Journal of Horticultural Science (1980) 55 (3) 313–321

Prediction and control of bitter pit in apples. II. Control by summer pruning, fruit thinning, delayed harvesting and soil calcium dressings

By J. VAN DER BOON
Institute for Soil Fertility, Haren (Gr.), The Netherlands

SUMMARY

Various orchard treatments were investigated as alternative or supplementary measures to routine spraying with $Ca(NO_3)_2$ solutions for the control of bitter pit in stored Cox's Orange Pippin and James Grieve apples. The leaf/fruit ratio was modified by summer pruning and fruit thinning, and picking date was delayed while, in orchards on sandy soils, Ca was applied either as $CaCO_3$ or $CaSO_4$ directly to the soil. Summer pruning produced a slight improvement in the storage quality of larger fruits from unsprayed trees. Spraying lowered the incidence of both bitter pit and breakdown, and reduced external bitter pit to such an extent that no additive effect of pruning was discerned. Fruit thinning at the end of June or in early July did not seriously affect fruit storage quality and there was some evidence that late picking decreased bitter pit incidence. In four trials in Cox orchards on sandy soils liming lessened the incidence of bitter pit slightly after several successive years of treatment. Although gypsum dressings produced a more marked, earlier response, soil Mg levels were depressed to unacceptable levels. It was concluded that none of the supplementary treatments was effective enough to replace or reduce the frequency of spraying with $Ca(NO_3)_2$ during the season. Moreover late thinning of the crop was unlikely to necessitate any increase in the amount of Ca applied in routine spray programmes.

THE extent to which the susceptibility of apples to bitter pit can be affected other than by spraying with $Ca(NO_3)_2$ during the growing season was studied in a series of experiments in which the fruit/leaf ratio was modified by summer pruning or fruit thinning. Attempts were also made to increase Ca levels in fruits by applying soil dressings of $Ca(NO_3)_2$, $CaSO_4$ and $CaCO_3$ to different pH levels.

If liming and gypsum dressing or summer pruning were effective in reducing susceptibility to bitter pit, the frequency of Ca spraying might be reduced. In most orchard trials the response to Ca soil dressing has been small (van der Boon, 1974; Fidler *et al.*, 1973) but, in new trials, Ca treatments were applied to orchards on sandy soils where generally the Ca status of leaves and fruit was low and the storage quality only moderate. Summer pruning has been shown to reduce the incidence of bitter pit (Bangerth and Link, 1972; Preston and Perring, 1974) in some trials, but Schumacher and Fankhauser (1972) failed to obtain any reduction in the disorder by this treatment. Fruit thinning to obtain commercial improvements in fruit size increased the risk of bitter pit (Sharples, 1964) and it is possible that such practices would result in an increased need for Ca spraying.

Early picking may lead to an increase in the occurrence of bitter pit but literature reviews (Fidler *et al.*, 1973; Delver, 1978) have shown that this effect is inconsistent and that in many instances no reduction was recorded in bitter pit incidence as picking was delayed. This aspect was re-examined as part of the present studies.

Although the experiments were mainly designed to study bitter pit, storage data on breakdown were also obtained and are presented in the results.

MATERIALS AND METHODS

Fruit thinning and summer pruning trial on cv Cox's Orange Pippin

This factorially designed trial was conducted in 1970 on Cox's Orange Pippin trees on M.4 rootstock growing on a river clay soil. It comprised 2^4 treatments, each replicated seven times with two trees per plot, in a split plot design as follows:

A. Pruning on 8-15 July in addition to winter pruning, compared with winter pruning alone. The summer pruning treatment included removing all water shoots and most of the current extension shoots, including those at the ends of fruit-bearing branches. Exhausted lateral branches with fruits were also removed.
B. Fruit thinned on 15-17 July to at least 15 cm apart, compared with no thinning. The treatment was somewhat more severe than is customary in commercial practice.
C. Spraying 17 times between 20 May and 17 September (i.e., from flowering until picking) with 0.75% $Ca(NO_3)$ solution, compared with no spraying.
D. Harvesting either early or late (10 or 23 September respectively).

Fruit thinning, delayed harvesting and soil dressing trial on cv James Grieve

This factorially designed trial was conducted in 1968 and 1969 on James Grieve trees on M.4 rootstock growing on a river clay soil. It comprised 2^5 treatments, each replicated three times with two trees per plot, in a split plot design as follows:

A. Fruit thinned on 24 and 28 June 1968 to a spacing distance of 15 cm, compared with no thinning.
B. Fruit thinned as in A on 30 June 1969, compared with no thinning.
C. Late soil dressing with $Ca\ (NO_3)_2$ (0.3 mol Ca m^{-2}) on 25 June 1968 and 30 April 1969 or no soil treatment.
D. Spraying with 0.75% $Ca\ (NO_3)_2$ solution five or six times in July and August, compared with no sprays.
E. Harvesting either early or late (22 August and 4 September in 1968 and 3 and 10 September in 1969).

Delayed harvesting

These trials were conducted in six or seven (depending on the year) different orchards of Cox's Orange Pippin in each of three years. The sites were located in different parts of the Netherlands and formed part of the survey experiment described in Part I. Fruits were harvested from the sample plots three times, viz. one week earlier than the estimated optimum, at the optimum date itself and one week later.

Calcium soil treatments

In 1970 four similar trials were laid out in orchards on sandy soils as randomized blocks with five treatments replicated three times. Each experimental plot comprised nine to twelve Cox's Orange Pippin trees on M.2 rootstock which were 7-12 years old at the start of the trials. Five treatments were included at each site as follows:

A. No calcium dressing.
B. $CaCO_3$ (38.7% Ca) applied to obtain the optimum pH-KCl at 0-20 cm. (This pH is specified by the Dutch Advisory Service as 5.8 and 5.5 for soil lower or higher than 4% in organic matter respectively).
C. Dressing with 1.5 times the amount of $CaCO_3$ required to obtain the optimum pH in B above.
D. As B with 1.86 mol Ca m^{-2} as gypsum.
E. As C with 1.86 mol Ca m^{-2} as gypsum.

In 1970 the Ca was applied to the soil in February and in the following years in December or early January. Two of the trials (1601 and 1602) were continued for five consecutive years, one (1600) for four years and a fourth (1603) for two years only.

The methods used for leaf and fruit sampling and analysis and for storing and assessing fruit quality have been described in Part I (van der Boon, 1980). The severity of pitting was assessed on a scale from 1-3 multiplied by the percentage of affected fruit to give a maximum index of 300.

Soil pH was determined in N KCl, K-HCl with 0.1N HCl plus oxalate to neutralize $CaCO_3$, and MgO-NaCl with 0.5 N NaCl, all in a soil: solution ratio of 1:10. Water-soluble Ca was determined following extraction in a soil:water ratio of 1:3.33, while exchangeable Ca was estimated by percolating the soils with N NaCl.

RESULTS

Summer pruning

Pruning during the summer resulted in smaller fruit at harvest and lower yields (Table I). Although bitter pit incidence was very low, it was reduced significantly ($P<0.05$) by the pruning treatment. A slight reduction in breakdown was also recorded, significant in the larger fruits (diameter >70 mm). Intensive spraying with $Ca(NO_3)_2$ from flowering onwards enhanced the shedding of young fruit and led to a lower yield at harvest (Table I) but, in spite of the resulting lower fruit/leaf ratio, the incidences of bitter pit and breakdown decreased significantly

TABLE I
Effects of summer pruning and $Ca(NO_3)_2$ sprays on crop yield, leaf and fruit mineral composition and external quality of the fruit after storage, cv Cox's Orange Pippin 1970

	Pruned in winter only		Pruned in summer & winter		Significance‡	
	Control	Sprayed	Control	Sprayed	Pruning	Spraying
Yield (kg/tree)	45.5	38.8	39.3	34.9	**	***
Healthy fruit (%)† 70-75 mm fruit	55.8	91.3	69.4	92.7	*	***
Bitter pit (%)	1.7	0	0.6	0	*	***
Breakdown (%) 70-75 mm fruit	38.9	5.8	30.1	4.3	*	***
Leaf Ca (% dry wt)	1.44	2.21	1.71	2.41	**	***
Fruit Ca (mg/100 g dry wt) 75-80 mm fruit	22.3	34.6	22.9	39.3	n.s.	***
Fruit (K + Mg)/Ca (eq/eq) 75-80 mm fruit	19.7	13.3	20.0	12.1	n.s.	***

†Healthy = Percentage of fruit free from external symptoms of disorders or rots.
‡Main effect of treatments significant at $P<0.05$*, 0.01**, 0.001***

TABLE II
Effects of fruit thinning and spraying with $Ca(NO_3)_2$ on crop yield, fruit mineral composition and external fruit quality after storage, cv Cox's Orange Pippin 1970

	Unthinned		Thinned		Significance†	
	Control	Sprayed	Control	Sprayed	Pruning	Spraying
Yield (kg/tree)	49.5	42.3	35.3	31.4	***	***
Healthy fruit (%)	70.2	94.2	59.0	86.9	***	***
Bitter pit (%)	1.3	0	1.1	0	n.s.	***
Breakdown (%)	24.7	2.8	35.5	9.6	*	*
Fruit (K + Mg)/Ca (eq/eq) 70-75 mm fruit	17.7	11.7	21.2	12.2	n.s.	n.s.

†Main treatment effects significant at $P<0.05$* or 0.001***

($P<0.001$). The beneficial effects of spraying were distinctly greater than those of summer pruning. The percentage of healthy fruits with diameters >70 mm was increased by pruning but the effect was confined to fruit from the unsprayed trees (interaction significant at $P<0.05$); spraying markedly increased the Ca contents of both fruits and leaves.

Summer pruning led to an early increase in the Ca content of the lower leaves of the extension shoots and these differences persisted until the end of August (Table I); the Ca concentration was also increased in the fruit. At harvest, the Ca content of the larger fruit from summer-pruned trees was significantly greater than that of similar sized apples from unpruned trees only where $Ca(NO_3)_2$ had been applied (interaction significant at $P<0.05$).

Fruit thinning

The fruit thinning treatments, which were more intensive than those normally used in commercial practice, decreased yield by 27% for Cox in 1970 (Table II) and by 17% and 12% for James Grieve in 1968 and 1969 respectively (Table III). In the trial on Cox, fruit numbers were reduced from an average of 432 to 292 per tree and mean fruit weight was raised from 106 g to 114 g at harvest. Fruit thinning caused an increase in breakdown incidence in Cox (Table II), especially in the large fruit-size grades (diameter >70 mm) but had no effect on the very low incidence of bitter pit in spite of the marked increase in fruit size. The beneficial effects of spraying in reducing breakdown incidence were much greater than the increases caused by thinning.

In the trial on James Grieve (Table III) the average number of fruit per tree was reduced by thinning from 378 to 301 (1968) and 209 to 168 (1969) while mean fruit weight increased from 133 g to 138 g (1968) and 118 g to 129 g (1969). Yield reduction, to be expected after thinning, was partly compensated for by a larger proportion of fruit in the higher size grades. Spraying with $Ca(NO_3)_2$ reduced bitter pit slightly in 1968 and again in 1969. Thinning increased the severity index for bitter pit in the large size grades in 1968 on the unsprayed plots only (interaction significant at $P<0.01$).

James Grieve trees which had been thinned in

TABLE III
Effects of fruit thinning in same year and spraying with $Ca(NO_3)_2$ on crop yield, fruit mineral composition and fruit quality after storage, cv James Grieve

Year		Unthinned		Thinned		Significance†	
		Control	Sprayed	Control	Sprayed	Pruning	Spraying
Yield (kg/tree)	1968	44.8	55.8	40.2	43.1	*	n.s.
	1969	46.0	52.7	42.3	44.1	*	n.s.
Bitter pit (index) (max 300) 70-75 mm fruit	1968	41	45	65	44	**	*
Bitter pit (%)	1969	32.5	24.9	35.1	29.2	n.s.	**
Breakdown (%) 70-75 mm fruit	1968	39.3	37.3	42.4	37.3	n.s.	n.s.
Internal breakdown (%) 75-80 mm fruit	1969	26.8	14.2	25.4	23.3	n.s.	n.s.
Fruit (K+Mg)/Ca (eq/eq) 70-75 mm	1968	17.3	16.3	17.1	17.0	n.s.	n.s.
75-80 mm	1969	22.6	21.4	21.6	22.4	n.s.	n.s.

†Main treatment effects significant at $P<0.05$* or 0.01**

1968 produced a higher yield in 1969 than those which had not been thinned in the previous year. The higher yield was due to a greater number of fruits which were slightly less prone to bitter pit and breakdown (data not presented).

Although thinning led to slightly lower Ca concentrations and higher (K+Mg)/Ca ratios in Cox fruit at harvest no consistent effect was found in the trials on James Grieve and none of these differences reached statistical significance at $P<0.05$.

Picking time

The effects of time of harvesting on the average incidence of bitter pit in Cox apples from six or seven (depending on the year) commercial orchards between 1970 and 1972 are shown in Table IV. It is evident that wastage generally decreased as picking was delayed, due mainly to a progressively lower incidence of bitter pit in the fruit after storage ($P<0.001$). No clear differences in fruit mineral composition were recorded over the two-week period between early and late picking.

No marked reductions were recorded in the incidence of bitter pit in late-picked apples from the fruit thinning trials on Cox (1970) and James Grieve (1968 and 1969) and there were no interactions between picking time and the other treatments in any of these trials.

TABLE IV
Average storage quality of cv Cox's Orange Pippin apples picked at three different times

Picking date	Healthy fruit (%)			Bitter pit (%)		
	1970	1971	1972	1970	1971	1972
Early	75.8	77.9	93.8	20.0	20.4	4.3
Normal	81.4	84.8	96.1	13.8	11.9	2.5
Late	81.6	90.5	95.9	13.3	5.8	1.5

Calcium soil treatments

No responses were observed to late soil applications of $Ca(NO_3)_2$ made in two successive seasons in the James Grieve orchard on river clay.

In the trials on Cox, where the sandy soil was limed with $CaCO_3$, Ca penetrated only slowly into the non-cultivated strip under the tree (e.g. see data for Experiment 1601, Table V) and it was not until the third year that a slight increase in the average Ca concentration was recorded in the leaves sampled from each of the four trials (Table VI). Once established, however, these slight differences were maintained in both 1973 and 1974. The higher rate of application of lime had no further effect on soil or leaf composition. Although leaf K levels were not affected, $CaCO_3$ depressed average leaf Mg levels in the later years of the trials.

When gypsum was applied in addition to lime, the water-soluble Ca content of the soil increased even in the deeper layers (5-20 cm, Table V). In the deeper layers exchangeable Ca levels were not always increased. The levels of Mg available to the plant (MgO-NaCl-extract) were decreased by gypsum to an undesirably low level. Gypsum applications also depressed average leaf Mg and raised leaf Ca even within the first year of the trials. There was no significant decrease in K levels in the soil and although the mean (K+Mg)/Ca ratio in the leaf fell somewhat it did not reach the value required for freedom from bitter pit (see Part I).

TABLE V

The effects of three successive annual dressings of limestone ($CaCO_3$) and gypsum ($CaSO_4$) on soil pH and the contents of Ca and Mg in the 5-20 cm layer of a sandy soil in an orchard of cv Cox's Orange Pippin (Data from experiment 1601 in 1973).

Treatments (see Methods for details)	A Control	B Liming to optimum pH	C Extra lime	D B+gypsum	E C+gypsum
pH–KCl	4.4	4.6	4.8	4.6	4.7
Exchangeable Ca ($g/10^6$ g dry soil)	30	37	37	25	25
Water soluble Ca (g/m^3 extract)	31	37	33	100	81
MgO—NaCl ($g/10^6$ g dry soil)	73	34	40	21	25

TABLE VI

Effects of limestone ($CaCO_3$) and gypsum ($CaSO_4$) on average concentrations of Ca and ratios of (K + Mg)/Ca in apple leaves of cv Cox's Orange Pippin from four orchards on sandy soils 1970-74

Treatment (see Methods for details)		Leaf composition						
		A Control	B Liming to optimum pH	C Extra liming	D B+ gypsum	E C+ gypsum	No. of times† when main treatment effects were significant ($P<0.05$)	
							Ca supply v. control	Gypsum+lime v. lime
Ca concentration (% dry wt)	1970 (4)†	1.26	1.17	1.27	1.30	1.33	1	2
	1971 (4)	1.37	1.34	1.40	1.53	1.50	0	2
	1972 (3)	1.09	1.16	1.18	1.31	1.26	2	2
	1973 (3)	1.21	1.32	1.26	1.46	1.46	3	2
	1974 (2)	0.94	0.96	0.94	1.23	1.21	2	2
K+Mg)/Ca ratio (eq/eq)	1970 (4)†	0.91	0.95	0.90	0.88	0.86	0	1
	1971 (4)	0.83	0.84	0.80	0.74	0.74	1	3
	1972 (3)	0.95	0.89	0.89	0.80	0.81	3	2
	1973 (3)	0.98	0.86	0.88	0.76	0.76	3	2
	1974 (2)	1.41	1.32	1.34	1.02	1.02	2	2

†Figures in parentheses in left-hand column indicate numbers of trials (maximum 4) in any particular year

Fruit mineral composition was barely affected although the (K+Mg)/Ca ratio was again slightly reduced by the application of gypsum and lime.

The effects of the soil treatments on the incidence of bitter pit (Table VII) were much less than the differences due to site or season. The incidence of bitter pit decreased from 1971 onwards, the effects of gypsum being greater than those of lime alone. In one of the trials (1601) gypsum actually caused an increase in bitter pit in the first year, due probably to the release of K from the exchange complex (van der Boon *et al.*, 1968). In trial 1603, where the storage quality of the crop was generally good, no response to gypsum was obtained during the two years of treatment and some bitter pit still remained in fruits from the treated plots. In comparison with the control, statistically significant decreases in bitter pit were recorded for soil-applied Ca (lime and lime with gypsum) in six out of sixteen observations (sites×seasons), and in eight out of sixteen observations significantly greater improvements in the control of bitter pit were obtained from lime with gypsum than from lime alone. The higher rate of lime did not increase the effectiveness of bitter pit control.

Bitter pit was more prevalent in large apples even where gypsum had been applied. With regard to the variation in average bitter pit incidence between sites and seasons, the disorder appeared to be lower in high yielding orchards with smaller fruit and low cation ratios. Thus, in 1973 the correlation coefficients of treatment means for bitter pit were –0.46* with yield, 0.70** with size of fruit, 0.53* with leaf (K+Mg)/Ca ratio and 0.71** with the fruit (K+Mg)/Ca ratio.

The data in Figure 1, which are taken from the four soil Ca dressing trials, indicate that bitter pit levels are likely to exceed 10% if the (K+Mg)/Ca ratio of the 65-70 mm fruit at harvest exceeds 20 (eq/eq). Moreover, it is evident from Figure 2 that

TABLE VII

Effects of limestone ($CaCO_3$) and gypsum ($CaSO_4$) on average incidence of bitter pit in cv Cox's Orange Pippin fruit from four orchards on sandy soils, 1970-74

Treatment (see Methods for details)	Average bitter pit (%)					No. of trials *or* years when main treatment effects were significant ($P<0.05$)	
	A Control	B Liming to optimum pH	C Extra liming	D B+ gypsum	E C+ gypsum	Applied Ca *v.* control	Gypsum+lime *v.* lime
Year							
1970 (4)†	46.1	45.9	44.9	46.3	42.0	0	1
1971 (4)	20.4	19.0	15.5	9.1	9.8	2	2
1972 (3)	4.7	2.6	2.3	2.6	1.6	1	1
1973 (3)	16.8	13.7	15.0	10.6	6.9	1	2
1974 (2)	42.6	35.9	42.9	18.0	13.8	2	2
Trial No.							
1600 (4)‡	20.4	16.7	16.3	13.6	14.0	2	2
1601 (5)	26.7	21.4	23.1	20.8	17.2	3	3
1602 (5)	38.5	37.9	38.1	25.5	21.1	1	3
1603 (2)	4.4	8.5	4.0	5.6	6.0	0	0

†Figures in parentheses in left-hand column indicate numbers of trials (max. 4) in each particular year.
‡Figures in parentheses indicate number of years (max. 5) for which each trial was continued.

a fruit Ca content of 27 mg/100 g (dry matter) is required to ensure that bitter pit does not exceed 10% in stored Cox's Orange Pippin apples.

DISCUSSION

Spraying Cox with $Ca(NO_3)_2$ on 17 occasions during the growing season effectively eliminated bitter pit and reduced the incidence of breakdown. However, when James Grieve trees were sprayed only five or six times in July and August, this treatment was less effective than on Cox. The reduced number of sprays, the waxy skin (van

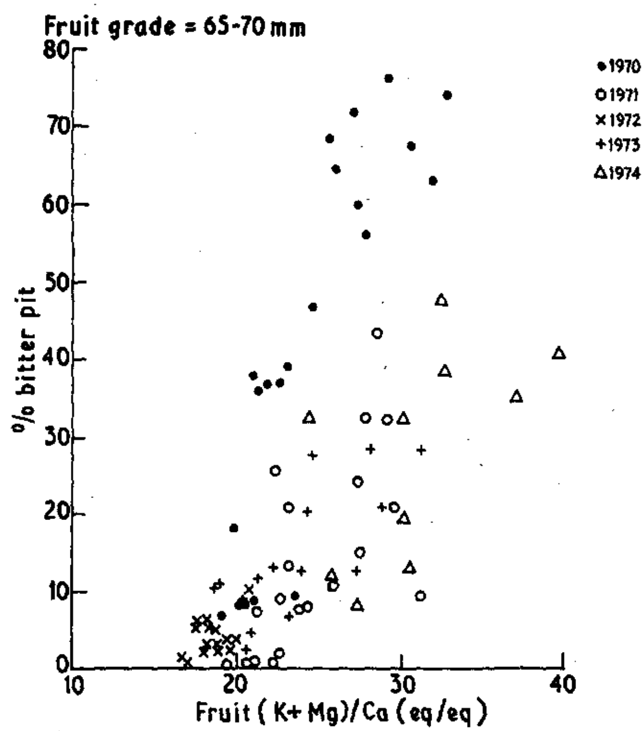

FIG. 1.

Relationship between bitter pit (%) after storage in air at 3-4°C until December or January and a further week at 18-20°C and the (K + Mg)/Ca ratio in the fruit at picking time. Points are treatment means from Ca soil dressing trials at four sites (1970, 1971), three sites (1972, 1973) and two sites (1974).

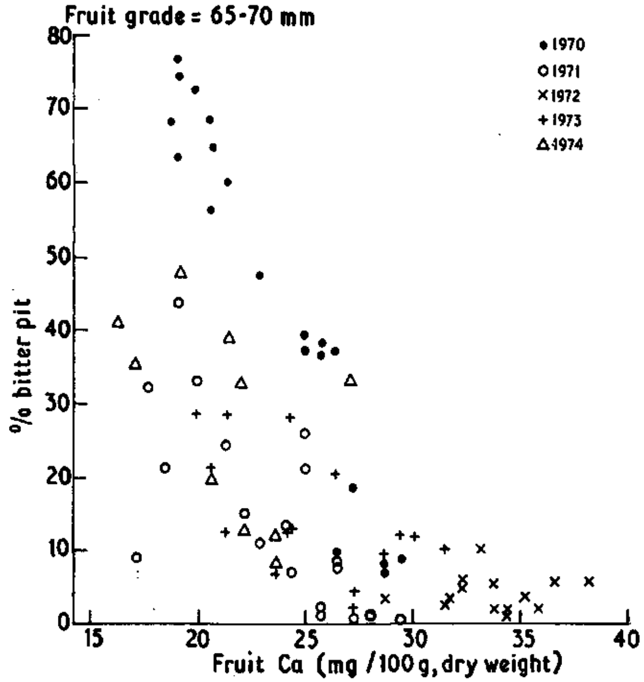

FIG. 2

Relationship between bitter pit (%) after storage in air at 3-4°C until December or January and a further week at 18-20°C and the Ca level of the fruit at picking time. Points are treatment means from Ca soil dressing trials at four sites (1970, 1971), three sites (1972, 1973) and two sites (1974).

Goor, 1973) and the very high susceptibility of this cultivar to the disorders would undoubtedly explain the relatively poor response which was obtained from Ca sprays on James Grieve.

These studies were undertaken to establish whether, in such situations, control of bitter pit can be improved by attention to other factors which influence the development of this disorder in apples (van der Boon, 1980). The higher fruit/leaf ratio which is obtained by summer pruning decreases the supply of assimilates from the leaf to the fruit *via* the phloem sap. This is low in Ca (Wiersum, 1966) and, as the fruit received more Ca *via* the xylem, it accumulates a higher concentration of Ca and becomes more resistant to both bitter pit and breakdown. In these experiments, however, the response to summer pruning was relatively small. It is possible that the conflicting reports in the literature are due to the omission of winter pruning in some trials. Where, as here, winter pruning is also carried out, vegetative growth is stimulated which can be only partly controlled by summer pruning. Summer pruning alone repeated over several years tends to reduce tree vigour and this will itself produce a higher fruit/leaf ratio.

Schmitz and Engel (1973) found that summer pruning only improved fruit quality when it was used in combination with $Ca(NO_3)_2$ sprays. In this work the Ca concentration of the fruit was increased by pruning later in the season, particularly in apples from trees which had also been sprayed (Table I). This probably reflects the greater efficiency with which sprays reach fruit when the leaf canopy has been reduced by the removal of a large proportion of the current season's extension growth.

Fruit thinning to improve the proportion of apples in larger size grades lowers the fruit/leaf ratio and thereby increases the risk of bitter pit. In the trials reported here, however, thinning to an extent only slightly more severe than that adopted in commercial practice resulted in a negligible increase in the disorder. Bangerth and Link (1972) considered that bitter pit was likely to be increased only by severe thinning carried out early. It is probable that, by the time these late thinning treatments were applied, a large proportion of the required Ca had already reached the fruit.

In general, some reduction in bitter pit incidence was obtained by delayed picking and it is evident that, in years when the risk of this disorder is high, later picking can provide an added measure of control of bitter pit under Dutch conditions.

Since the Ca level of the fruit is largely determined by uptake during the first six weeks after blossom (Chiu and Bould, 1977), it would seem vital that adequate supplies of Ca should be available to the tree in the spring. Moreover, the availability of Ca late in the season is also important since the element is then stored in the lower parts of the plant and re-utilized by the developing fruit in the following year (Wieneke and Führ, 1975). There is therefore a requirement for an adequate, continuous supply of Ca from the soil to overcome the low mobility of the element in the plant (Marschner, 1974). However, although the Ca content of fruit can be directly influenced by Ca dressings in sand culture (Mason and McDouglas, 1974), responses in orchards are generally poor (van der Boon, 1974) and, although in these trials on sandy soils a decrease in bitter pit incidence was observed from the second season onwards, the measure of control was insufficient even with gypsum. Furthermore, gypsum depressed the level of available Mg in the soil to an extent where Mg-deficiency symptoms were recorded in the leaves of trees at two of the sites.

The addition of lime and gypsum had no effect on soil K levels. Similar results were obtained in an earlier experiment (van der Boon, 1978) on marine clay where an undesirably high level of soil K could not be reduced by dressings of these two materials.

The threshold values for fruit (K+Mg)/Ca (Figure 1) and fruit Ca (Figure 2) derived from the soil dressing trials are somewhat higher and lower respectively than those proposed by van der Boon (1980). As in the sample plots (see Part I), bitter pit was much less prevalent after the cool summer of 1972. However, in contrast to the data reported in Part I, in 1972 the reduced incidence of bitter pit could be partly attributed to a more favourable fruit mineral composition. It was found that the slopes of the regression lines relating the percentage of bitter pit to either fruit Ca concentration or the (K + Mg)/Ca ratio differed for each of the four experimental years. Consequently it is impossible to predict the probable incidence of bitter pit accurately from these indexes although, in practice, these may still be very useful for indicating the general level of risk. Furthermore, even after raising fruit Ca levels with soil dressings of gypsum, prediction still remained only approximate because fruit Ca concentrations which are adequate to ensure complete freedom from bitter pit are so rarely attained in apples grown on the sandy soils of Holland.

REFERENCES

BANGERTH, F. and LINK, H. (1972) Möglichkeiten der Entstehung und Bekämpfung von Stippigkeit und Lentizellflecken II. *Erwerbsobstbau,* **14,** 138-40.

BOON, J. VAN DER (1974). Influence of nutrition on bitter pit in apples. *Acta Horticulturae,* No. 45, 9-16.

BOON, J. VAN DER (1978). Het tegengaan van kali-overmaat in de boomstrook van boomgaarden. *Instituut voor Bodemvruchtbaarheid, Rapport,* 5-77.

BOON, J. VAN DER (1980). Prediction and control of bitter pit in apples. I. Prediction based on mineral leaf composition, cropping levels and summer temperatures. *Journal of Horticultural Science,* **55,** 307-12.

BOON, J. VAN DER, DAS, A. and SCHREVEN, A. C. (1968). Control of bitter pit and breakdown by calcium in the apples Cox's Orange Pippin and Jonathan. *Agricultural Research Report,* **711,** Centre for Agricultural Publishing and Documentation, Wageningen.

CHIU, T. T. and BOULD, C. (1977). Sand-culture studies on the calcium nutrition of young apple trees with particular reference to bitter pit. *Journal of Horticultural Science,* **52,** 19-28.

DELVER, P. (1978). Stip in appels. *Mededelingen van het Proefestation voor de Fruitteelt, Wilhelminadorp,* No. 17.

FIDLER, J. C., WILKINSON, B. G., EDNEY, K. L. and SHARPLES, R. O. (1973). *The biology of apple and pear storage.* Commonwealth Agricultural Bureaux, Farnham Royal, Slough, UK.

GOOR, B. J. VAN (1973). Penetration of surface-applied ^{45}Ca into apple fruit. *Journal of Horticultural Science*, **48**, 261-70.

MARSCHNER, H. (1974). Calcium nutrition of higher plants. *Netherlands Journal of Agricultural Science*, **22**, 275-82.

MASON, J. L. and MCDOUGLAS, J. M. (1974). Influence of calcium concentration in nutrient solutions on breakdown and nutrient uptake in 'Spartan' apple. *Journal of the American Society for Horticultural Science*, **99**, 318-21.

PRESTON, A. P. and PERRING, M. A. (1974). The effect of summer pruning and nitrogen on growth, cropping and storage quality of Cox's Orange Pippin apple. *Journal of Horticultural Science*, **49**, 77-83.

SCHMITZ, K. J. and ENGEL, G. (1973). Untersuchungen und Beobachtungen zur Stippigkeit. *Erwerbsobstbau*, **15**, 9-14.

SCHUMACHER, R. and FANKHAUSER, F. (1972). Beeinflussung der Stippigkeit durch Sommerschnitz und Wachstumregulatoren bei der Sorte Gravensteiner. *Schweizerische Zeitschrift für Obst- und Weinbau*, **108**, 243-51.

SHARPLES, R. O. (1964). The effect of fruit thinning on the development of Cox's Orange Pippin in relation to the incidence of storage disorders. *Journal of Horticultural Science*, **39**, 224-35.

WIENEKE, J. and FÜHR, F. (1975). Untersuchungen zur Translokation von ^{45}Ca im Apfelbaum. IV. Sekundäre Ca-Verlagerung nach der Ruheperiode. *Gartenbauwissenschaft*, **40**, 105-12.

WIERSUM, L. K. (1966). Calcium content of fruits and storage tissues in relation to the mode of water supply. *Acta Botanica Neerlandica*, **15**, 406-18.

(Accepted 7 February 1980)