigated in 1958—1960. In 1958 and 1960 the Jonathan was picked three times, *viz.* on the commercial picking date, and one week before and one week after that date. The fruits were stored at 2°—3° C.
The later the picking time, the more breakdown increased and the more the quality deteriorated. The last picking time particularly aggravated the breakdown.
On the whole the influence of the various dressings on the incidence of breakdown was small and not consistent. Only the magnesium dressing aggravated the breakdown of the Jonathan over the three years. This unfavourable effect was unexpected. It can be explained by the fact that the apples had grown larger as a result of the magnesium dressing and were more susceptible to the disease. After the 1960 data had been corrected by analysis of covariance on the size of the fruit, the unfavourable influence of magnesium was eliminated.
A very significant interaction between picking time and potassium was only found in 1960. Potassium appeared to exert an unfavourable effect on the apples of the last picking time, the breakdown being considerably aggravated. This effect remained highly significant after correction for apple size. This means that Jonathan must not be picked too late when the nutrition is unbalanced by an excessive supply of potassium (TABLE 11).

TABLE 11. Breakdown of Jonathan in 1960; effect of picking time and potassium dressing

Picking time	Percentage breakdown			
dressing (kg/ha K_2O):	0	200	400	mean
I (early)	9.5	9.5	6.7	8.5
II (normal)	7.5	7.7	8.5	7.9
III (late)	24.8	35.7	43.2	34.6
Mean	13.9	17.6	19.5	

On the other hand, potassium exerted a slight favourable effect in 1958 and 1959, perhaps because the fruit were smaller according as more K was given. The reason for the considerably unfavourable effect in 1960 may be an increasing unbalance of the nutrition, or special climate factors during the season. The appearance of serious water core in the apples of the third picking in 1960 in particular seems important to us in this connection (VAN SCHREVEN and ROEVEN, 1963). Further research work is needed to elucidate this relation.

There was a tendency for nitrogen to reduce the Jonathan breakdown. In 1960 a significant effect was found after correction for apple size.

3.5.2. *Effect of the various dressings on spot of Jonathan*

The apples were examined for spot after storage. No consistent effect of fertilization was found in 1958—1960, except for calcium, which had a small unfavourable, statistically non-significant effect.

3.5.3. *Effect of the various dressings on bitter pit of Cox's Orange Pippin*

On this experimental field the Cox's Orange Pippin was very susceptible to bitter pit. It is well known that the size of the crop, and especially the leaf/fruit ratio has an effect on the susceptibility to bitter pit. The same is true of the fruit size (VAN SCHREVEN, VAN DER BOON and DAS, 1962). In this experiment also more bitter pit was found on trees bearing large apples (correlation coefficient in 1958 = +0.29 and in 1960 = +0.55**) and on trees with a low yield in relation to the size of the tree (correlation coefficient in 1960 = —0.68**).
The various dressings may have both a direct and indirect effect on the susceptibility to pit, *viz.* either owing to a change in the nutritional status or by an effect on crop and fruit size. In 1960 the effect of the size factor was eliminated by analysis of covariance.
Potassium increased the incidence of bitter pit in Cox's Orange Pippin both on the tree and after storage (TABLE 12). Dressing with magnesium markedly reduced magnesium deficiency of the leaves. Potassium and magnesium are working antagonistically in the leaves. A same contrast was expected for the fruit. However, magnesium gave more bitter pit in the fruit, the same detrimental effect as potassium (TABLE 13).
On the other hand, calcium had a beneficial effect on the health of the fruit. As

TABLE 12. Effect of potassium dressing on the percentage of bitter pit of Cox's Orange Pippin

Year	Percentage tree and storage pit			
dressing (kg/ha K_2O):	0	200	400	statistical evaluation
Tree pit				
1958	8	9	13	n.s.
1959	16	25	46	—
1960	8	10	15	*
Storage pit				
1958	22	21	26	n.s.
1960	13[1] (14)[2]	22[1] (22)[2]	22[1] (20)[2]	**[1] *[2]

n.s. not significant.
— not calculated.
significant at P = 0.05.
** significant at P = 0.01.

1 corrected for differences in yield/size of tree ratios.
2 corrected for differences in fruit size.

TABLE 13. Effect of magnesium dressing on the percentage of bitter pit of Cox's Orange Pippin

Year	Percentage tree and storage pit			
dressing (kg/ha K_2O):	0	192	384	statistical evaluation
Tree pit				
1958	10	11		n.s.
1959	20		31	—
1960	9		13	*
Storage pit				
1958	15	28		n.s.
1960	13[1] (14)[2]		25[1] (23)[2]	* *

Code see *table* 12.

TABLE 14. Effect of calcium dressing on the percentage of bitter pit of Cox's Orange Pippin

Year	Percentage tree and storage pit of dressings		
dressing (kg/ha CaO):	0	155	statistical evaluation
Tree pit			
1958	13	7	*
1959	31	23	—
1960	12	10	n.s.
Storage pit			
1958	21	23	n.s.
1960	22[1] (22)[2]	15[1] (16)[2]	**[1] *[2]

already stated, it had no effect on the magnesium deficiency of the foliage. The percentage of bitter pit was decreased as stated in TABLE 14.

As mentioned above calcium was given in the form of calcium carbonate in the first experimental year and in the form of gypsum in the following years. The beneficial effect on bitter pit may be either due to the slight increase in the pH caused by calcium carbonate or to the larger supply of calcium from gypsum. An experiment was started to determine the effect of these two factors. In 1959 a 1 % solution of calcium lactate was sprayed on a small scale and in 1960 this experiment was carried out on a larger scale. In 1959, spraying was done twice (on 6/9 and 7/14), and in 1960 five times (on 6/11, 7/8, 7/11, 8/4 and 8/23).

TABLE 15 shows that spraying with Ca-lactate was even more favourable than dressing with Ca-salts with regard to the control of bitter pit.

Experiments on other trial fields confirmed the results obtained. It was found possible to increase bitter pit in fruit by spraying with a solution of potassium and magnesium nitrate. Bitter pit was decreased by spraying with calcium salts. Calcium nitrate, sprayed five times in a 0.75 % solution, was most efficient and reduced the physiological disease by 75 % (VAN DER BOON, DAS and VAN SCHREVEN, 1962, 1963). These results correspond to those obtained by other research workers (GARMAN and MATHIS, 1956; VAN SCHREVEN, 1961 (review)).

Nitrogen had no worked effect on bitter pit in this experiment. In 1960 a significant N × K-interaction was found. At a low level of potassium a nitrogen supply

TABLE 15. Effect of calcium-lactate spraying (1 %) on the percentage of bitter pit of Cox's Orange Pippin

Year	Control	Sprayed	No. of trees p. treatment	Statistical evaluation
Tree pit				
1959	48	20	3	—
1960	12	4	22	**
Storage pit				
1960	21	7	6	*

decreased the incidence of bitter pit, and at a high potassium level the reverse was true. A nitrogen dressing may be harmful when the fruit are enlarged, but a favourable effect may be expected when the number of fruit is increased and the size of the fruit is unchanged or reduced.

3.5.4. *Keeping quality of fruit and chemical composition of foliage and fruit*

As was discussed in the preceding chapter, both potassium and magnesium dressings had an unfavourable effect on the keeping quality of the fruit. On the other hand, calcium reduced bitter pit. Magnesium had enlarged the size of the fruit and this may partly explain this undesirable and unexpected phenomenon. There may also be a physiological antagonism of magnesium and potassium with regard to calcium (GARMAN and MATHIS, 1956). This is borne out by the positive correlation between the keeping quality and the calcium contents of the foliage, as well as the positive correlation with the Ca/Mg-ratio (TABLE 16).

The extrapolation of the regression formulae predicted that no bitter pit was to be expected when the calcium level of the foliage exceeded 1.9 % CaO, the CaO/MgO-ratio 11 and the K_2O/CaO-ratio was less than 0.8 (FIG. 14).

The correlation coefficients between the appearance of bitter pit and the composition of the fruit gave no clear-cut results. In 1958 the signs of the correlation coefficients agreed with those found for the foliage, but no corresponding results were

TABLE 16. Correlation coefficients between keeping quality and magnesium dressing and chemical composition of leaf and fruit

	Healthy fruit				Breakdown Jonathan		Bitter pit Cox's Orange Pippin	
	Jonathan		Cox's O.P.					
	1958	1960	1958	1960	1958	1960	1958	1960
Dressing with Mg:	—0.26	—0.61**	—0.57*	—0.58***	+0.31	+0.14	+0.52*	+0.43*
K_2O % foliage	—0.09	—0.19		—0.11	—0.20	+0.29		+0.20
CaO % „	+0.26	+0.73**		+0.63**	+0.19	—0.39*		—0.49**
MgO % „	—0.11	—0.29		—0.28	+0.44**	—0.09		+0.17
K_2O/CaO „	—0.19	—0.56**		—0.57**	—0.25	+0.43*		+0.50**
CaO/MgO „	+0.32(*)	+0.54**		+0.50**	—0.38*	—0.11		—0.35(*)
K_2O % fruit	—0.02	—0.62***	—0.33	—0.39*	+0.01	+0.54**	+0.28	+0.44*
CaO % „	+0.07	+0.15	—0.01	—0.44**	—0.12	—0.25	—0.01	+0.46**
MgO % „	—0.04	—0.53**	—0.16	—0.61***	—0.11	+0.34	+0.11	+0.59**
K_2O/CaO „	—0.09	—0.41**	—0.19	+0.01	+0.10	+0.47**	+0.19	—0.01
CaO/MgO „	+0.07	+0.31	+0.08	—0.13	—0.09	—0.31	—0.08	+0.18

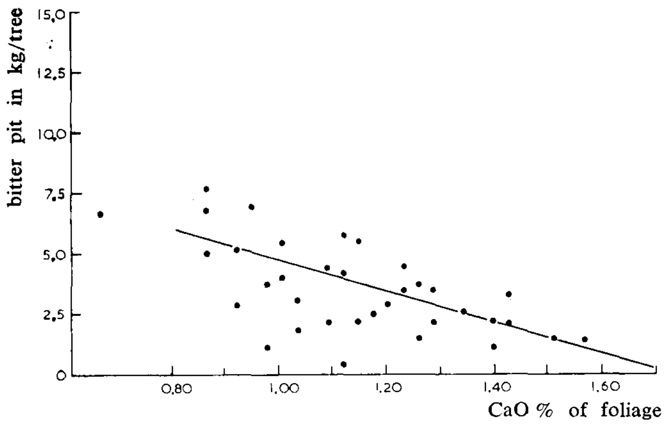


FIG. 14
Bitter pit in Cox's Orange Pippin and calcium content of foliage

found in 1960. No explanation could be found. Improved calcium analysis might have produced better results.

VAN STUIVENBERG and POUWER (1952) assumed that potassium improved the keeping quality up to a certain critical level. The quality of Jonathan was lowered in their experiment when the K-level of the foliage exceeded the limit. VAN SCHREVEN (1961, 1963), however, found no reliable correlation between the incidence of breakdown and the chemical composition of the foliage and fruit of Jonathan in a three-year soil-survey method.

Our experiment only gave a reliable, unfavourable correlation for Jonathan in the last experimental year. The potassium content in the foliage was high (2.59 % K_2O) and the calcium moderately low (1.59 % CaO) (TABLE 4).

3.5.5. *Conclusion*

The various dressings had hardly any effect on the keeping quality of Jonathan. It was only in 1960 that heavy dressings of potassium resulted in considerably more breakdown in late-picked fruits. In this season much water core was also found. No effect was found on spot of Jonathan.

Bitter pit of Cox's Orange Pippin was increased by dressing with potassium and magnesium and decreased by a calcium dressing. Spraying with a solution of calcium lactate confirmed the favourable effect of this cation. The data suggested that no bitter pit appeared at a CaO-level in the foliage above 1.9 % and a K_2O/CaO-level below 0.8. In our experiment nitrogen caused no change in the percentage of bitter pit.

4. Discussion

Apple trees on sandy soils grow rapidly and bear early, but in many cases they soon decline. Magnesium deficiency is very often seen. The keeping quality of the fruit is very sub-standard. Frequent occurrence of bitter pit is a particularly serious problem. In this connection the effect of inorganic fertilizers was studied on a fertilizer-trial plot.

Like most sandy soils in the Netherlands, the soil of the trial plot in question was characterized by a fairly low K-concentration, low Mg- and Ca-levels and a poor humus content, but the apple trees appeared to absorb the potassium very easily.

Hence it is easy to appreciate why magnesium deficiency is soon induced on sandy soils in which the magnesium content is low. The symptoms of this shortage only decreased slowly after heavy dressings of epsom salt. It has been suggested already that this may be due to the slow movement of the Mg-ions to the subsoil in contradistinction with the more rapid downward movement of K. Consequently spraying with a 2 % solution of epsom salt, carried out 4—6 times in the growing season, should certainly not be omitted in practice.

As a result of the low calcium content of the soil the crop also had a low calcium level. Gypsum dressings had no effect on the degree of magnesium deficiency, but bitter-pit incidence was significantly reduced. On the other hand this disease was increased by potassium and magnesium dressings. Highly significant correlations were found between the percentages of bitter pit and the Ca-content or the $\frac{K}{Ca}$- and $\frac{Mg}{Ca}$-ratios of the foliage, the susceptibility to pit being lower with increasing Ca-contents and decreasing K/Ca and Mg/Ca. This fully confirms the findings of GARMAN and MATHIS (1956). It also provided an explanation of the frequent occurrence of bitter pit in apples from sandy soils, the crop on these soils always having a low Ca-content and high $\frac{K}{Ca}$- and $\frac{K + Mg}{Ca}$-ratios.

Hence the calcium content of sandy soils would need a great deal of improvement. However, this is not hereby a matter of a more abundant supply of calcium salts. As calcium carbonate led to an excessive increase in the pH in our trials, gypsum was given instead. It was found that like magnesium, calcium only moves slowly to the sub-layers. It also expelled the magnesium from the soil minerals, thereby decreasing still further the poor Mg-content of the soil. Thorough mixture of the subsoil with Mg- and Ca-salts might solve this problem. This would have to be done before planting.

In any case a heavy potassium dressing should be avoided. It might be necessary for the annual supply of K to be stopped for the time being or considerably reduced in several orchards.

It was surprising that the trees on the trial plot did not respond to the omission of nitrogen. Foliage analysis showed that the N-content remained normal. It is quite possible that sufficient N was liberated by mineralization of the humus of the upper layer. The orchard was clean-cultivated intensively in the spring, and this may have hastened the process. A leguminous crop was also sown in several years.

Despite fertilization with the inorganic nutritive elements N, K, Mg and Ca, the trees on the trial plot soon declined. True more trees died on the plots with the highest level of potassium and no calcium, but this was only a stay of execution. In fact the major elements were only of secondary importance with reference to the limited life of the apple trees. It is not known which factors are more important in this respect. Only assumptions can be made, which of course need a closer investigation.

In the first place a limited and irregular supply of water is mentioned. This might have been aided by the omission of organic manure throughout the experimental period. Clean-cultivation in the spring might also have aggravated the water shortage, because shallow ploughing damaged the roots in the upper layer thus reducing moisture absorption. The problem might be solved by laying down a permanent sward in strips and providing good sprinkle irrigation. It might also be advisable for the

topsoil to be thoroughly mixed with the subsoil before the trees are planted. At the same time calcium and magnesium would have to be added.
Secondly, dying of the trees may be due to a deficiency of one or more of the minor elements. However, chemical analysis of the shoots for B, Cu and Zn gave no indication that one of these elements was present in an insufficient concentration. Whereas this fertilizer trial clearly showed the relationship of the frequent occurrence of magnesium deficiency and bitter pit with the disbalanced supply of K, Mg and Ca on sandy soils, the question of the early decline on these soils was unanswered and needs further research.

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