Journal of Horticultural Science (1984) **59** (1) 71–78

Effects of lime, gypsum and trace elements on bitter pit and breakdown in apples from trees growing on river clay

By P. VAN LUNE
Institute for Soil Fertility, Haren (Gr.), The Netherlands

SUMMARY

From 1969 to 1977 Cox's Orange Pippin apple tree on M.9 rootstock were grown on river clay in 137-l asbestos cement vessels to study the effect of liming with $CaCO_3$ or $CaCO_3$ + $CaSO_4$, and of the addition of trace elements, a combination of Fe, Mn and B, on the incidence of bitter pit and breakdown in apples. Liming to pH-KCl 7.4 with $CaCO_3$ had no effect on the incidence of these disorders. The addition of Fe, Mn and B at pH-KCl 7.4 to the soil reduced bitter pit, increased the percentage of healthy fruits and increased the Fe, Mn and B contents of leaves and fruits. In these treatments the addition of $CaSO_4$ to the soil had no effect on the incidence of bitter pit or breakdown in apples. Liming to pH-KCl 7.4 was accompanied by an increase in necrotic spots on the leaves and in mid-shoot leaf drop (Cox's disease). This aggravating effect on Cox's disease could be counteracted by the addition of Fe, Mn and B.

BITTER pit and breakdown in apple are still a problem for fruit growers. Martin *et al.* (1975) reported a predominant role of calcium in inhibiting bitter pit development. Van Goor (1968) and Bangerth (1974) suggested that Ca decreases the incidence of bitter pit and breakdown through decreasing cell membrane permeability. Some ions, especially K and Mg, probably have a competing effect on Ca metabolism in the fruit, which may result in an increase in the incidence of the diseases.

Two methods have been found to raise the Ca content of fruits and to reduce bitter pit and breakdown, viz., spraying the trees, and especially the fruits, with a Ca salt or the application of a Ca salt to the soil. Spraying the trees with a solution of $Ca(NO_3)_2$ or $CaCl_2$ in the investigations of Sharples and Little (1970), Van Goor (1971), Van der Boon (1980a) and Delver (1980a) resulted in a considerable reduction in bitter pit and breakdown. However, in practice, it would be advantageous to replace the laborious practice of frequent spraying by annual soil applications of a Ca salt. The supply of Ca to the root can be improved by fertilization with $CaCO_3$ or gypsum and by decreasing the K supply. Schumacher and Fankhauser (1968) and Van der Boon (1980b) obtained some reduction in bitter pit by liming sandy soil with $CaCO_3$, especially in combination with gypsum (Van der Boon, 1980a, Van der Boon, 1980b). Liming clay soil, however, did not affect the occurrence of bitter pit (Schumacher and Fankhauser, 1968), nor did the combination of $CaSO_4$ + $Ca(NO_3)_2$ (Van der Boon *et al.*, 1963). Sadowski and Swiderska (1977) obtained a significant decrease in the percentage of bitter pit by supplying 343 kg CaO ha^{-1} as $CaCO_3$, $CaCl_2$ or $Ca(NO_3)_2$ to an acid, loamy soil only in the years with a high yield at a high N and K supply.

Liming lowers the availability to the plant of a number of microelements such as Mn, Fe, Zn and Cu. It is conceivable that the effects of liming on the occurrence of bitter pit and breakdown in apple are a consequence of the reduced availability of microelements. Therefore experiments were carried out to study the effect of lime, gypsum and microelements on the occurrence of bitter pit and breakdown in apples from trees growing on clay soil.

MATERIALS AND METHODS

In April 1969 two-year-old cv Cox's

Orange Pippin apple trees on M.9 rootstock were planted in asbestos cement vessels with a 50 cm diameter and a height of 70 cm, filled with a river clay soil with 16.8% particles < 16 µm, 2.3% organic matter and a pH-KCl determined in a suspension of soil and N KCl (1:5=w:v) of 5.1. Six treatments with 12 single-tree replicates of each were applied. These treatments were:

I. Control, pH-KCl in the soil 5.1;
II. Liming with $CaCO_3$ to pH-KCl 6.5;
III. Liming with $CaCO_3$ to pH-KCl 7.4;
IV. Liming with $CaCO_3$ as in Treatment III + addition of $CaSO_4$.

Treatments III and IV were subdivided into A (addition of Fe, Mn and B) and B (no addition of microelements). The amounts of Fe, Mn and B applied to the trees of Treatment IIIA and IVA are shown in Table I.

EXPERIMENTAL

Dressings

The following dressings were mixed through the entire soil volume of the culture vessels (pots) at the start of the experiment: All pots 0.13 mol N as $Ca(NO_3)_2$, 0.02 mol P as monocalciumphosphate, 0.19 mol K as K_2SO_4 and 0.02 mol Mg as $MgSO_4$; pots of Treatment I 0.24 mol Ca as $CaCO_3$; of Treatment II 1.42 mol Ca as $CaCO_3$, of Treatment III 5.90 mol Ca as $CaCO_3$, of Treatment IV 5.90 mol Ca as $CaCO_3$ plus 1.54 mol Ca as $CaSO_4$. From mid-April until mid-September soil samples (0–20 cm and 20–40 cm) were taken monthly and analysed for pH-KCl and extractable N, P, K and Mg. Dressings were supplied on the basis of soil analysis data; they were heavier than is normally recommended in commercial practice because the volume of soil available to the roots was restricted. The annual dressings are listed in Table II. The doses of lime and gypsum were incorporated a few centimeters into the soil; the other fertilizers were dissolved in water and given as solutions.

Culture conditions

At the bottom of each culture vessel was a drainage hole; a second hole 38 cm from the upper edge of the vessel made it possible to supply water also to the centre portion of the soil volume. The pots were set up outdoors in rows of 12 pots 2 m apart with 3.5 m between the rows. In the first two winters the pots were placed in a barn to prevent frost damage. In the autumn of 1971 the pots were dug in to avoid extreme soil temperatures in summer and winter in the following experimental years. The trees were pruned in autumn or spring so that they were all about the same size. Fruits were thinned every year, and the number of fruits per tree was equalized every year after fruit-drop in June.

Visual assessments

The incidence of necrotic spots on the leaves and mid-shoot leaf-drop (Cox's disease) was rated according to a scale from 0 (no Cox's disease) to 5 (severe symptoms of Cox's disease).

By mistake the trees of Treatment IIIA and IVA were sprayed in the earlier years with a 2% solution of $MnSO_4.H_2O$ (Table I), which is used in commercial practice for low-volume spraying. In the years of application this caused some browning of the margins of the leaves.

After the growing season of 1977 the experiment was terminated and the root system of one tree in each of Treatments I and IVA was examined.

Sampling fruits and leaves

In mid-July and mid-September fruit samples (mean size at that time) were taken. The diameter of the apples in a sample varied no more than ± 1 mm. The stalks of the sampled fruits were removed; the apples were washed with deionised water, dried with a towel, dried at 105°C and then ground in a Starmix MXC 500.

In mid-August samples of the third and fourth leaves from the bases of newly formed shoots were taken. The leaves were washed twice with deionised water for 1 min, blotted between filter paper, dried at 105°C and then ground in a Starmix MXC 500.

Harvest, storage and examination of fruits

At harvest the apples were graded into classes increasing by 5 mm, and the weight in each class was determined. The apples were then stored at *c.* 4°C for $2\frac{1}{2}$ months and then at *c.* 20°C for two weeks. The apples of each

TABLE I
Addition of Fe, Mn and B to the trees of Treatments IIIA and IVA

Compound	Method of application	Time	Year
0.1% Borax + 0.05% wetting agent	spraying	just before flowering	1969–1977
6 g FeEDDHA per pot	soil	early June	1969–1971
1.5 g FeEDDHA per pot	soil	early June	1972–1977
2% $MnSO_4.H_2O$ + 0.05% wetting agent	spraying	early June, July and August	1969–1971
2% $MnSO_4.H_2O$ + 0.05% wetting agent	spraying	early June and August	1973
0.2% $MnSO_4.H_2O$ + 0.05% wetting agent	spraying	early June and August	1974–1977

TABLE II
Annual dressings

Fertilizer	1969	1970	1971	1972	1973	1974	1975	1976	1977
kg N ha^{-1} as NH_4NO_3					1150(6)	1700(7)	1950(7)	1850(6)	1850(6)
kg N ha^{-1} as blood-meal	75(1)					100(1)		150(1)	150(1)
kg N ha^{-1} as $Ca(NO_3)_2$	175(2)	275(4)	350(4)	550(6)					
kg K_2O ha^{-1} as K_2SO_4	300(4)	300(3)	250(3)	1100(7)	1400(6)	1800(7)	2400(7)	2250(7)	2100(6)
kg P_2O_5 ha^{-1} as $Ca(H_2PO_4)_2$	120(2)	120(2)	120(2)	120(2)	240(4)	300(5)	600(6)	660(7)	600(6)
kg MgO ha^{-1} as $MgSO_4$	110(2)	100(1)	100(2)	250(4)	400(6)	425(7)	550(7)	600(7)	600(6)
Treatment									
I: kg CaO ha^{-1} as $CaCO_3$								3500(2)	
II: kg CaO ha^{-1} as $CaCO_3$		1100(2)			500(1)	200(1)	5800(4)	1000(1)	1000(1)
III: kg CaO ha^{-1} as $CaCO_3$		10000(5)	8000(2)	3000(1)	6000(2)	6000(2)	6000(2)	6000(2)	4000(1)
IV: kg CaO ha^{-1} as $CaCO_3$		10000(5)	8000(2)	3000(1)	6000(2)	6000(2)	6000(2)	6000(2)	4000(1)
IV: kg $CaSO_4.H_2O$ ha^{-1}	3000(1)	8750(5)	7000(2)	3000(1)	6000(2)	6000(2)	6000(2)	6000(2)	3000(1)

( ) Frequency of dressings.
100 kg ha^{-1} is equivalent to 1.96 g per pot.

size grade were then examined for bitter pit, breakdown, decay and other disorders after peeling and cutting into slices 5 mm thick at right angles to the axis. All slices were examined for any signs of these disorders and the same size grades were compared per treatment.

Analysis of leaves and fruits

After ashing the plant material at 400°C, K was determined flamephotometrically. Calcium and Mg contents of leaves and fruits were determined by atomic absorption spectrophotometry after ashing the plant material at 600°C. The B content was determined spectrophotometrically with carmine after ashing at 600°C. After digesting the leaves and fruits in a mixture of concentrated HNO_3, H_2SO_4 and $HC1O_4$ (32:8:1=v:v:v) the contents of Fe and Mn were determined by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

The length of time in which the trees were exposed to experimental conditions and the size of the trees may have had an effect on the results of the experiment. Therefore the results for 1974, 1975 and 1977, in which the trees of Treatments IIIA and IVA were sprayed with the correct Mn solution, were averaged to provide a better overall impression of the data obtained towards the end of the experiment. The individual results for these last three years of the experiment are reported when they were different from the results over the whole period.

In 1976 many fruits were attacked by mould (*Monilia*) and therefore the results obtained in that year (with the exception of Cox's disease) were not included in the considerations. The effects of liming (Treatments I, II and IIIB) were evaluated by linear trend analysis, and the effects of $CaSO_4$ and trace-elements (Treatments IIIB, IIIA, IVB and IVA) by analysis of variance. The results of the experiment have already been described in detail in an internal report of the Institute for Soil Fertility (Van Lune, 1981) and only the main findings are presented here. To illustrate the incidence of diseases and fruit yield in the experiment, the average results are shown in Table III, and the average mineral contents in leaves and fruits are shown in Table IV. In the Netherlands a classification scheme of the mineral contents in leaves and fruits has been developed for predicting the susceptibility of apples to bitter pit (Pouwer, 1974; Delver, 1980b). According to this scheme the average K contents in the leaves of the experiment described here were good, the Mg contents were low/good and the Ca contents too low. In the fruits sampled in mid-September the average K contents were normal/high, the Mg contents high and the Ca contents normal.

Effects of treatments on bitter pit

Liming with $CaCO_3$: Liming had no significant effect on the occurrence of bitter pit (Table V). A number of authors (Van der Boon *et al.*, 1963, 1980b; Schumacher and Fankhauser, 1968) also reported no effect on bitter pit of liming a clay soil.

Addition of Fe, Mn and B at pH-KCl 7.4 in the soil: The addition of Fe, Mn and B caused a decrease in the percentage of bitter pit and raised the percentage of healthy fruits (Table V). The decrease in the percentage of bitter pit in Treatments III and IV due to the addition of Fe, Mn and B is not supported by results in the literature. Martin *et al.* (1976a) reported a decrease in the Ca content of the fruits and an increase in the occurrence of bitter pit and breakdown upon raising the Fe concentration in the culture solution of

TABLE III

Incidence of disorders and weight of fruits. Average of all years of the experiment. (Healthy: no disorder or rot)

Treatment	Yield (g per tree)	Number of apples per tree	Mean weight of apples per tree (g)	Bitter pit (%)	Breakdown (%)	Healthy (%)	Cox's disease (scale 0–5)
I	4879	40.2	121	16.4	9.5	62.6	1.8
II	4995	40.2	124	12.8	7.6	69.8	2.0
IIIB	4127	32.0	129	15.9	4.7	65.1	3.0
IIIA	4859	38.8	125	7.3	3.4	74.2	1.6
IVB	4191	33.9	124	16.1	3.3	64.7	2.9
IVA	4531	37.0	122	7.1	2.1	75.4	1.5

TABLE IV

Mineral contents (dry-weight basis) of leaves and fruits. Average of all years of the experiment

Treatment	Ca (%)	K (%)	Mg (%)	K/Ca (equiv.)	(K + Mg)/Ca (equiv.)	Fe	Mn	B	Mn*
						(mg kg^{-1})			
Leaves in mid-August (1970–1977)									
I	1.04	1.41	0.18	0.71	0.94	114	206	16.6	358
II	1.24	1.25	0.21	0.53	0.74	107	123	14.4	182
IIIB	1.25	1.29	0.21	0.53	0.73	98	48	10.8	28
IIIA	1.25	1.19	0.23	0.49	0.71	113	534	14.7	200
IVB	1.27	1.40	0.17	0.57	0.74	97	39	11.4	25
IVA	1.32	1.33	0.18	0.53	0.69	112	518	15.6	192
Fruits in mid-July (1970–1977)									
I	0.103	1.34	0.079	7.24	8.32	17.6	19.1	11.7	26.9
II	0.107	1.24	0.078	6.26	7.23	16.3	11.4	8.7	15.5
IIIB	0.107	1.29	0.078	6.29	7.22	17.0	5.2	5.8	4.4
IIIA	0.106	1.25	0.078	6.13	7.05	17.8	34.8	10.4	8.0
IVB	0.112	1.33	0.079	6.30	7.20	17.1	5.3	7.1	4.9
IVA	0.112	1.30	0.081	6.07	6.96	20.9	39.3	10.7	8.7
Fruits in mid-September (1971–1977; B 1972–1977)									
I	0.029	0.86	0.035	15.31	16.83	11.6	6.3	6.4	6.4
II	0.029	0.81	0.037	15.26	16.91	10.2	4.6	5.3	5.6
IIIB	0.033	0.89	0.038	14.67	16.19	8.6	2.4	3.9	2.3
IIIA	0.033	0.86	0.040	14.36	15.95	12.8	13.3	6.4	6.1
IVB	0.035	0.92	0.039	13.98	15.41	8.9	2.4	4.8	2.0
IVA	0.034	0.92	0.039	14.24	15.70	13.5	13.7	7.2	6.8

* Average 1974, 1975 and 1977.

TABLE V
Results of linear trend analysis (Treatments I, II and IIIB) and analysis of variance (Treatments IIIB, IIIA, IVB and IVA).

	Linear trend of liming (pH)		Analysis of variance			
	In all years	In 1974, 1975 and 1977	In all years		In 1974, 1975 and 1977	
			$CaSO_4$	Trace elements	$CaSO_4$	Trace elements
Leaves in mid-August						
% Ca	n.s.	n.s.	n.s.	n.s.	n.s.	+*
% K	n.s.	n.s.	+***	–**	+**	–**
% Mg	n.s.	n.s.	–***	+*	–***	n.s.
K/Ca, equiv.	n.s.	n.s.	n.s.	n.s.	+**	–**
(K+Mg)/Ca, equiv.	n.s.	n.s.	n.s.	n.s.	n.s.	–**
Fe, mg kg^{-1}	n.s.	–*	n.s.	+***	n.s.	+*
Mn, mg kg^{-1}	n.s.	n.s.	n.s.	+**	n.s.	+***
B, mg kg^{-1}	–**	n.s.	n.s.	+***	n.s.	+***
Fruits in mid-July						
% Ca	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
% K	n.s.	n.s.	+*	n.s.	+*	n.s.
% Mg	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
K/Ca, equiv.	n.s.	n.s.	n.s.	n.s.	n.s.	–**
(K+Mg)/Ca, equiv.	n.s.	n.s.	n.s.	n.s.	n.s.	–**
Fe, mg kg^{-1}	n.s.	n.s.	n.s.	n.s.	n.s.	+*
Mn, mg kg^{-1}	n.s.	n.s.	n.s.	+*	n.s.	+***
B, mg kg^{-1}	n.s.	–*	n.s.	+***	n.s.	+**
Fruits in mid-September						
% Ca	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
% K	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
% Mg	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
K/Ca, equiv.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
(K+Mg)/Ca, equiv.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Fe, mg kg^{-1}	n.s.	n.s.	n.s.	+*	n.s.	+*
Mn, mg kg^{-1}	–**	n.s.	n.s.	+**	n.s.	+***
B, mg kg^{-1}	n.s.	n.s.	+**	+***	n.s.	+***
Yield of apples	n.s.	n.s.	n.s.	+**	n.s.	+**
Number of apples per tree	n.s.	–**	n.s.	+**	n.s.	n.s.
Mean fruit weight per tree	n.s.	+**	n.s.	n.s.	n.s.	n.s.
Shoot growth (one year old)	n.s.	n.s.	–*	n.s.	n.s.	n.s.
% bitter pit	n.s.	n.s.	n.s.	–**	n.s.	–*
% breakdown	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
% bitter pit and/or breakdown	n.s.	n.s.	n.s.	–***	n.s.	–*
% healthy (no diseases or rot)	n.s.	n.s.	n.s.	+*	n.s.	+**
Cox's disease	+*	n.s.	n.s.	–***	n.s.	–***

Treatment effects significant at $P<0.05$*, 0.01** or 0.001***
+ Contents, incidence of diseases etc. increased.
– Contents, incidence of diseases etc. decreased.
In analysis of variance no significant effect of the interaction $CaSO_4$ x trace elements was ascertained.

Jonathan apple trees. No results have been found in the literature as to the effect of fertilizing/spraying with Mn on the incidence of bitter pit. Spraying with B compounds has been reported as having no effect (Smock *et al.*, 1962; Martin *et al.*, 1965, 1976b; Dixon *et al.*, 1973), or to have lowered the incidence of bitter pit (Wiebosch, 1948; Van Stuivenberg and Pouwer, 1950; Dunlap and Thompson, 1959; Shorrocks and Nicholson, 1980).

Addition of $CaSO_4$ at pH-KCl 7.4 in the soil: The addition of gypsum had no effect on the incidence of bitter pit (Table V). Van der Boon (1980a; 1980b) reported, however, a sharper decrease in the percentage of bitter pit when, in addition to $CaCO_3$, gypsum was applied to sandy soil.

Effect of treatments on breakdown

Liming to pH-KCl 7.4 with $CaCO_3$ had no effect on the percentage of fruits with breakdown (Table V). At pH-KCl 7.4 in the soil the addition of trace elements (Fe, Mn and B) and $CaSO_4$ had no effect on breakdown (Table V). Martin *et al.* (1976b) reported an increase in breakdown following spraying with B compounds, but Shorrocks and Nicholson (1980) found no effect.

Effect of treatments on nutrient contents of leaves and fruits

Liming with $CaCO_3$: Averaged over all the years of the experiment liming resulted only in decreases in the B content of the leaves and in the Mn content of the fruits sampled in mid-September (Table V). In the last three years of the experiment the Fe content of the leaves and the B content of the fruits sampled in mid-July were reduced (Table V). In the investigations of Van der Boon (1977; 1980b) and Smith and Green (1980) liming resulted in an increase in the Ca content of the leaves, whereas the Ca content of the fruits was only slightly affected. In the experiment reported here liming did not affect the Ca content of leaves and fruits.

Addition of Fe, Mn and B at pH-KCl 7.4 in the soil: The addition of Fe, Mn and B caused an increase in the Fe, Mn and B contents of the leaves and of the fruits sampled in mid-July and mid September (Table V). However, the Fe content of the fruits sampled in mid-July was affected only in the last three years of the experiment. In this period the K/Ca and (K+Mg)/Ca ratios decreased in the leaves and in the fruits sampled in mid-July.

Addition of $CaSO_4$ at pH-KCl 7.4 in the soil: The addition of $CaSO_4$ caused a decrease in the Mg content of the leaves, an increase of the K content of the leaves and of the fruits sampled in mid-July, and an increase of the B content of the fruits sampled in mid-September (Table V). In the last three years of the experiment the K/Ca ratio in the leaves was raised.

Mineral composition of leaves and fruits and occurrence of bitter pit and breakdown

The decrease in bitter pit, following the addition of Fe, Mn and B at pH-KCl 7.4 in the soil, was accompanied by a rise in the Fe, Mn and B contents of the leaves and generally also of the fruits, and, in the last three years of the experiment also by decreases in the K/Ca and (K+Mg)/Ca ratios in the leaves and in the fruits sampled in mid-July (Table V).

Tree growth and yield of apples

The growth of the trees in the pots was considerably poorer than that of the comparable trees in the orchard. The limited root volume of trees contained in the pots was probably the cause of this reduced growth. Rooting density in two pots, excavated at the conclusion of the experiment, was high enough to allow the uptake of water and minerals from the whole volume of soil. To create comparable growing conditions in all treatments, the trees were pruned to the same size in autumn or spring and the number of fruits per tree was made equal for all treatments after fruit drop in June and again a few weeks later. Nevertheless the yield of apples and the number of fruits in Treatments IIIB and IVB were lower (more fruit drop) than in Treatments IIIA and IVA (Table V). However, the mean weight of the fruits per tree was similar for all treatments, so any effect of the treatments on the occurrence of bitter pit could not have been due to differences in the rate of fruit growth. Moreover, the effect of the treatments on bitter pit was determined per size grade.

The addition of $CaSO_4$ at pH-KCl 7.4 in the soil resulted in a decrease of shoot growth (Table V).

Cox's disease

Liming the soil to pH-KCl 7.4 with $CaCO_3$ was accompanied by a significant increase in the number of necrotic spots on the leaves and in mid-shoot leaf drop (Cox's disease, Table V). The increase in Cox's disease was not accompanied by a change in the Ca, K and Mg contents of the leaves (Table V), although Oud (1968) reported a decreased leaf content of Ca and Mg with increasingly severe Cox's disease. Comparing leaves from diseased and healthy trees, Boekel and Van der Boon (1978) found lower Ca, K, Mg and P contents and higher sugar and B contents in affected leaves, although the Mn and N contents were similar. In the experiment reported here the increase in Cox's disease by liming the soil to pH-KCl 7.4 could be counteracted by the addition of Fe, Mn and B to the trees (Table V). This treatment also increased the Mg, Mn, B and Fe contents and lowered the K content in the leaves (Table V).

Ca and Mg content of the soil

Liming increased exchangeable and watersoluble Ca in the soil and decreased exchangeable Mg.

CONCLUSION

Liming to pH-KCl 7.4 had no effect on bitter pit and breakdown in apples. If Fe, Mn and B were supplied at pH-KCl 7.4 the incidence of bitter pit decreased and the percentage of healthy fruits increased. The decrease in bitter pit was usually accompanied by a rise in the Fe, Mn and B contents of the leaves and fruits. The effect of Fe, Mn, B and perhaps others microelements at different soil pH levels on the occurrence of bitter pit in apples needs further investigation.

The assistance of Mr Wolf of the Section of Mathematical Statistics of the Institute for Soil Fertility is gratefully acknowledged.

REFERENCES

BANGERTH, F. (1974). The function of calcium in the cell and in the subcellular units of apple fruit. *Acta Horticulturae*, **45**, 43–7.

BOEKEL, P. and BOON, J. VAN DER (1978). Voortzetting van het onderzoek naar het optreden van Cox's-ziekte in de Noordoostpolder in de periode 1966–1968. *Instituut voor Bodemvruchtbaarheid, Rapport 8–78.*

BOON, J. VAN DER (1977). Bestrijding van stip en zacht in appel op zandgronden door bekalking en gipstoediening. *Instituut voor Bodemvruchtbaarheid, Rapport 15–77.*

BOON, J. VAN DER (1980a). Dressing or spraying calcium for bitter pit control. In: *Mineral nutrition of fruit trees.* (D. Atkinson, J. E. Jackson, R. O. Sharples and W. M. Waller, Eds), Butterworth, London, 309–15.

BOON, J. VAN DER (1980b). Prediction and control of bitter pit in apples. II. Control by summer pruning, fruit thinning, delayed harvesting and soil calcium dressings. *Journal of Horticultural Science*, **55**, 313–21.

BOON, J. VAN DER, DAS, A. and SCHREVEN, A. C. VAN (1963). Proeven in '61 en '62 ter bestrijding van stip in Cox's Orange Pippin door toevoeging van calciumzouten. *Fruitwereld*, **24**, 14, 15, 17.

DELVER, P. (1980a). Calciumbespuitingen tegen stip en zacht. *Fruitteelt*, **28**, 876–7.

DELVER, P. (1980b). Het pluk- en bewaaradvies voor de appelrassen Cox's Orange Pippin en Schone van Boskoop, op basis van calcium- en kaliumgehalten in vroeg geplukte vruchtmonsters en gewasfactoren. *Instituut voor Bodemvruchtbaarheid*, Nota 90.

DIXON, B., SAGAR, G. R. and SHORROCKS, V. M. (1973). Effect of calcium and boron on the incidence of tree and storage pit in apples of the cultivar Egremont Russet. *Journal of Horticultural Science*, **48**, 403–11.

DUNLAP, D. B. and THOMPSON, A. H. (1959). Effect of boron sprays on the development of bitter pit in the York Imperial apple. *Bulletin A-102, University of Maryland.*

GOOR, B. J. VAN (1968). The role of calcium and cell permeability in the disease blossom-end rot of tomatoes. *Physiologia Plantarum*, **21**, 1110–21.

GOOR, B. J. VAN (1971). The effect of frequent spraying with calcium nitrate solution on the mineral composition and the occurrence of bitter pit on the apple Cox's Orange Pippin. *Journal of Horticultural Science*, **46**, 347–64.

LUNE, P. VAN (1981). Invloed van bekalking van rivierklei met calciumcarbonaat en calciumsulfaat, in combinatie met ijzer, mangaan en borium, op het optreden van stip en zacht bij Cox's Orange Pippin appels. *Instituut voor Bodemvruchtbaarheid, Rapport 8–81.*

MARTIN, D., LEWIS, T. L. and CERNY, J. (1965). Experiments with orchard spray treatments for the control of bitter pit in apples in Tasmania. *C.S.I.R.O., Division of Plant Industry, Technical Paper* No. 22.

MARTIN, D., LEWIS, T. L., CERNY, J. and RATKOWSKY, D. A. (1975). The predominant role of calcium as an indicator in storage disorders in Cleopatra apples. *Journal of Horticultural Science*, **50**, 447–55.

MARTIN, D., LEWIS, T. L., CERNY, J. and RATKOWSKY, D. A. (1976a). Der Einfluss erhöhter Eisen-, Bor- und Calcium-Versorgung auf die Fruchtzusammensetzung und das Auftreten physiologischer Störungen bei 'Johnathan'. *Erwerbsobstbau*, **18**, 70–4.

MARTIN, D., LEWIS, T. L., CERNY, J. and RATKOWSKY, D. A. (1976b). The effect of tree sprays of calcium, boron, zinc and naphthalene-acetic acid, alone and in all combinations on the incidence of storage disorders in Merton apples. *Australian Journal of Agricultural Research*, **27**, 391–8.

OUD, P. (1968). Nieuwe inzichten betreffende de Cox's ziekte. *Fruitteelt*, **58**, 1172–4.

POUWER, A. (1974). Leaf analysis. *Acta Horticulturae*, **45**, 33–7.

SADOWSKI, A. and SWIDERSKA, S. (1977). Studies on bitter pit of apples. VII. Effect of calcium fertilization applied to the soil. *Zeszyty Naukowe Szkoly Glównej Gospodarstwa Wiejskiego Akademii Rolniczej w Warszawie Ogrodnictwo*, **10**, 105–17.

SCHUMACHER, R. and FANKHAUSER, F. (1968). Die Entstehung und Verminderung stippiger Aepfel. *Früchte und Gemüse*, No. 35.

SHARPLES, R. O. and LITTLE, R. C. (1970). Experiments on the use of calcium sprays for bitter pit control in apples. *Journal of Horticultural Science*, **45**, 49–56.

SHORROCKS, V. M. and NICHOLSON, D. D. (1980). The influence of boron deficiency on fruit quality. In: *Mineral nutrition of fruit trees*. (D. Atkinson, J. E. Jackson, R. O. Sharples and W. M. Waller, Eds), Butterworths, London, 103–8.

SMITH, C. B. and GREENE, G. M. (1980). Nitrogen and lime treatment effects on the nutrient balance of apples. In: *Mineral nutrition of fruit trees*. (D. Atkinson, J. E. Jackson, R. O. Sharples and W. M. Waller, Eds), Butterworths, London, 294–5.

SMOCK, R. M., FISHER, E. G. and FORSHEY, C. G. (1962). Bitter pit of apples. *Proceedings, 1962 Annual Meeting, New York State Horticultural Society*, 118—23.

STUIVENBERG, J. H. M. VAN and POUWER, A. (1950). Onderzoek over de bestrijding van 'stip' bij notarisappels. *Mededelingen Directeur van de Tuinbouw*, **13**, 201–11.

WIEBOSCH, W. A. (1948). Bespuitingen van vruchtbomen met mangaan en boriumzouten. *Mededelingen Directeur van de Tuinbouw*, **11**, 320–3.

(Accepted 5 August 1983)