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Control of bitter pit and breakdown by calcium in the apples Cox's Orange Pippin and Jonathan

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Contents

1 Introduction

In 1956 Garman and Mathis published their studies on control of bitter pit by calcium salts. Ever since, similar research in various countries and with various varieties nearly always showed the beneficial effect of calcium, especially if sprayed. However, the effectiveness of various calcium compounds differed, $Ca(NO_3)_2$ and $CaCl_2$ giving better results than calcium acetate or calcium lactate (Baxter, 1960; Buchloh, 1960; Beyers, 1962; Smock *et al.*, 1962; Schumacher and Fankhauser, 1964; Porreye and Piot, 1964). $CaHPO_4$ appeared well-nigh inactive (Askew *et al.*, 1960; Buchloh, 1960; Martin *et al.*, 1960). The right time to spray has not yet been thoroughly investigated and results so far are inconclusive (Baxter, 1960; Beyers, 1962; Porreye and Piot, 1964).

After spraying potassium and magnesium, Garman and Mathis (1956) found more bitter pit. They related increased susceptibility to bitter pit with higher values for $(K+Mg)/Ca$ and Mg/Ca in the fruits. This was confirmed by Askew *et al.* (1960), Martin *et al.* (1960), Oberley and Kenworthy (1961), Yamazaki and Mori (1961), Bünemann (1962), Bouhier de l'Ecluse (1962).

In The Netherlands Van der Boon *et al.* (1966), Van Schreven *et al.* (1962), obtained corresponding results in a fertilizer trial on sandy soil, whereas preliminary spraying experiments showed calcium lactate to diminish the incidence of bitter pit. This led to a series of combined spraying and fertilizer trials in orchards with different soils during 1961-3.

Crops from these trials were stored. Investigation into the relation between susceptibility to pit and mineral composition of the crop led to analysis of soil, leaf and fruit.

The investigations were made in co-operation with workers of the Institute for Soil Fertility in Haren-Groningen and the Sprenger Institute in Wageningen. Soils and leaves were analysed at the Laboratory for Soil and Crop Testing in Oosterbeek.

2 Lay-out of experiments

The experiments were laid out in commercial orchards; the Horticultural Extension Service assisted in their selection, which was based on frequent occurrence of bitter pit and uniformity of the trees. Nine fields were situated on sandy soil, two on river clay and three on marine clay.

In 1961 the trials were carried out in 11 orchards. In 1962 all 14 fields were used, but in 1963 two of them had to be replaced as their trees were badly affected by cancer. In each orchard every treatment was applied in triplicate on 10-12 trees per plot. The treatment of any particular plot had been allocated at random within the block of trees used in the trial. In all experiments the variety Cox's Orange Pippin was used, except one, where Crimson Cox was used. The following points were investigated:

a. The influence of increasing concentrations of $Ca(NO_3)_2$ on the occurrence of leaf injury was studied over two years, with $Ca(NO_3)_2$ AR and with a commercial calcium nitrate fertilizer (Mekog Flakes) as spray with concentrations from 0.5 to 2 %, and as mist spray with concentrations from 2 to 10 %. The trials were in triplicate on separate branches of the trees.

b. The influence of a supply of calcium on the occurrence of bitter pit on various soil types was investigated in 1961 by spraying five times with a 1 % solution of calcium lactate. In 1962 and 1963 this solution was replaced by the more active $Ca(NO_3)_2$ with a concentration of 0.77 %. The spray rate was about 3200 litres solution per ha each time. The spray contained a non-ionized detergent (Agral 1:3000). In two orchards the spray was given as dust at a concentration of 6 %. Purified calcium salts were used, except in two orchards, where the cheaper, technical grade $Ca(NO_3)_2$ was applied as Mekog Flakes.

The effects of sprays with different calcium compounds, nitrate, lactate and acetate, were compared in one orchard over three years. The calcium content of all solutions was equivalent to that of 1 % calcium lactate.

In 8 (7 in 1963) orchards the effect of sprayed calcium was compared with dressing with gypsum, applied in the autumn at a rate of 3000 kg per ha. Besides the nitrogen was given as calcium nitrate at rates from 50 to 200 kg N per ha, according to grower's requirements. This fertilizer was supplied on the clay soils in December and on the sandy soils in February-March. Growers mostly used nitrochalk ($NH_4NO_3 + CaCO_3$).

c. Effect of number of sprays and moment of spraying. In all trials, except one, five sprays were carried out during the growing season, one in June, two in July

Scheme 1. Scheme for studying the effect of time and number of sprayings on incidence of bitter pit

Treatment	$Ca(NO_3)_2$ sprays 1	2	3	4	5	6 *	$Mg(NO_3)_2$ sprays 1	2	3	4	5	6 *
control	—	—	—	—	—	—	—	—	—	—	—	—
2 × Ca E	+	+	—	—	—	—	—	—	—	—	—	—
,, M	—	—	+	+	—	—	—	—	—	—	—	—
,, L	—	—	—	—	+	+	—	—	—	—	—	—
4 × Ca E	+	+	+	+	—	—	—	—	—	—	—	—
2 × Ca E + 2 × Ca L	+	+	—	—	+	+	—	—	—	—	—	—
4 × Ca L	—	—	+	+	+	+	—	—	—	—	—	—
6 × Ca	+	+	+	+	+	+	—	—	—	—	—	—
6 × Mg	—	—	—	—	—	—	+	+	+	+	+	+
4 × Mg + 2 × Ca	—	+	—	—	+	—	+	—	+	+	—	+
2 × Mg + 4 × Ca	+	—	+	+	—	+	—	+	—	—	+	—

+ = sprayed
— = not sprayed

E = early spraying
M = mid-season ,,
L = late ,,

* dates of spraying
1962: 27/6, 11/7, 25/7, 8/8, 29/8, 12/9
1963: 25/6, 5/7, 19/7, 2/8, 21/8, 5/9

and two in August.

In one orchard the number of sprays and the moment of spraying varied according to scheme 1. The first spray was given in the fourth week of June. The following sprays were applied at intervals of about a fortnight.

d. The effects of sprays containing calcium, potassium and magnesium nitrate were compared in one orchard in 1961 and 1962 and in another in 1963. The cation concentration of every solution was equivalent to that of a 0.77 % $Ca(NO_3)_2$ solution.

Magnesium deficiency is quite common on sandy soils in The Netherlands as also is spraying with $MgSO_4$ during the growing season. As this may increase the susceptibility to bitter pit, an experiment was inserted in order to investigate combined sprayings with $Ca(NO_3)_2$ and $Mg(NO_3)_2$. This trial was carried out in the same orchard as the investigation on moment of spraying (see scheme 1).

e. Dipping in $Ca(NO_3)_2$ and $CaCl_2$ solutions of 0.75 and 1 %, respectively, was in triplicate with apples from one source immediately after harvesting in 1962 and 1963.

2.1 Records of experiments

a. At the beginning of the experiment soil samples were taken 0-20 cm and 20-40 cm deep, to estimate pH-KCl, clay and humus content, and exchangeable K_2O, MgO and CaO content (DE VRIES and DECHERING, 1960). At the end of the experiment soil samples were taken again, however only from the orchards which

had been dressed with gypsum.
b. In August the average size of the crop of a trial field was estimated in relation to vegetative development of the trees and given a value. In every orchard, trees of the same relation of crop to leaf mass supplied fruit for the storage trials. The differences in fruit size for differently treated apples appeared to be negligible for each orchard.
c. To estimate the influence upon the total of N, P, K, Mg and Ca in the leaves about 100 leaves of each treatment were picked in every orchard from the base of the annual shoots (3rd-5th leaf) of the selected trees, in mid August.
d. Fruit analyses. At harvest 30 fruits were picked from the south side of the selected trees. Samples were 200 g, consisting of the mid sections without peel and core. Dry matter, ash and K, Mg and Ca content were estimated in duplicate by methods developed at the Sprenger Institute (ZONNEVELD and GERSONS, 1966; ZONNEVELD, 1967).
e. Observations at harvest. The selected trees were cleared at one time. The yield of every tree was weighed. The fruit was sorted for tree pit, cracks, and rots. For each plot the visually 'sound' apples from two selected trees were mixed. If possible, the storage trials were with 4 boxes of 15 kg for each plot, thus 12 boxes per treatment. The apples in the boxes were counted and average apple weight was calculated. From other trials at the Sprenger Institute (VAN SCHREVEN and VAN DER MEER, 1956) the specific gravities of mature fruits of one variety were identical and almost independent of apple size and orchard. Therefore the mean fruit weight could be used as an indication of mean fruit size.
f. Observations after storage. The fruit was stored at 4°-5°C from September to December or January and sorted on rots, total bitter pit and total breakdown, after a further week at room temperature to bring out latent breakdown. The percentages of sound fruit and weight loss were also determined. The experiments were too extensive to establish exact ratings of internal and external bitter pit. The percentages of bitter pit given in the tables, comprise only the apples with signs of this decay on the outside, with many and with few pits.

Many fruits were cut to diagnose the severity of internal bitter pit and a high percentage of external pit was always associated with a high percentage of internal pit.

3 Results of experiments

3.1 Soil type, bitter pit and leaf composition

a. Characterization of soils. As mentioned before the experimental orchards were selected on the frequent occurrence of bitter pit during preceding seasons. The clay content of the orchards ranged from 2 to 41 weight % particles smaller than 16 μ (about 2 to 28 % particles smaller than 2 μ). Table 1 shows that the content of exchangeable K, Mg and Ca and the pH-KCl in the various orchards showed a significant positive correlation with clay content. With increasing percentage of clay the relation (K + Mg)/Ca decreased.

All the orchards, except one, had too high a potassium content by the standards of the Dutch Advisory Service for Fertilizing in Horticulture in the Open.

b. Soil and leaf composition and bitter pit on untreated plots. In The Netherlands it is well known that bitter pit is found especially in apples from sandy soils, and our trials did show a negative correlation between the occurrence of bitter pit and the clay content of the soil (table 2).

Because of the few trials on sandy and loamy soils, and the high correlations between cation contents and clay percentages on the other, the reason for the higher susceptibility to bitter pit on sandy soil could not be elucidated.

Table 1. Correlation coefficients of potassium, magnesium, calcium content, pH and (K+Mg)/Ca in soils with percentage by weight of clay (particles < 16 μ), and extreme values of the factors

	K_2O-HCl	MgO-NaCl	Exchangeable CaO	pH-KCl	$\frac{K+Mg}{Ca}$
% particles < 16 μ	+0.80^{++}	+0.80^{++}	+0.90^{++}	+0.71$^{+(+)}$	—0.50
Range in m-equiv./100 g air dry soil	0.28-1.25	0.30-1.81	3.5-37.1	4.6-7.3	0.09-0.38

Note: Statistical evaluation:
not calculated = —
not significant = n.s.
P < 0.10 = (+)
P < 0.05 = +
P < 0.01 = ++
P < 0.001 = +++

Table 2. Average data for bitter pit and soil and leaf composition for sandy and loamy soils in 1961

Soil type	Pit during storage %	K soil exchang.	K leaf total	Ca soil exchang.	Ca leaf total	Mg soil exchang.	Mg leaf total	(K+Mg)/Ca soil exchang.	(K+Mg)/Ca leaf total
		m-equiv. per 100 g dry matter							
sandy soil	51	0.43	55.2	4.4	47.1	0.60	15.4	0.24	1.59
mean: 7 % range: 4-11 % } < 16 μ (n = 5)									
loamy soil	28	0.84	46.5	13.6	62.4	1.33	16.9	0.20	1.06
mean: 26 % range: 15-41 % } < 16 μ (n = 6)									
Statistical evaluation	+	+++	+	+	n.s.	+	n.s.	n.s.	+
P	0.03	0.00	0.02	0.03	0.13	0.02	0.24	0.33	0.03

Note: see table 1

Leaf composition as an index of nutritional status of the tree, however, could give an indication, K content in apple leaf on sandy soils being higher than on clay soils. But exchangeable K was much higher on clay soils. Hence, on sandy soils potash was more easily absorbed. More Ca was found in the leaf of apple-trees on loamy soils, corresponding to the positive correlation between clay content and exchangeable Ca. But the Mg content of apple leaf on sandy soils was only slightly lower, despite far less exchangeable Mg in the soil. This could be the result of frequent spraying with $MgSO_4$ to control Mg deficiency.

Consequently the relation (K + Mg)/Ca in leaf was significantly higher on the untreated plots on sandy soils. Like GARMAN and MATHIS (1956), we observed more bitter pit.

Thus bitter pit on sandy soils may be subject to a high uptake of K through the trees in proportion to the available K, and also to lack of available Ca. Other factors such as acid subsoil and irregular water supply may also play a part.

3.2 Influence of dressing with gypsum

a. The changes in concentration of the various components of soil as a result of dressing with 3 tons gypsum per ha per year are summarized in table 3. For that purpose we compared the data from soil analyses, carried out in 1963 on the control and manured plots.

This table shows that a dressing of gypsum hardly changed the pH. The concentration of exchangeable Ca in the layer 0-40 cm increased in sandy soils on

Table 3. Change in various components of soil as a result of three years' dressing with gypsum

No. trial plot	Clay content	pH-KCl	Depth 0-40 cm K_2O-HCl	exch. CaO	MgO-NaCl
			m-equiv./100 g air dry soil		
sandy soil					
2	4	+0.1	0	+0.47	—0.02
3	5	—0.1	—0.03	+1.46	—0.18
7	10	—0.4	—0.16	—0.81	—0.24
loamy soil					
5	15	+0.6	0	+0.07	—0.47
6	17	+0.1	—0.08	+0.79	—0.52
4	22	+0.3	0	+1.30	—0.19
1	23	+0.1	—0.03	—2.15	—0.21

average by 0.4 m-equiv., in loamy soils there was an increase in 3 of 4 cases. The most striking effect was the decrease in Mg content; on sandy soils Mg decreased by 0.15 m-equiv. and on clay soils by 0.35 m-equiv. in the layer 0.40 cm. Dressing with gypsum, therefore, is certainly not recommended for sandy soils, as the original Mg content is very low.

K fell by 0.06 m-equiv. in the sandy soils after treatment with gypsum. On soils with a higher content of clay than 15 % the results were not clear; in two of four cases the K content fell.

We supposed that the effect of gypsum, especially on Mg and to a lesser extent on K, may be thus explained: that both these absorbed ions are exchanged for Ca and leached out.

b. The average effects of dressing with gypsum on the incidence of bitter pit and breakdown are shown in table 4 [1]. They are divided in two groups, according to the clay content of the soil.

On sandy soils a supply with gypsum decreased the decay by bitter pit. On the loamy soils in 1961, the average decrease in bitter pit was only small; in 1962 and 1963 there was even an increase. The latter was mainly due to the increase of pit in one of the orchards after this treatment. In a fertilizer trial on sandy soil VAN DER BOON *et al.* (1966) also stated a significant decrease in bitter pit through dressing with gypsum. Breakdown also diminished.

CHITTENDEN *et al.* (1963) reported an increase in bitter pit after application of gypsum for three years, especially during the first two seasons. They suggested that this effect was due to the release of N by accelerated breakdown of organic matter in the soil. The data of PORREYE and PIOT (1964) suggest that in the first year of

[1] To allow a satisfactory comparison the results of only the complete trial fields are given in the tables. Statistical treatment and judgement in the text are generally based on all available data.

Table 4. Effect of a supply of 3 ton gypsum per ha per year on percentage bitter pit and breakdown

	Sandy soils			Loamy soils		
	clay content < 15 % of particles < 16 μ			clay content > 15 % of particles < 16 μ		
Season	1961	1962	1963	1961	1962	1963
Number of orchards	3	3	3	3	3	3
Mean % bitter pit						
control	52.2	54.3	43.6	31.6	13.9	14.5
gypsum	46.8	38.8	27.1	29.9	16.6	15.2
% decrease in decay through bitter pit	10	29	38	5	—19	—5
Statistical evaluation	n.s.	++	(+)	n.s.	n.s.	n.s.
Mean % breakdown						
control	10.2	7.6	11.5	8.9	2.7	1.9
gypsum	10.1	4.1	7.2	9.3	2.5	1.6
Statistical evaluation	n.s.	(+)	n.s.	n.s.	n.s.	n.s.

Note: see table 1

Table 5. Influence of gypsum on mineral composition of leaf

Season	Treatment	N	K	Ca	Mg	K/Ca	K+Mg/Ca	Mg/Ca
		% of dry weight				m-equiv.		
1961	sandy soil							
	control (n = 3)	2.46	2.27	0.85	0.20	1.43	1.80	0.37
	gypsum (n = 3)	2.49	2.25	0.85	0.21	1.41	1.81	0.40
	loamy soil							
	control (n = 3)	2.55	1.83	1.23	0.19	0.79	1.04	0.25
	gypsum (n = 3)	2.58	1.83	1.27	0.20	0.76	1.02	0.26
1963	sandy soil							
	control (n = 3)	2.81	1.99	1.07	0.30	0.96	1.42	0.46
	gypsum (n = 3)	2.84	1.93	1.25	0.27	0.79	1.15	0.36
	loamy soil							
	control (n = 3)	2.98	1.82	1.21	0.24	0.81	1.13	0.32
	gypsum (n = 3)	2.92	1.79	1.29	0.22	0.76	1.00	0.27
Statistical evaluation								
	1961 total	(+)	n.s.	P < 0.20	(+)	n.s.	n.s.	P < 0.20
	1963 total	n.s.	P < 0.20	++	(+)	++	++	+

Note: see table 1

experiment bitter pit increased and in the second year it decreased.

c. The influence of an application of gypsum on mineral composition of leaves and fruits is shown in tables 5 and 6. Again the results for sandy and loamy soils are given separately. In 1962 a number of leaf samples got lost, which was the reason why these data could not be inserted.

In interpreting these data the following points should be kept in mind:

1. An increasing influence of dressing with gypsum is to be expected in the course of the experiment.
2. Secondary effects will occur as the Ca ions of gypsum exchange cations on clay minerals. This may result in absorption of the latter by the plant but these nutrients may be leached to a greater extent.
3. Weather conditions will exert a distinct influence on both absorption and leaching and the results may vary over the year.

Owing to the complexity of these factors and the small number of data only the main trends could be noted. In the third year of experiment a dressing of gypsum

Table 6. Influence of gypsum on mineral composition of fruit

Season	Treatment	Dry matter %	N	K	Ca	Mg	K/Ca	K+Mg/Ca	Mg/Ca
			mg per 100 g fresh weight					m-equiv.	
1961	sandy soil								
	control (n = 3)	16.25	70.1	159	2.15*	4.32*	40.2*	43.9*	3.7*
	gypsum (n = 3)	16.62	60.7	154	2.26*	4.27*	37.4*	40.8*	3.4*
	loamy soil								
	control (n = 3)	16.28	71.0	138	2.59	4.15	27.3	30.0	2.7
	gypsum (n = 3)	16.26	67.9	131	2.59	4.03	25.6	28.3	2.6
1962	sandy soil								
	control (n = 3)	15.10	62.6	147	1.60	4.12	48.5	49.5	4.3
	gypsum (n = 3)	15.15	56.6	134	1.81	3.68	38.4	41.8	3.4
	loamy soil								
	control (n = 3)	15.14	64.3	119	2.16	3.61	27.6	30.3	2.8
	gypsum (n = 3)	15.28	57.5	113	2.20	3.30	26.0	25.1	2.5
1963	sandy soil								
	control (n = 3)	15.56	59.5	159	1.99	4.50	40.8	44.6	3.8
	gypsum (n = 3)	15.34	52.6	149	2.14	4.21	35.4	38.7	3.3
	loamy soil								
	control (n = 3)	15.66	52.9	124	2.37	3.99	28.0	30.8	2.9
	gypsum (n = 3)	15.29	54.2	118	2.37	4.01	26.1	29.0	2.7
Statistical evaluation									
	1961	n.s.	(+)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	1962	n.s.	+	n.s.	$P<0.20$	+++	$P<0.20$	(+)	++
	1963	++	n.s.	+	$P<0.20$	$P<0.20$	+	++	+

* from 2 trial plots only, one analysis omitted as unreliable

Note: see table 1

caused a significant increase in the mean Ca content and a significant decrease in the relations K/Ca, (K+Mg)/Ca and Mg/Ca in leaf. A tendency in this direction was found for the first relation only in the first year of experiment. In 1961 an enhancement of the Mg content of the leaves was found in 4 of 6 cases, resulting in a higher relation Mg/Ca in the plots treated with gypsum. However, in 1963 a decrease in the Mg content of leaves from these plots was observed in 4 of 6 cases, the relation Mg/Ca being lower in all cases. These results may accord with the supposition that Mg ions, being released by the gypsum, will be absorbed more quickly at first, but slower later, as a result of a greater loss in the upper soils (see also 3.2, first paragraph).

A small and not significant lowering of K in leaves occurred during both seasons of the experiment.

At first the N content of the leaves increased on most of the trial plots. In 1963 the N content on the loamy soils was found to decrease after supply of gypsum.

The influence of a dressing of gypsum on fruit composition can be summarized in the following points:

1. Each year the Ca content increased in all three field trials on sandy soils except in 1961 in one field, omitted as unreliable. However, in apples from loamy soils Ca content did not increase.
2. The Mg content fell significantly but in 1963 not on loamy soils.
3. The K content tended to decrease, significantly in 1963.
4. As a result the relations K/Ca, (K+Mg)/Ca and Mg/Ca in fruit decreased significantly in 1963.
5. In 1961, N in fruit tended to decrease with gypsum, whereas in leaves it tended to increase.

3.3 Influence of spraying with calcium salts

a. *Influence on leaf and fruit injury* Sprays of a 1 % calcium lactate aqueous solution with a non-ionic wetting agent at about 3200 litres/ha seemed harmless, sprays with $Ca(NO_3)_2$ AR in concentrations of 0.5 and 0.75 % caused only slight injury, leaving narrow brown margins on the leaves of spurs. With a concentration of 1 % it became more serious and the tips of the youngest leaves of the shoots died off. At concentrations 1.5, 1.75, 2.0 %, these symptoms became more widespread and the basal leaves of the shoots started to show brown margins. In these trials wind direction bore no relation to leaf injury. However, experience shows that the safest time for spraying is in the morning and at the end of the afternoon. A favourable concentration is 0.75 %.

In 1962 the harmful effects of $Ca(NO_3)_2$ AR and a commercial fertilizer of calcium nitrate (Mekog Flakes) were identical when given in equivalent concentrations. In 1963 sprayings with higher concentrations of Mekog Flakes induced slightly more injury. This was also true for sprays applied as mists (400 litres/ha). Mists should not exceed 4 % in concentration.

The minor injuries from $Ca(NO_3)_2$ on fruits were black spots at lenticels on the peel where a drop of solution had adhered.

Most investigators use $Ca(NO_3)_2$ in concentrations 0.5 to 1.0 % to restrict damage. Some think it wise to spray a lower concentration early in the growing season.

Only SMOCK *et al.* (1962), and SCHUMACHER and FANKHAUSER (1964) mention injury by $Ca(NO_3)_2$ as well as by $CaCl_2$ sprays. According to SMOCK *et al.* serious leaf injury occurred during spraying with $Ca(NO_3)_2$ in concentrations above 0.4 % and with $CaCl_2$ in concentrations above 0.2 %. But they used salts of commercial grade.

SCHUMACHER and FANKHAUSER (1964) advise against spraying less than 2-3 weeks before harvest as they found a greasy deposit on the apples, especially Gold Pairman, after spraying 0.5 to 1.0 % $Ca(NO_3)_2$, so that the apples could only be used for pulping. $CaCl_2$ had the same harmful effect, but to a lesser extent. The apples were also tainted. They do not mention the purity of the salts.

The fruits from our trials were not tainted either with pure $Ca(NO_3)_2$ or $Ca(NO_3)_2$ as Mekog Flakes. For this purpose sprayed and dipped apples were tested by a taste panel of 8 persons from the Sprenger Institute.

b. *Influence on bitter pit and breakdown* In accordance with the literature $Ca(NO_3)_2$ in one orchard in 1961 was clearly more favourable than calcium lactate.

Table 7. Control by calcium sprays of bitter pit and breakdown

	Sandy soils clay content < 15 % p. < 16 μ			Loamy soils clay content > 15 % p. < 16 μ		
	1961	1962	1963	1961	1962	1963
Number of field	4	7	7	6	7	6
Mean fruit weight g	127	95	108	133	115	130
Mean % bitter pit						
control	55.4	51.4	29.7	28.2	16.7	11.7
calcium lactate 1 %	31.7			15.3		
$Ca(NO_3)_2$ 0.77 %		12.6	5.2		4.1	1.6
% decrease in bitter pit						
mean	43	75	83	46	76	86
max.	55	91	94	84	98	95
min.	33	59	59	18	58	60
Statistical evaluation	++	+++	++	++	+++	++
Mean % breakdown						
control	7.6	9.1	6.9	7.4	5.2	2.4
calcium lactate 1 %	3.1			4.0		
$Ca(NO_3)_2$ 0.77 %		1.7	1.4		1.5	0.3
Statistical evaluation	n.s.	+++	n.s.	+++	+	(+)

Note: see table 1

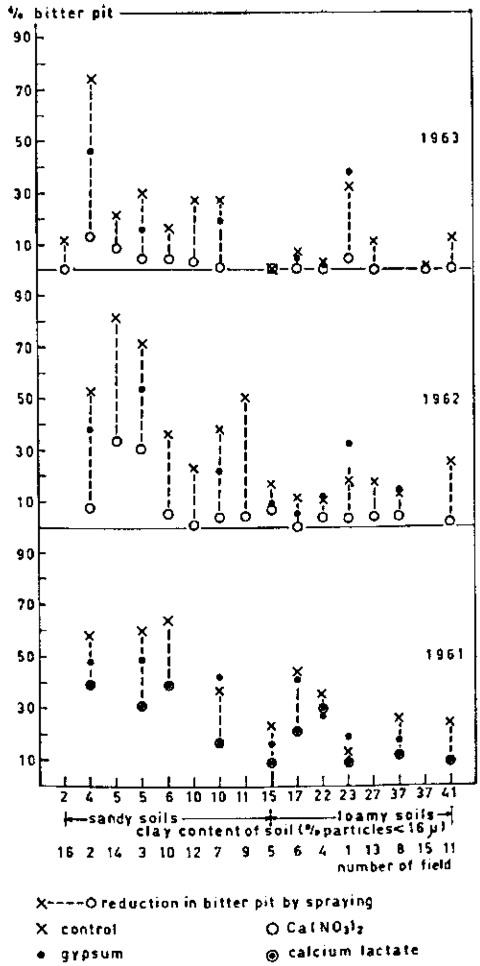

Fig. 1. A survey of experimental results by clay content of soil

So in 1962 and 1963 0.77 % $Ca(NO_3)_2$ was used instead of calcium lactate in all 14 field trials and reduced bitter pit on average by 75 to 85 %.

Table 7 sums up the mean results obtained in the 3 years. A distinction was again made between data from sandy soils and loamy soils. On sands more bitter pit was usually seen than on loams. In fig. 1 the effect of spraying is set out against clay content of the soils, for each field trial.

First of all, the data show that the occurrence of bitter pit was much less in 1963 than in two preceding seasons. Most bitter pit had been found in 1961. In 1962 the apples were small. We (VAN SCHREVEN *et al.*, 1962) would expect few bitter pits but under other circumstances this would probably not be so.

Secondly, calcium sprays, especially $Ca(NO_3)_2$, reduced the incidence of bitter pit in varying degrees in nearly all orchards, independent of soil type. Variations may have been due to:

a. Differences in nutritional conditions and water supplies of the crop
b. Differences in crop and fruit size
c. Differences in health of the leaves, influencing the penetration of salts
d. Changing of weather between sprayings.

Thirdly, fig. 1 shows that $Ca(NO_3)_2$ sprays usually restricted bitter pit to less than 5 %.

Fourthly, purity seemed to have no effect. $Ca(NO_3)_2$ AR seemed as effective as $Ca(NO_3)_2$ fertilizer (Mekog Flakes). As no more injury was found with the recommended concentrations of Mekog Flakes this product is cheaper for control of bitter pit.

Fifthly, mist spraying proved equally good as spraying.

Sixthly, spraying with these calcium salts decreased breakdown significantly, thus improving the keeping of fruit.

c. *Influence on leaf and fruit composition* The results of analysing leaf and fruit samples from different plots are shown in tables 8 and 9. In 1962 leaf samples from 4 orchards got lost.

Ca content of leaf increased very significantly by spraying with calcium salts. Washing with both water and 0.1 N HCl showed that only a negligible amount of this increase was due to residues of sprays. K and Mg decreased continuously in leaves, significantly in 1963. N content was almost constant. The decreases of K/Ca, (K+Mg)/Ca and Mg/Ca were highly significant in the last season.

In 1962 the overall Ca content of leaves was lowest, whereas K/Ca, (K+Mg)/Ca and Mg/Ca were highest. High susceptibility to pit was found in 1962 despite the smallness of the apples. On the contrary 1963 showed the highest average Ca content and the lowest values for K/Ca and (K+Mg)/Ca. In this season bitter pit

Table 8. Effect of spraying with calcium salts on the mineral composition of leaves

Season	Treatment	Number of orchards	N	K	Ca	Mg	K/Ca	(K+Mg)/Ca	Mg/Ca
			% of dry weight				m-equiv.		
1961	control	10	2.59	1.98	1.09	0.20	1.02	1.33	0.31
	calcium lactate	10	2.57	1.96	1.18	0.19	0.91	1.19	0.28
1962	control	10	2.64	1.92	0.94	0.19	1.25	1.64	0.39
	$Ca(NO_3)_2$	10	2.62	1.86	1.13	0.19	1.01	1.32	0.31
1963	control	14	2.92	1.82	1.13	0.25	0.85	1.24	0.36
	$Ca(NO_3)_2$	14	2.89	1.74	1.34	0.23	0.68	0.99	0.30
Statistical evaluation									
	1961		n.s.	n.s.	++	n.s.	++	++	+
	1962		n.s.	(+)	++	n.s.	++	++	++
	1963		n.s.	++	++	+	+++	+++	+++

Note: see table 1

was least frequent. This supports the view that bitter pit is due to shortage of Ca and incorrect relations between Ca, K and Mg.

Table 9. Effect of spraying with calcium salts on the mineral composition of fruit

Season	Treatment	Number of orchards	% dry matter	N	K	Ca	Mg	$\frac{K}{Ca}$	$\frac{K+Mg}{Ca}$	$\frac{Mg}{Ca}$	Mean fruit weight
				mg per 100 g fresh weight				m-equiv.			g
1961	control	10	15.92	67.8	141	2.51	4.36	29.5	32.4	2.9	133
	calcium lactate	10	15.84	67.4	136	2.70	4.36	27.0	29.3	2.7	
1962	control	14	14.77	63.7	126	1.98	3.81	33.7	37.0	3.3	105
	$Ca(NO_3)_2$	14	14.71	65.3	123	2.36	3.56	27.3	29.8	2.5	
1963	control	13	15.29	52.7	133	2.20	4.17	31.9	35.1	3.2	117
	$Ca(NO_3)_2$	13	14.99	56.9	132	2.66	4.24	26.0	28.7	2.7	
Statistical evaluation											
	1961		n.s.	(+)	+	(+)	n.s.	$P<0.20$	+	n.s.	
	1962		n.s.	+	$P<0.20$	+++	++	+++	++	+++	
	1963		+	n.s.	n.s.	+++	n.s.	+++	+++	+++	

Note: see table 1

Ca content of fruit increased in 35 of 38 trials by spraying with calcium salts, K content decreased every year and in 1961 significantly. But Mg content fell only in 1962, and highly significantly. K/Ca, (K + Mg)/Ca and Mg/Ca in fruit dropped significantly in 1962 and 1963. So $Ca(NO_3)_2$ may seem more effective than calcium lactate, had not the sprayings perhaps worked cumulatively.

Almost like leaves, fruit showed the lowest Ca content and the highest relations K/Ca, (K + Mg)/Ca and Mg/Ca in 1962. But the low susceptibility to pit in 1963 was not reflected by particularly low relations between these minerals in fruit, as did happen in leaves that season. In 1961 high susceptibility to pit occurred with higher Ca content and lower K/Ca, (K + Mg)/Ca and Mg/Ca in fruit than in 1963.

In 1962 supply of $Ca(NO_3)_2$ raised the N content of fruit significantly, in contrast to leaves, where N remained constant.

The dry matter in fruit in 1962 was very clearly lower than in 1961 and 1963 and also in 1963 lower than in 1961. Mean weight of fruits followed the same trend, being least in 1962 and greatest in 1961. As a result of spraying Ca dry matter content in fruit decreased each year, in 1963 significantly. The same influence of spraying Ca on percentage dry matter has been found in other trials. In 1963 dry matter was also significantly diminished by gypsum (table 6).

3.3.1 Comparative effects of spraying with lactate, nitrate and acetate of calcium

a. *Influence on bitter pit* The comparative effect of spraying with lactate, nitrate and acetate of calcium was investigated in one orchard over the whole period. Ca content of these solutions was equivalent to 1 % calcium lactate. Again 5 sprays were given over the season. Table 10 gives results.

In 1961 and 1962 sprayings with $Ca(NO_3)_2$ were considerably more effective in controlling bitter pit than spraying with calcium acetate or calcium lactate. In 1963 calcium nitrate and calcium acetate sprays appeared to be almost equally effective. It is not clear why the beneficial effect of calcium acetate seemed to increase during the experiment. Perhaps there was an aftereffect. The greater effect of $Ca(NO_3)_2$, than of calcium acetate has been established by several workers (BAXTER, 1960; BUCHLOH, 1960; BEYERS and GINSBURG, 1961; BEYERS, 1962; SMOCK *et al.*, 1962). Some of them achieved equally good results by spraying with $CaCl_2$, though this often caused more leaf injury. BEYERS and GINSBURG (1961) recommended $CaCl_2$ for the control of bitter pit in red varieties because $Ca(NO_3)_2$ sprays might result in greener apples at harvest. But striking differences in background colour of fruit of Cox's Orange Pippin, whether or not sprayed with $Ca(NO_3)_2$, never appeared in our trials.

SCHUMACHER and FRANKHAUSER (1964) noted that $CaCl_2$ was more effective at base of salt concentration than $Ca(NO_3)_2$. (However, in this case the first spray contained more Ca.) In their trials the activity of calcium lactate was as small as in our experiments. The greater activity of $Ca(NO_3)_2$ and $CaCl_2$, than of calcium lactate or calcium acetate, may be due to differences in hygroscopicity of the salts, as ALLEN (1960) found for the effectiveness of Mg salts. BAXTER (1960) also

Table 10. Effect of spraying with lactate, nitrate and acetate of calcium on the percentage bitter pit and breakdown

Season	Mean fruit weight g	% bitter pit				% breakdown			
		control	calcium lactate	calcium nitrate	calcium acetate	control	calcium lactate	calcium nitrate	calcium acetate
1961	134	64.8	38.8	17.4	40.7	0.0	0.0	0.0	0.0
1962	91	36.4	18.0	5.4	14.9	9.5	5.0	1.9	4.0
1963	104	16.7	10.0	4.4	5.1	5.0	2.5	0.7	1.4
Statistical evaluation [1]									
	1961	++	N, A, L < c; N < A, L			—			
	1962	+++	N, A, L < c; N < A, L			n.s.			
	1963	+++	N, A, L < c; N, A, < L			n.s.			

[1] N = nitrate, A = acetate, L = lactate, c = control
Note: see table 1

supposed some relation with the degree to which saturated solutions of sprayed Ca salts remain moist on leaves. We tried to elucidate which salt increased Ca content most, by analysis of fruits and leaves.

b. *Influence on leaf and fruit composition* The results of comparative sprayings with lactate, nitrate and acetate of calcium on leaf and fruit composition were not consistent, though this trial was carried out in an almost uniform plantation. Table 11 only gives data for Ca content, and for K/Ca, (K + Mg)/Ca and Mg/Ca. No differences were found between N, P, K and Mg contents of the various plots.

Table 11. Influence of various calcium salts on composition of leaves and fruit

Treatment	Mean fruit weight g	Leaves				Fruit			
		Ca g/100 g dry wt	K/Ca	(K+Mg)/Ca	Mg/Ca	Ca mg/100 g fresh wt	K/Ca	(K+Mg)/Ca	Mg/Ca
			m-equiv.				m-equiv.		
1961									
control	129	0.83	1.26	1.57	0.31	2.38	33.2	36.7	3.6
calcium lactate	135	0.93	1.12	1.39	0.28	2.51	31.0	34.5	3.4
calcium acetate	138	0.96	1.11	1.36	0.26	2.25	36.3	40.0	3.7
calcium nitrate	135	0.95	1.13	1.39	0.26	3.01	24.6	27.3	2.7
1962									
control	91	0.57	1.86	2.39	0.53				
calcium lactate	93	0.67	1.55	2.02	0.46				
calcium acetate	93	0.72	1.46	1.90	0.43				
calcium nitrate	93	0.66	1.58	2.05	0.47				
1963									
control	103	0.86	1.06	1.45	0.38	1.96	33.8	37.2	3.4
calcium lactate	107	0.96	0.97	1.32	0.35	2.18	30.6	34.0	3.4
calcium acetate	103	1.03	0.89	1.22	0.34	2.28	29.2	32.3	3.0
calcium nitrate	105	1.06	0.87	1.17	0.30	2.22	28.9	32.2	3.2
Statistical evaluation [1]									
1962	—	+++ N,A,L>c A>N,L	++ N,A,L<c	++ N,A,L<c	++ N,A,L<c	—	—	—	—
1963	—	++ N,A,L>c N>L	++ N,A,L<c N,A<L	++ N,A,L<c N<L	n.s.	—	—	—	—
total [2] 1961-1963	—	++ N,A,L>c	n.s.	+ N,A,L<c	+ N,A,L<c	n.s.	n.s.	n.s.	n.s.

[1] see table 10
[2] interaction year × treatment as error variance
Note: see table 1

Indeed, in every season Ca sprays increased the Ca content of leaves. In 1961 differences between the Ca treatments could scarcely be noticed; in 1962 calcium acetate increased Ca content most, whereas in 1963 calcium nitrate caused the largest rise in Ca content of leaves and significantly greater than calcium lactate. So calcium lactate was least effective.

The relations K/Ca, (K+Mg)/Ca and Mg/Ca in leaves always fell after spraying with a calcium salt. Again in 1961 the differences between Ca treatments were negligible. In 1962 the lowest relations were found after spraying with calcium acetate, in 1963 after spraying with $Ca(NO_3)_2$. In 1963 the effect of calcium nitrate on the first two relations was significantly greater than of calcium lactate.

As the data on fruit analysis in 1962 seemed unreliable they were not included in table 11.

Data only for 1961 and 1963 could be compared. In 1961 the largest increase in Ca content of fruit was after spraying with $Ca(NO_3)_2$ and was associated with the lowest values for K/Ca, (K+Mg)/Ca and Mg/Ca. The influence of calcium acetate spray on fruit composition did not fit into these series and did not correspond with the data on leaf analysis. In 1963 the largest increase in Ca was found in fruit sprayed with calcium acetate but differences in K/Ca and (K+Mg)/Ca of fruit treated with calcium acetate or calcium nitrate were small.

The influence of the three treatments on leaf and fruit composition conformed to the concept that less pit is associated with more Ca or lower values for K/Ca or (K+Mg)/Ca. But compositions gave no clear evidence for the more beneficial effect of calcium nitrate, which increased the Ca content only slightly more than the other salts. Total calcium in leaves and fruit was apparently not the only reason for differences in bitter pit over the years.

3.3.2 Effect of number of sprayings and time of spraying

a. *Influence on bitter pit and breakdown* The influence of number of sprayings at different periods of the growing season was investigated in 1962 and 1963 in one orchard (scheme 1, see p. 4). The results are given in table 12.

This table shows that in both years late spraying resulted in better control of bitter pit and breakdown than early spraying. In fact, 6 sprays distributed over the entire growing season gave best results. But the last two sprays in 1962 and the last four in 1963 nearly equalled this. Without presenting exact data several workers claimed that the sprayings in the last weeks before harvest are the most important for control of bitter pit (MATTHEWS and WILSON, 1961; HILKENBÄUMER and O'DANIEL, 1962; RAPHAEL and RICHARDS, 1962; SMOCK *et al.*, 1962). BAXTER (1960) found early spraying with calcium acetate reduced tree pit in Granny Smith more than later ones. But later ones were more effective than earlier ones in preventing development of bitter pit during storage. In our own trials no tree pit occurred and Baxter's findings could not be checked.

In experiments by BEYERS (1962) in South Africa mid-season sprayings appeared

Table 12. Effect of number and time of spraying on bitter pit and breakdown

Treatment	1962			1963		
	mean fruit weight g	% bitter pit	% breakdown	mean fruit weight g	% bitter pit	% breakdown
Control	96	23.9	7.4	107	27.4	4.4
2 × Ca E	97	15.5	4.3	115	12.8	3.1
2 × Ca M	100	5.0	1.6	113	7.3	0.5
2 × Ca L	98	2.9	1.1	109	7.5	0.3
4 × Ca E	100	5.0	2.0	121	7.9	0.7
2 × Ca E + 2 × Ca L	99	3.3	1.5	111	4.8	0.5
4 × Ca L	101	5.0	2.2	111	3.6	0.6
6 × Ca	100	1.9	0.6	112	3.3	0.9
4 × Ca + 2 × Mg	94	2.9	0.8	115	4.5	0.2
2 × Ca + 4 × Mg	106	20.3	5.0	110	11.1	1.6
6 × Mg	99	24.9	8.3	114	50.5	4.6
Statistical evaluation [1]	—	+++ Ca < c L < E Mg > Ca	++ Ca < c L < E Mg > Ca	—	+++ Ca < c Mg > Ca	++ Ca < c Mg > Ca

[1] E = early-, M = mid-season-, L = late spraying; c = control
Note: see table 1

more effective in reducing bitter pit in Golden Delicious than early or late sprayings. PORREYE and PIOT's (1964) findings were not consistent. Except for Beyers and Porreye and Piot, all workers favoured late sprayings to prevent storage pit. Climate may be responsible for discordant results in South Africa. Weather conditions would be associated with a temporary shortage of Ca and so would harm the fruit.

b. *Influence on leaf and fruit composition* The results of analysing leaves and fruit from the trial in which number and time of spraying were varied are shown in table 13. In 1962 the leaves were picked in mid September, in 1963 by a mistake in August, before the last 2 sprays. So only the data for the former season give a true picture of the effect of the various sprayings on composition of leaves.

It appeared that the Ca content of leaves sampled late in summer increased with increasing number of $Ca(NO_3)_2$ sprays. Mid-season and late-season sprays, if few, raised this content somewhat more than early-season sprays. In agreement with the antagonism between Ca and K, K content dropped and apparently more by late-season sprays than by early-season sprays. No distinct influence of Ca sprays on Mg content could be observed. Of course Mg content of leaves raised when the number of Mg sprays increased. The K content decreased by Mg sprays and more than by Ca sprays. In 1962 spraying with nitrates of Ca or Mg gave a small increase in N content, but in 1963 not.

Data of both seasons on fruits were not faulted by errors in sampling. Though much attention was paid to satisfactory fruit sampling it seemed that the composition of fruits did not reflect the influence of various sprays as uniformly as the

Table 13. Effect of number and time of spraying on composition of leaves and fruit

Treatment	N		K		Ca		Mg	
	1962	1963	1962	1963	1962	1963	1962	1963
	Leaves g per 100 g dry weight							
control	2.47	3.09	1.81	1.59	1.24	1.27	0.22	0.37
2 × Ca E	2.52	3.10	1.73	1.58	1.23	1.30	0.21	0.34
2 × Ca M	2.45	3.07	1.71	1.49	1.35	1.32	0.23	0.37
2 × Ca L	2.50	—*	1.61	—*	1.35	—*	0.22	—*
4 × Ca E	2.52	3.00	1.76	1.54	1.46	1.42	0.22	0.34
4 × Ca E + L	2.57	—*	1.58	—*	1.46	—*	0.22	—*
4 × Ca L	2.63	—*	1.61	—*	1.46	—*	0.22	—*
6 × Ca	2.62	—*	1.58	—*	1.51	—*	0.22	—*
6 × Mg	2.64	3.01*	1.53	1.38*	1.38	1.26*	0.41	0.50*
4 × Mg + 2 × Ca	2.53	3.12*	1.54	1.37*	1.24	1.26*	0.35	0.41*
2 × Mg + 4 × Ca	2.59	3.07*	1.54	1.47*	1.38	1.36*	0.24	0.37*
	Fruits mg per 100 g fresh weight							
control	46.9	48.5	113	110	2.45	2.35	3.84	3.71
2 × Ca E	50.9	53.5	130	113	2.14	2.81	3.79	3.93
2 × Ca M	44.5	52.2	102	113	2.61	2.85	3.51	3.80
2 × Ca L	45.9	48.7	114	102	2.72	2.48	3.85	3.52
4 × Ca E	54.7	51.9	123	112	2.42	2.61	3.67	3.81
4 × Ca E + L	63.9	51.3	118	115	2.70	2.89	3.70	3.84
4 × Ca L	55.4	56.2	118	120	2.96	2.70	4.08	4.04
6 × Ca	59.8	53.1	115	113	2.88	3.22	3.85	3.94
6 × Mg	62.8	52.6	102	104	2.30	2.61	3.89	4.08
4 × Mg + 2 × Ca	55.2	50.5	112	117	2.34	2.59	3.84	3.87
2 × Mg + 4 × Ca	59.8	45.6	114	116	2.28	2.72	3.84	3.71
Statistical evaluation **								
leaves	n.s.	+ Ca<c	++ Ca<c Mg<c L<E	+ Mg<c Mg<Ca	++ Ca>c Mg<Ca	+ Ca>c Mg<Ca	+ Mg>c Mg>Ca	+ Ca<c L>E Mg>c Mg>Ca
fruit 1962/1963 ***	n.s.		n.s.		n.s.		n.s.	

* latest two sprays not yet executed at sampling date
** see table 12
*** interaction year × treatment as error variance
Note: see table 1

composition of leaves did. Indeed Ca sprays usually increased the Ca content of fruits. In 1962 a greater rise in Ca content occurred when the number of sprays increased. This rise was greater after later sprays than after early sprays. In 1963 no such trend appeared in the Ca content of fruits. Especially in 1963, sprays with $Mg(NO_3)_2$ gave higher Mg content, lower K content and probably lower Ca content of the fruits. The concentration of N nearly always raised when nitrates of Ca or Mg were applied. However, we got the impression that especially on this vast field the common way of sampling, *viz.* 30 fruits per treatment, was not satisfactory though only apples which almost equalled in size were picked from trees with equal relations between crop and leaf mass.

3.4 Effect on bitter pit of dipping apples in $Ca(NO_3)_2$ and $CaCl_2$ solutions

In 1962 and 1963 apples were dipped for about half a minute in solutions of 0.75 % and 1 % $CaCl_2$ and $Ca(NO_3)_2$ directly after harvesting. The fruits were allowed to dry in boxes. Other apples as controls were washed in tap water.

The results are summarized in table 14.

Table 14. Effect of dipping in solutions of $Ca(NO_3)_2$ and $CaCl_2$ on the occurrence of bitter pit in Cox's Orange Pippin

Treatment	1962		1963	
	mean fruit weight g	% bitter pit	mean fruit weight g	% bitter pit
control	96	18.4	108	29.4
$Ca(NO_3)_2$ 0.75 %	94	11.2	109	20.9
,, 1 %	96	10.1	108	15.6
control	91	12.0	103	14.5
$CaCl_2$ 0.75 %	91	9.7	106	6.5
,, 1 %	96	11.8	103	4.8
Statistical evaluation [1]	—	(+)	—	++ Ca < c

[1] c = control
Note: see table 1

Especially in 1963 an obvious reduction in pits was found as a result of dipping fruit in solutions of $Ca(NO_3)_2$ and $CaCl_2$. This confirmed the findings of BUCHLOH (1960), HILKENBÄUMER and O'DANIEL (1962), and JACKSON (1961). The results of dipping however did not equal the effect of spraying (table 12).

3.5 Effects of spraying with nitrates of Ca, K and Mg

a. *Influence on bitter pit and breakdown* The effects of spraying with nitrates of calcium, potassium and magnesium were compared in only one orchard. In 1963 this experiment was transferred to a second orchard as the first was seriously affected by cancer. The results are shown in table 15.

Whereas calcium salts did not harm apples, a spray of 0.8 % $Mg(NO_3)_2$ caused injuries which could easily be confused with bitter pit. They were round pits with a central lenticel, appearing on the spots which remain wet longest after spraying (photo 1). These lesions were superficial.

Table 15. Effect of spraying with nitrates of calcium, magnesium and potassium on the incidence of bitter pit and breakdown in Cox's Orange Pippin

Season	Mean fruit weight g	% bitter pit				% breakdown			
		control	$Ca(NO_3)_2$	$Mg(NO_3)_2$	KNO_3	control	$Ca(NO_3)_2$	$Mg(NO_3)_2$	KNO_3
1961	112	35.6	5.1	48.2	46.1	6.8	0.5	6.2	7.3
1962	96	50.3	4.5	59.1	66.0	10.5	0.3	6.2	6.2
1963	126	2.0	0.5	1.4	1.9	0.5	0.0	0.4	0.6
Statistical evaluation [1]									
1961		+++	Ca < K, Mg, c			+	Ca < K, Mg, c		
1962		++	Ca < K, Mg, c			+	Ca < K, Mg, c		
1963		n.s.				n.s.			

[1] c = control
Note: see table 1

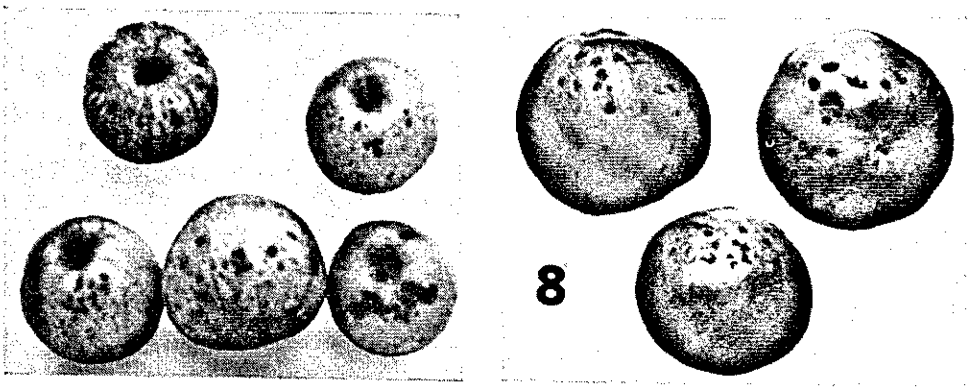

Photo 1. Superficial injury like bitter pit of Cox's Orange Pippin (left) after spraying with $Mg(NO_3)_2$ solution and bitter pit on Gronsvelder Klumpke (right)

KNO_3 appeared to be harmless.

In the first and second year much bitter pit occurred. In both seasons bitter pit tended to be encouraged by sprays of $Mg(NO_3)_2$ and KNO_3, although the differences from controls were not significant. But in 1963 no such trend was found, either with $Mg(NO_3)_2$ or KNO_3. However, in that season susceptibility to bitter pit seemed very small.

Breakdown was also controlled by Ca supply, while Mg and K did not evoke it.

Nitrates of calcium and magnesium were sprayed together onto the same trial plot in which number of sprays and time of spraying were being investigated (see scheme 1 and table 12). These experiments confirmed that excessive Mg may increase the occurrence of bitter pit. But this effect was not consistent. Whereas in 1963 six sprays with $Mg(NO_3)_2$ considerably increased bitter pit, no such effect was seen in 1962. Four sprays of $Mg(NO_3)_2$ partly cancelled the beneficial effect of two sprays with $Ca(NO_3)_2$. The effect of Mg and K in advancing the incidence of bitter pit has been noted before by several investigators (GARMAN and MATHIS, 1956; MORI and YAMAZAKI, 1960; ASKEW *et al.*, 1960; GERRITSEN, 1960; MARTIN *et al.*, 1960; OBERLY and KENWORTHY, 1961; BÜNEMANN, 1962).

MARTIN *et al.* (1960) saw only a detrimental effect of $Mg(NO_3)_2$ sprays, whereas KNO_3 sprays seemed not to affect his trials. According to BEYERS (1962) $MgSO_4$ early in the season did not increase the susceptibility to pit.

b. *Influence on leaf and fruit composition* Nitrates of calcium, magnesium and potassium were sprayed onto Cox's Orange Pippin and Jonathan in the same field trial. The latter variety is not susceptible to bitter pit but was inserted in these trials to study the influence on Jonathan breakdown by the various sprays. As the effects of these sprays on the composition of leaves and fruit showed the same trend for Cox and Jonathan, the data on them are given in table 16. As the growth period for Jonathan is one month longer than for Cox the number of sprayings was increased from 5 to 7 in 1962 and 1963.

The main results were as follows:

1. The N content of fruits increased in 10 of 12 treatments after spraying with nitrates of Ca, Mg or K, whereas the N percentage of leaves scarcely changed.
2. $Ca(NO_3)_2$ raised the Ca content of fruits in all series and the Ca content of leaves in 5 of 6 treatments. It had no influence on the content of Mg or K, either in leaves or in fruit.
3. Mg sprays resulted in an increase of Mg content and a decrease of K and Ca in leaves of all series. As for fruits the same happened in 3 of 4 series.
4. K sprays reduced the Ca and Mg content of leaves in 5 of 6 treatments; K content always increased. Spraying with KNO_3 increased K content and decreased Ca content of fruit in 3 of 4 series; the influence on Mg content was not clear.
5. $Ca(NO_3)_2$ always depressed $(K+Mg)/Ca$ in both leaves and fruits. KNO_3 and $Mg(NO_3)_2$ sprays raised this relation in the leaves in 5 of 6 treatments but in the fruits only in 3, and in 2 of 4 series, respectively. Especially in 1963, no increase

Table 16. Influence of comparative spraying with nitrates of calcium, magnesium and potassium on leaf and fruit composition of Cox's Orange Pippin and Jonathan

Treatment	Cox's Orange Pippin				Jonathan			
	Leaves		Fruit		Leaves		Fruit	
	Ca mg/100 g dry wt	$\frac{K+Mg}{Ca}$ m-equiv.	Ca mg/100 g fresh wt	$\frac{K+Mg}{Ca}$ m-equiv.	Ca mg/100 g dry wt	$\frac{K+Mg}{Ca}$ m-equiv.	Ca mg/100 g fresh wt	$\frac{K+Mg}{Ca}$ m-equiv.
1961								
Control	1.33	1.59	3.20	28.7	1.46	0.76		
$Ca(NO_3)_2$	1.11	1.39	3.85	21.2	1.64	0.66		
$Mg(NO_3)_2$	0.96	2.10	3.08	26.6	1.39	1.05		
KNO_3	1.11	1.92	2.49	34.4	1.29	0.93		
1962								
Control	1.05	2.02	2.35	28.9	1.69	0.71	2.35	26.1
$Ca(NO_3)_2$	1.20	1.66	2.52	27.8	2.12	0.57	2.72	19.9
$Mg(NO_3)_2$	0.97	2.13	2.19	33.3	1.58	0.87	1.88	31.2
KNO_3	0.94	2.31	2.08	35.3	1.82	0.72	1.61	39.6
1963 [1]								
Control	1.17	1.48	2.55 [2]	22.9	0.91	1.21		
$Ca(NO_3)_2$	1.43	1.19	3.31	19.5	1.01	1.09		
$Mg(NO_3)_2$	1.11	1.48	2.91	19.4	0.81	1.44		
KNO_3	1.11	1.65	3.00	21.3	0.86	1.34		
Statistical evaluation [3]								
1962	+++ Ca>c>K,Mg	+++ K,Mg>c>Ca	—	—	—	—	—	—
1963	+(+) Ca>c,K,Mg	++ K,Mg,c>Ca	—	—	+ Ca>K,Mg	+ K,Mg>Ca	—	—
total for two varieties [4] 1961-1963	n.s.	Cox's Orange Pippin and Jonathan (+) Mg>Ca	+ Ca>c,K,Mg	+ K>Ca				

Note: see table 1 [1] new trial plot [2] no reliable analysis [3] c = control [4] interaction year × treatment as error variance was found on the new trial plot, perhaps through faulty chemical analysis.

In the trial with $Mg(NO_3)_2$ and $Ca(NO_3)_2$ together a drop of K and a rise of Mg in leaves were resulted from spraying more Mg and less Ca; but Ca did not change. For fruit the same appeared to be true as for leaves. (K+Mg)/Ca in leaves increased, whereas it was contstant in fruit.

From this it follows that in various plots the detrimental effect on bitter pit from Mg and K sprays may be considered to result from a decrease in Ca content or an increase of the relation (K+Mg)/Ca. This appeared especially from leaf analysis but to some extent also from fruit analysis.

3.6 Influence of supply of calcium salts and nitrates of K and Mg on the occurrence of breakdown in Cox's Orange Pippin and Jonathan

Sorting the data showed that calcium either as dressing of gypsum or as spray of calcium lactate, nitrate or acetate also reduced breakdown in Cox's Orange Pippin (tables 4, 7 and 10). Sprays, especially $Ca(NO_3)_2$ proofed more effective than dressings. But the influence of nitrates of K and Mg was not clear (table 15).

Thus breakdown seemed to be limited by Ca but it was not clear whether it was provoked by too low a temperature during storage or connected with the same basic disorder as bitter pit. Even though the temperature is kept fairly high, 4°-5°C as in our trial, Cox can then sometimes be affected by low-temperature breakdown.

However, the susceptibilities to pit and to breakdown were parallel on the

Table 17. Influence of spraying with nitrates of calcium, magnesium and potassium on the percentages of breakdown and spot in Jonathan

Treatment	1961		1962		1963 [2]	
	bd [1]	spot	bd [1]	spot	bd [1]	spot
control	56.4	25.3	52.0	—		
$Ca(NO_3)_2$	59.2	26.1	60.7	—		
Statistical evaluation	n.s.	n.s.	n.s.			
control	12.9	3.9	16.1	1.6	15.5	76.6
$Ca(NO_3)_2$	7.6	3.1	1.0	0.1	11.1	57.0
$MgNO_3$	10.8	1.3	10.4	1.2	10.6	66.3
KNO_3	12.1	1.1	7.4	1.3	9.9	73.2
Statistical evaluation [3]	+ Ca<K,Mg,c	+ K,Mg<c	+ Ca<K,Mg,c	n.s.	n.s.	n.s.

[1] bd = breakdown
[2] new trial plot
[3] c = control
Note: see table 1

various trial plots, a high susceptibility to bitter pit was associated with much breakdown.

SUTHERLAND (1937) discerned in Cox's Orange Pippin a type of breakdown associated with bitter pit.

After the beneficial effect of Ca on the appearance of breakdown in Cox on two plots, Jonathan was also sprayed. Jonathan is highly susceptible to breakdown when stored at less than 3°C, though it usually stays free from bitter pit.

On one plot only the influence of $Ca(NO_3)_2$ sprays was studied, on the other field the effects of spraying with nitrates of Ca, Mg and K were compared. The treatments were again in triplicate and identical concentrations were used as in trials on the control of bitter pit. We sprayed Jonathan 5 times in 1961, and 7 times in 1962 and 1963. If possible 12 boxes of apples per treatment were stored from each orchard. In 1961 and 1962 this was not possible for the field on which nitrates of K, Ca and Mg were sprayed. As the trees of this orchard were severely affected by cancer this trial was transferred to a very similar orchard in 1963.

The Jonathans were stored at 2°C. After removal the fruit remained at room temperature (20°C) for another week to bring out latent breakdown. Table 17 shows data on total breakdown and total Jonathan spot.

Table 17 shows that $Ca(NO_3)_2$ decreases the appearance of breakdown and spot but this effect is not consistent for place or time.

4 Relationships between K, Mg and Ca in leaves and fruit

Relations between K, Mg and Ca in leaves and fruit, are given in tables 18, 19 and 20.

Between leaves and fruit positive correlations were found significant for Ca and for K, but no reliable values appeared for Mg. In fruit K increased highly significantly with increasing ash content. In fact the percentage ash is halfly determined by K content. The Mg content of fruit increased significantly with increasing ash content. Ca and ash were negatively correlated in fruit. In our trials a high ash content of fruit was associated with low Ca and Mg in ash, the decrease in Ca being the most stringent.

A negative correlation was found between K in leaf and Ca in fruit, and between K in fruit and Ca in leaf. In both leaves and fruit significant negative correlations were found between these nutrients. This might be explained by the antagonism between Ca and K or by the fact that sandy soils from which K is more easily absorbed, are poorest in exchangeable Ca. Many workers have already noted the antagonism between K and Ca in leaves (SHEAR *et al.*, 1953; GRUPPE, 1955, 1961; GHOSHEH, 1962; VAN DER BOON *et al.*, 1966). JOLIVET and COIC (1954) found a negative relation between K and Ca in fruit too. Also our trials showed that spraying with KNO_3 lowered Ca in leaves as well as in fruit. Ca sprays usually reduced K in leaves, whereas fruits only tended to.

K content of leaves and Mg content of fruit tended to increase together. But in the first two years the concentration of Mg in leaves rose as the K content of fruit fell. For leaves the K and Mg content were negatively correlated during the earlier years. But in 1963 no such relationship could be established, despite the low Mg contents of the sandy soils from which K was most easily absorbed. The spraying trials with KNO_3 and $Mg(NO_3)_2$ clearly showed the well known antagonism between K and Mg in leaves.

In fruit significant positive correlations were found between K and Mg, an increasing content of K appearing with an increasing concentration of Mg. Also WILKINSON (1958) and VAN DER BOON (1964) noted a positive correlation between K and Mg in fruit. WILKINSON supposed that as a result of an increased concentration of total acid in case of an increasing K concentration more Mg will be transported to the fruits.

For the antagonism of Mg and Ca between leaves and fruit no relationship was found. In 1961 and 1962 a positive correlation was found for leaves, perhaps through the positive correlation between Mg and Ca in the soils of our trial plots.

There was no distinct relationship between these nutrients for fruit. Still in 14 trials spraying with Ca salts resulted on an average in a small, and in 1963 significant, decrease of Mg in leaves; in fruit only in 1962 a significant decrease was noted. The other trials gave no results.

Spraying with $Mg(NO_3)_2$ depressed Ca both in leaves and fruit on several plots. In a fertilizer trial on sandy soils VAN DER BOON *et al.* (1966) stated a significant reduction in Ca content of leaves after dressing with $MgSO_4$, but they found no significant change in Mg after dressing with gypsum, nor in Ca and Mg in fruit

Table 18. Relationships between K, Mg and Ca between leaves and fruit on control plots

Factors			Correlation coefficients		
			1961 n = 11	1962 n = 14	1963 n = 13
leaves		fruit			
K (% dry wt)	:	K (% dry wt)	$+0.78^{++}$	$+0.81^{+++}$	$+0.72^{++}$
K (% dry wt)	:	K (m-equiv. fresh wt)	$+0.83^{++}$	$+0.80^{+++}$	$+0.75^{++}$
Ca (% dry wt)	:	Ca (% dry wt)	+0.42	+0.30	$+0.51^{(+)}$
Ca (% dry wt)	:	Ca (m-equiv. fresh wt)	+0.39	+0.28	$+0.50^{(+)}$
Ca (% dry wt)	:	Ca (% ash)	$+0.58^{(+)}$	+0.38	$+0.54^{(+)}$
Mg (% dry wt)	:	Mg (% dry wt)	−0.16	+0.16	+0.38
Mg (% dry wt)	:	Mg (m-equiv. fresh wt)	−0.18	+0.13	+0.20
Mg (% dry wt)	:	Mg (% ash)	+0.29	$+0.58^{+}$	$+0.52^{(+)}$
(K+Mg)/Ca	:	(K+Mg)/Ca (m-equiv.)	$+0.64^{+}$	$+0.64^{+}$	$+0.58^{+}$
K/Ca	:	K/Ca (m-equiv.)	$+0.69^{+}$	$+0.69^{++}$	$+0.58^{+}$
Mg/Ca	:	Mg/Ca (m-equiv.)	−0.04	+0.18	+0.44
K (% dry wt)	:	Ca (% dry wt)	-0.62^{+}	−0.42	−0.33
K (% dry wt)	:	Mg (% dry wt)	+0.20	+0.12	$+0.62^{+}$
Ca (% dry wt)	:	K (% dry wt)	−0.51	-0.54^{+}	−0.43
Ca (% dry wt)	:	Mg (% dry wt)	+0.04	+0.04	−0.13
Mg (% dry wt)	:	K (% dry wt)	−0.50	-0.63^{+}	+0.08
Mg (% dry wt)	:	Ca (% dry wt)	+0.18	−0.03	+0.15

Note: see table 1

Table 19. Relationships between K, Mg and Ca for leaves on control plots

Factors			Correlation coefficients		
			1961 n = 11	1962 n = 10	1963 n = 14
K	:	Ca (% dry wt)	—0.65^{+}	—0.72^{+}	—0.58^{+}
K	:	Mg (% dry wt)	—0.43	—0.30	+0.13
Ca	:	Mg (% dry wt)	+0.56$^{(+)}$	+0.39	+0.19
K	:	Mg/Ca	+0.26	+0.64^{+}	+0.46$^{(+)}$
Mg	:	K/Ca	—0.61^{+}	—0.09	—0.03
K	:	Ca + Mg	—0.65^{+}	—0.73^{+}	—0.35
Ca	:	K + Mg	—0.35	—0.72^{+}	—0.23

Note: see table 1

Table 20. Relationships between K, Mg and Ca for fruit on control plots

Factors			Correlation coefficients		
			1961 n = 11	1962 n = 14	1963 n = 13
K	:	ash (mg fresh wt)	+0.95^{+++}	+0.88^{+++}	+0.99^{+++}
Ca	:	ash (mg fresh wt)	—0.32	—0.52$^{(+)}$	—0.39
Mg	:	ash (mg fresh wt)	+0.60^{+}	+0.44	+0.83^{+++}
K	:	Ca (m-equiv. fresh wt)	—0.42	—0.62^{+}	—0.43
K	:	Mg (m-equiv. fresh wt)	+0.59$^{(+)}$	+0.63^{+}	+0.83^{+++}
Ca	:	Mg (m-equiv. fresh wt)	+0.20	—0.45	—0.15
K	:	Mg/Ca (m-equiv. fresh wt)	+0.79^{++}	+0.73^{++}	+0.78^{++}
Mg	:	K/Ca (m-equiv. fresh wt)	+0.23	+0.62^{+}	+0.59^{+}
K	:	Ca + Mg	+0.49	+0.15	+0.64^{+}
Ca	:	K + Mg	—0.38	—0.62^{+}	—0.42

Note: see table 1

after dressing with $MgSO_4$ and gypsum.

For leaves a significant negative correlation was shown between K and Mg + Ca, but fruits tended to have a positive correlation. For fruit a negative correlation was found between Ca and K + Mg, emphasizing the differences in distribution of K, Mg and Ca between leaves and fruit.

For K/Ca and (K + Mg)/Ca, but not for Mg/Ca, significant positive correlations were found between leaves and fruit.

Leaves tended to have a positive correlation between K and Mg/Ca and a negative correlation between Mg and K/Ca. Fruit showed positive correlation between K: Mg/Ca and Mg: K/Ca. This difference between leaves and fruit seems due to different relationships between K and Mg.

The main results of these calculations can be summarized as follows:

1. Between leaves and fruit positive correlations occurred for K and Ca and (K + Mg)/Ca and K/Ca.
2. Between leaves and fruit and for both leaves and fruit a negative relationship could be established between K and Ca.
3. For fruit significant positive correlations were found between K and Mg, for leaves none or negative correlations.

5 Relationships between bitter pit and mineral composition of leaves and fruit

Correlation coefficients as conceived by GARMAN and MATHIS (1956) were calculated between decay from bitter pit and K and Ca contents and K/Ca, (K+Mg)/Ca and Mg/Ca, both for leaves and fruit (table 21). Only data from 1962 and 1963 were used, as in both seasons $Ca(NO_3)_2$ was sprayed on almost every trial plot and one person analysed all the fruit.

Like GARMAN and MATHIS we found significant correlations between bitter pit and Ca and K, and K/Ca, (K+Mg)/Ca and Mg/Ca for both leaves and fruit. The only low correlation coefficients were for plots treated with gypsum which were all not significant except one. With increasing concentration of Ca or decreasing concentration of K and decreasing K/Ca, (K+Mg)/Ca and Mg/Ca, pit was less.

The relationships between bitter pit and Ca content and (K+Mg)/Ca, respectively, for leaves and fruit are shown in figures 2 and 3. These graphs show that Ca content and (K+Mg)/Ca were almost linearly related to bitter pit, especially in fruit. The same held for K/Ca.

Figure 3 shows that no bitter pit occurred when (K+Mg)/Ca was less than 20-25 in fruit. GARMAN and MATHIS (1956) mentioned values of 20-30 and BOUHIER DE L'ECLUSE (1962) below 23. Figure 2 shows that bitter pit in Cox's Orange Pippin will remain less than 10 % if Ca is more than 2.8 mg per 100 g fresh matter, or more than 19 mg Ca per 100 g dry matter.

For leaves it appeared that bitter pit was negligible when K is less than 1.5 %, Ca more than 1.6 %, K/Ca less than 0.5 or (K+Mg)/Ca less than 0.6.

On the 1962 trial plot where times of spraying and number of sprays were varied there was a distinct relationship between bitter pit and (K+Mg)/Ca in leaves (figure 4), rather than in fruit. For in 1963 this relationship was smaller yet. We have already discussed why samples of 30 apples may have been insufficient on this large plot.

Also in the field on which influences of nitrates of Ca, Mg and K were compared Ca contents were reduced and (K+Mg)/Ca increased by KNO_3 and $Mg(NO_3)_2$ sprays, usually increasing bitter pit.

Figures 2 and 3 show that the 1961 data after spraying with calcium lactate coincided quite well with control data. But data from plots sprayed with $Ca(NO_3)_2$ in 1962 and 1963 did not. On these plots less bitter pit occurred than expected from Ca content or (K+Mg)/Ca, the differences being statistically significant. Also the more outstanding effect of calcium nitrate on bitter pit over calcium lactate and acetate could not be satisfactorily explained by occasional rises in Ca contents

Table 21. Correlation coefficients of bitter pit with K and Ca contents, and K/Ca, (K+Mg)/Ca and Mg/Ca for leaves and fruits (1962 and 1963)

Treatments	Leaves					Fruits				
	K	Ca	$\frac{K}{Ca}$	$\frac{K+Mg}{Ca}$	$\frac{Mg}{Ca}$	K	Ca	$\frac{K}{Ca}$	$\frac{K+Mg}{Ca}$	$\frac{Mg}{Ca}$
total	$+0.51^{+++}$	-0.47^{+++}	$+0.53^{+++}$	$+0.58^{+++}$	$+0.57^{+++}$	$+0.32^{+}$	-0.63^{+++}	$+0.57^{+++}$	$+0.66^{+++}$	$+0.67^{+++}$
controls	$+0.60^{++}$	$-0.40^{(+)}$	$+0.57^{++}$	$+0.61^{++}$	$+0.58^{++}$	$+0.46^{+}$	$-0.41^{(+)}$	$+0.60^{++}$	$+0.60^{++}$	$+0.51^{+}$
$Ca(NO_3)_2$	$+0.71^{+++}$	-0.60^{++}	$+0.77^{++}$	$+0.80^{+++}$	$+0.64^{+++}$	$+0.43^{+}$	-0.60^{++}	$+0.69^{+++}$	$+0.55^{+++}$	$+0.51^{+}$
gypsum	+0.17	+0.15	−0.06	+0.25	+0.45	+0.17	$-0.59^{(+)}$	+0.49	+0.51	$+0.75^{+}$

Note: see table 1

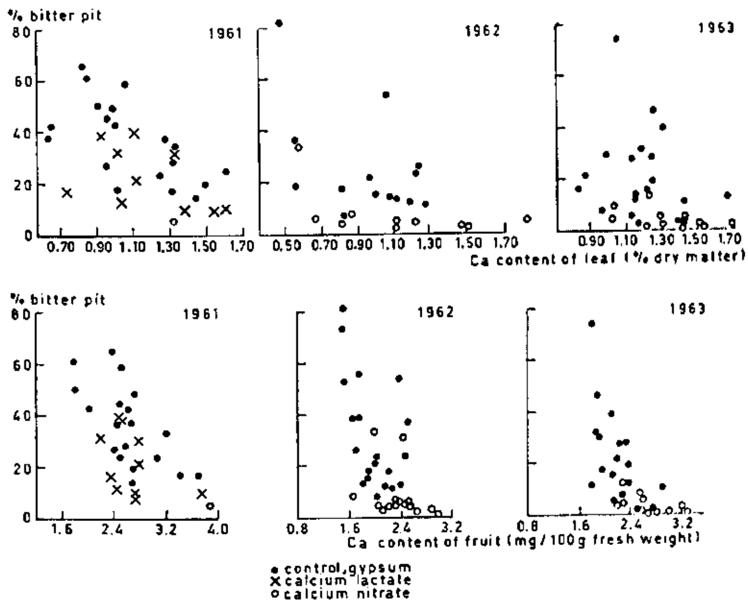

Fig. 2. Relationship between percentage pit during storage and calcium content in leaves (above) and fruit (below)

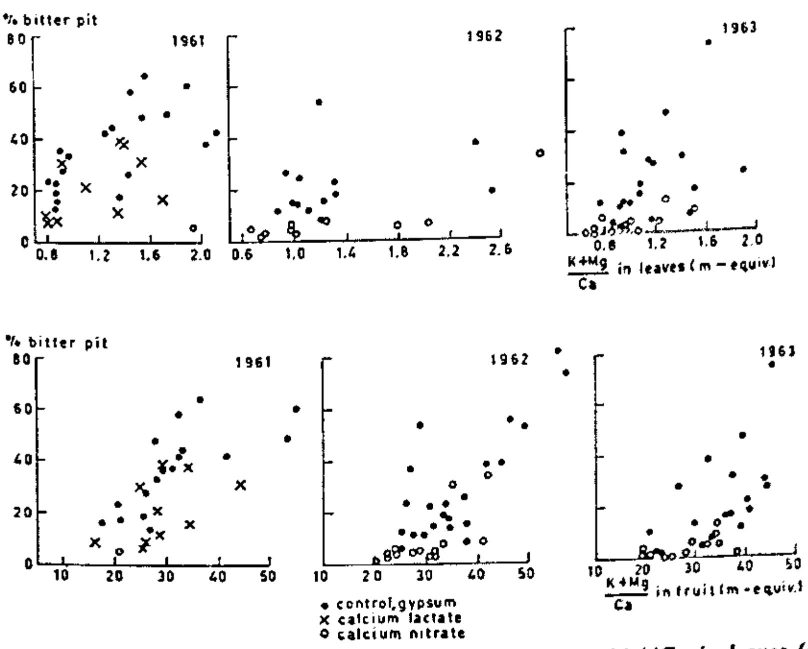

Fig. 3. Relationship between pit during storage and (K+Mg)/Ca in leaves (above) and fruit (below)

of leaves and fruit. This is difficult to explain but is dealt with in the discussion. However, it indicates that relationships between bitter pit and K, Mg and Ca will certainly not be simply a matter of total concentrations. This appeared also when data from different years were considered.

It has already been mentioned that the incidence of bitter pit through the years does not fully accord with average composition of leaves and fruit for Ca and K/Ca and (K+Mg)/Ca. Especially the results of fruit analysis do not satisfy this concept (tables 9 and 11). Fruit weight and crop size may also play a role. With the same Ca contents or (K+Mg)/Ca in fruit the susceptibility to pit may be different in various seasons as the disease will probably depend on different factors. Other workers have also indicated that leaf and fruit analysis as used in practice does not always reflect susceptibility to pit.

Between 18 orchards, OBERLY and KENWORTHY (1961) found a significant negative correlation between bitter pit and Ca, and a significant positive correlation between pit and K for leaves and fruits. But they could not establish the same relationships within each orchard. Referring to these results SCHAHRESTANY (1964) started to analyse corresponding leaves only. Thus he determined the mineral contents of leaves near fruits and of leaves from perennial branches, concluding that high susceptibility to pit would occur when the leaves near fruits show a higher Ca content than the leaves from perennial branches. This phenomenon may be caused by leaves withdrawing Ca from diseased adjacent fruits. When concentrations in leaves reversed, hardly any pit occurs.

So far we have considered only K, Mg and Ca in the crop. Many workers suppose a relationship with nitrogen too. Apple-trees dressed heavily with nitrogen

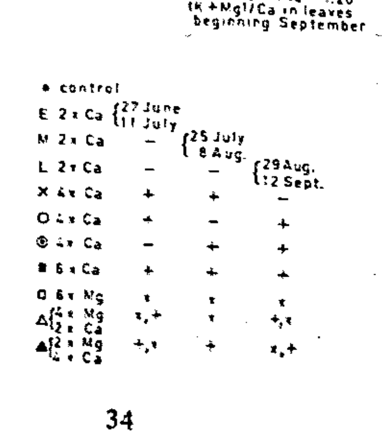

Fig. 4. Relation between percentage pit during storage and (K+Mg)/Ca in leaves, after various sprayings of calcium and magnesium nitrate at various times

Table 22. Total N and protein N in control and calcium-treated apples in 1962

No. trial field	Total N mg/100 g fresh wt		Protein N mg/100 g fresh wt		Storage pit	
	$Ca(NO_3)_2$	control	$Ca(NO_3)_2$	control	$Ca(NO_3)_2$	control
1a	55.4	57.2	24.4	23.4	3.9	18.3
1b	63.1	50.2	25.4	23.7	1.5	11.7
2	59.4	59.2	25.5	24.2	8.0	52.8
4	65.1	77.7	24.8	28.0	4.4	11.3
5	70.1	74.5	20.1	23.0	7.4	17.5
6	59.6	50.9	25.9	24.8	0.3	12.0
7	51.1	46.9	25.3	25.4	4.1	38.6
8	68.0	73.2	25.2	25.7	5.0	13.6
9	58.6	56.9	27.2	27.1	4.5	50.3
11	63.3	68.6	22.1	24.2	2.8	25.9

yield apples highly susceptible to pit (MARTIN, 1962). We never found any relationship between bitter pit and nitrogen in the crop (VAN SCHREVEN *et al.*, 1962; VAN DER BOON *et al.*, 1966). In a recent paper MARTIN *et al.* (1962) mentioned that apples developing bitter pit contain much more protein and respire faster than sound fruit. Apples in pots given no Ca had more bitter pit and protein.

Therefore we also estimated protein in our apples. The $CuSO_4$ method was used (VAN SCHREVEN and VAN DER MEER, 1957).

Control and calcium-treated fruits from the 1962 series were investigated. In that season bitter pit was severe. Sampling of fruit took place at harvest before serious decay from bitter pit could start. The results are in table 22.

Table 22 shows that in our trials no pronounced increase in protein could be established in unsprayed apples.

6 Discussion

In full agreement with workers such as GARMAN and MATHIS, our trials showed that bitter pit could be considerably decreased by supplying Ca. But sprays with KNO_3 and $Mg(NO_3)_2$ may increase its occurrence. Significant negative correlations were found with Ca contents of both leaves and fruit. Significant positive correlations occurred between disease and K content or K/Ca, (K+Mg)/Ca or Mg/Ca for both leaves and fruit. Especially the relationship with K/Ca and (K+Mg)/Ca were highly significant. However, it is impossible to say which correlation is crucial for pit. The strong interdependence of the distribution of K, Mg and Ca in leaves and fruit shown by our data complicates a verdict.

Besides their more specific activities these elements also have some interplay, *e.g.* at the boundary layers of plasma and plasmatic particles.

Calcium nitrate's exertion of a larger effect than could be deduced from the increase in Ca content of leaves and fruit might indicate that only part of the total Ca is important for bitter pit: only that from walls, or boundary layers.

The nitrate ion perhaps exerted a specific influence. It may change the pattern and concentrations of organic acids in the leaves of various species (DOESBURG, 1961). As the distribution of the minerals K, Mg and Ca around the various sides of the cells will be closely associated with organic acids, the nitrate ion may act this way. However, we can only make suppositions here.

Another point is that mineral differences may occur locally in fruits susceptible to bitter pit and would scarcely be reflected by analysis of the whole cortex. Generally more ash, Mg, K, N and P were found in apple tissues affected by bitter pit than in sound tissues (GARMAN and MATHIS, 1956; G. BÜNEMANN, 1959; ASKEW *et al.*, 1960; O. BÜNEMANN, 1960; HILKENBÄUMER and O'DANIEL, 1962). A striking increase in Mg and a smaller decrease in Ca was noted (GARMAN and MATHIS, 1956; BÜNEMANN, 1959; ASKEW *et al.*, 1960). ASKEW *et al.* supposed a migration of nutrients from sound tissues to adjacent spots affected by bitter pit.

Our analysis showed significant relationships between bitter pit and Ca content and Mg/Ca in fruit. But for Mg content no significant correlation could be found. This did not exclude possible influence of local accumulations of Mg. Until now it seemed impossible to determine whether these accumulations occur primarily or secondarily in the lesions of bitter pit when Ca in fruit was low. KIDSON *et al.* (1963) found a high calcium content in the peel. Some abnormality of the peel due to Ca shortage may induce symptoms of the disorder. Our short investigations on dipping after harvest point in the same direction.

Weather conditions such as dry or wet weather or sharp alternations influence the appearance of bitter pit. Drought increased K/Ca in tomato fruit. According to WIERSUM (1965) fruits are mainly fed with water and assimilates by the sieve tubes. These do not transport Ca. Only extra water supplied over the xylem, warrants a good Ca supply. Further studies are being made to elucidate the interaction of water supply and Ca transport to the fruits.

Certainly the real physiological cause of bitter pit and the roles of Ca, K and Mg in it are still not solved and need further physiological and biochemical research.

Summary

The influence of spraying and dressing, especially with calcium salts, on bitter pit in Cox's Orange Pippin has been studied in 11-14 orchards for 3 years.

Important soil characteristics were as follows:

1. The clay content of the trial plots varied from 2-41 % by weight of particles smaller than 16 μ. With increasing percentage of clay more K, Mg and Ca was exchangeable. However, K was more easily absorbed by trees on sandy soils than on loamy soils.
2. Dressings of gypsum, 3000 kg per ha per year, decreased Mg in soils considerably. Therefore, this treatment must be avoided especially on sandy soils with poor Mg content.

The influence of dressing and spraying on the incidence of bitter pit can be summarized as follows:

1. On sandy soils dressing with gypsum always reduced pit. On loamy soils no marked benefit was noted; in one of the five orchards the susceptibility to pit even increased.
2. Ca sprays decreased the incidence of pit on various soils. $Ca(NO_3)_2$ appeared especially effective where 5 sprayings over the season decreased decay by pit by about 80 %. Calcium lactate and acetate were less active.
3. Spraying late in the season was more effective than early in the season.
4. Dipping fruit in 0.75 % or 1 % $CaCl_2$ or $Ca(NO_3)_2$, directly after harvest, decreased bitter pit. In 1963 by even 50 %.
5. K and especially Mg spraying tended to increase the disease.

The results of dressing and spraying trials on the composition of leaves and fruit were as follows:

1. On sandy soils a dressing of gypsum increased Ca content of leaves and fruit and decreased Mg content of fruit. On loamy soils this was not always the case.
2. Ca spraying raised Ca in leaf and fruit and very often decreased K and Mg in leaf and fruit a little. K/Ca, (K+Mg)/Ca and Mg/Ca in leaf and fruit decreased highly significantly. Calcium nitrate influenced the composition a bit more than calcium lactate.
3. $Ca(NO_3)_2$ did not raise N in leaves, but usually increased the percentage N in fruit.
4. After spraying with Ca, apples contained less dry matter than control fruit.

5. Spraying late in the season increased the Ca content and decreased the K content of leaves more than sprays early in the season. In fruit these tendencies were not as evident as in leaves.
6. In leaves and fruit Ca content tended to drop after spraying with nitrates of K and Mg. Sprays with K and Mg increased (K+Mg)/Ca in leaves and to a lesser extent in fruit.
7. Generally leaf composition reacted more clearly to sprays than did fruit composition, though unsatisfactory techniques of fruit sampling may have prevented similar results.

Only slight leaf injury occurred after spraying with $Ca(NO_3)_2$ 0.75 %, both with AR and commercial-grade fertilizer (Mekog Flakes). On fruit $Ca(NO_3)_2$ sprays had no detrimental effect. Mist spraying in concentrations above 4 % resulted in serious leaf damage. $Mg(NO_3)_2$ caused no leaf injury but evoked pits, resembling bitter pit on the fruits.

K, Mg and Ca showed the following correlations for leaves and fruit:
1. Between leaves and fruit positive correlations were found for K and Ca content, and K/Ca and (K+Mg)/Ca.
2. For leaves and fruit and between them negative correlation was established between K and Ca.
3. Fruit had a significant positive correlation between K and Mg.

The relationships between bitter pit and the mineral compositions of leaves and fruit were as follows:
1. Significant negative correlations occurred between bitter pit and Ca content of both leaves and fruit. On the contrary significant positive correlations were found between pit and K and K/Ca, (K+Mg)/Ca and Mg/Ca in leaves and in fruit. On the gypsum plots, however, this relation did not hold for leaves.
2. Calcium nitrate caused a larger decrease in pit as would be expected from the increase in Ca content and the decrease in K/Ca, (K+Mg)/Ca and Mg/Ca in the leaves and fruit.
3. A rough estimate was that less than 10 % pit occurred in Cox's Orange Pippin if the fruit contained more than 2.8 mg Ca per 100 g fresh matter or if (K+Mg)/Ca was less than 20-25. No pit or little pit occurred if K in leaves was less than 1.5 %, Ca was more than 1.6 % and (K+Mg)/Ca was less than 0.6.
4. No relationship was found between bitter pit and N content either for fruits or leaves. Samples of apples highly susceptible to pit did not contain more protein N at harvest.

Besides decreasing bitter pit calcium salts also diminished the occurrence of breakdown in Cox's Orange Pippin. For Jonathan, Ca limited the occurrence of breakdown only in some years.

Acknowledgments

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Miss J. E. van der Wal assiduously analysed the samples of fruit.

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