Journal of Horticultural Science (1980) 55 (3) 307–312

Prediction and control of bitter pit in apples. I. Prediction based on mineral leaf composition, cropping levels and summer temperatures

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

SUMMARY

Early prediction of the probable incidence of bitter pit is required to enable growers to identify, at harvest time, fruit with a high risk of the disorder so that it may be excluded from long-term storage. Data were collected over four years from 28 orchards to investigate the factors related to its incidence. The mineral composition of leaves sampled in August was unsuitable for forecasting bitter pit, unless the fruit/leaf ratio of the tree and regularity of cropping between trees were also taken into consideration. Bitter pit in stored apples increased with the (K+Mg)/Ca ratio in leaf and fruit, and decreased with a higher fruit/leaf ratio and more regular cropping. Clear differences in the incidence of bitter pit were recorded between years, even where cation ratios and yield levels were comparable. Part of these differences could be attributed to the unfavourable effect of high temperatures in August. However, factor analysis from trials over a 15-year period failed to show any marked association between bitter pit and the weather during August and September.

MANY factors appear to influence the incidence of bitter pit in apples. Among them, the Ca concentration in the fruit and the fruit/leaf ratio have both been shown to be important. A low fruit Ca level is associated with the occurrence of bitter pit and other physiological disorders. However, since high K and Mg supplies also promote bitter pit, either directly or indirectly by lowering the fruit Ca level, the incidence of bitter pit can be predicted more reliably from the K/Ca, Mg/Ca or (K+Mg)/Ca ratios (van der Boon *et al.*, 1968). It is also generally found that the fruits from lightly cropping trees are usually larger and more susceptible to bitter pit than fruits from heavily cropping trees. The Ca content of the fruit is also less since the supply of phloem sap (which has a generally low Ca content) to the fruit predominates over that of the xylem sap in trees with a relatively low fruit/leaf ratio (Wiersum, 1966). Weather conditions may also influence bitter pit occurrence and Delver (1977) has suggested that warm summer weather leads to increased susceptibility by promoting the fruit growth rate even in apples on heavily cropping trees.

An early and reliable prediction of the probable incidence of bitter pit would give the grower time prior to harvest to allocate the crop either for short- or long-term storage. This study was intended to determine the factors which influence bitter pit incidence and to quantify their effects. Attention has been paid to the possible relationships between leaf composition and the disorder and also to seasonal effects associated with weather conditions. The relationship between time of harvest and storage quality was also investigated and is reported in Part II. Internal breakdown in the stored apples was also recorded but no detailed data of this disorder are given here since the general relationships between this disorder and the composition of leaves and fruits were similar to those described below for bitter pit.

MATERIALS AND METHODS

Two separate bodies of data have been analysed. The first set of results was obtained from a four-year survey carried out between 1969 and 1972 on 28 cv Cox's Orange Pippin orchards. Each sample plot comprised 20 trees. The soil of the orchards differed widely and included slightly acid sandy soils, light and heavy marine clay soils with free $CaCO_3$ and river clay soils with and without $CaCO_3$. During the growing season shoot growth vigour, leaf health, fruit set, fruit/leaf ratio (i.e., cropping level in relation to leaf number) and uniformity of cropping (i.e., variations in yield between trees in the same plot) were assessed visually on 0—5-point scales for each of the sample plots. Leaf samples were taken on three to five occasions during the growing season, and samples of the fruit were taken at harvest time. The concentrations of Ca, K and Mg were determined by the methods described by van Goor (1971). Mean fruit weight per tree was assessed on the tree, and later also recorded at harvest when 100 kg apples were taken from each orchard for storage in air at 3°-4°C until maximum bitter pit had developed. After storage the apples were ripened for a week at 18°-20°C before grading into six size categories. The fruits in each size grade were then inspected for external symptoms of bitter pit, breakdown and rotting. A restricted number of fruits of good external quality ('healthy') were cut and assessed for internal disorders.

The second set of data, which was used for a more extensive study of the influence of weather on the incidence of bitter pit, was obtained from all the trials concerned with the use of Ca $(NO_3)_2$ sprays for the control of bitter pit which had been conducted between 1961 and 1975. The data, which were from both treated and untreated plots, included soil analysis, Ca, K and Mg concentrations in leaves in mid-August and fruit at harvest, crop yield, fruit size and storage quality assessed as described above. Climatic data, taken from the nearest meteorological station to each of the experimental plots, included summer rainfall, mean daily temperature and the maximum and minimum temperatures in the three 10-day successive periods of August and the first two 10-day periods of September. Relationships were examined by calculating correlation coefficients and by factor analysis using the centroid method followed by varimax rotation (Harman, 1967).

Leaf samples consisted of the third and fourth leaves from the bases of the annual shoots. Fruits were analysed whole after washing with demineralized water and removing the fruit stalk and seeds. The results of fruit analysis were expressed on both dry and fresh weight bases. However, no differences were found in the simple correlation coefficients between bitter pit and fruit composition, which were similar regardless of the basis on which they were expressed and, in this paper, the data are derived from results expressed on a dry weight basis.

RESULTS

Seasonal effects

In all four seasons large apples developed more bitter pit and breakdown than the smaller ones; this effect was most marked in years when the disorder was prevalent (Table I). Season to season variations in the incidence of bitter pit were considerable and significant. (P=0.05 and less between pairs of years). However, a relatively high mean incidence of bitter pit in a certain year (e.g., 1971) was not always accompanied by increased susceptibility to breakdown in the same year.

The least wastage occurred in 1972 when the fruits were smallest, but it was also noted that in that year the mean daily temperature in August was the lowest for the four years. A general relationship was evident (Figure 1) between the percentage of bitter pit in fruits from the sample plots and the average daily maximum temperature in August. A similar relationship was established when the incidence of bitter pit in apples of the same size grade was plotted against the average daily maximum temperature, indicating that part of the effect was independent of seasonal differences in fruit size.

Composition of leaves and fruits

Calculating the correlation coefficients of the

TABLE I
Mean fruit weight at harvest and incidence of storage disorders in cv Cox's Orange Pippin apples from the same 19 orchards in each of four years.

Year	Mean fruit weight (g)	Healthy apples (%)	Bitter pit (%)		Breakdown (%)
			External	Internal	External
1969	127	81.9	4.3	4.4	10.3
1970	138	79.2	14.6	6.7	10.0
1971	121	90.2	6.3	7.0	2.9
1972	107	95.7	1.4	1.5	2.0

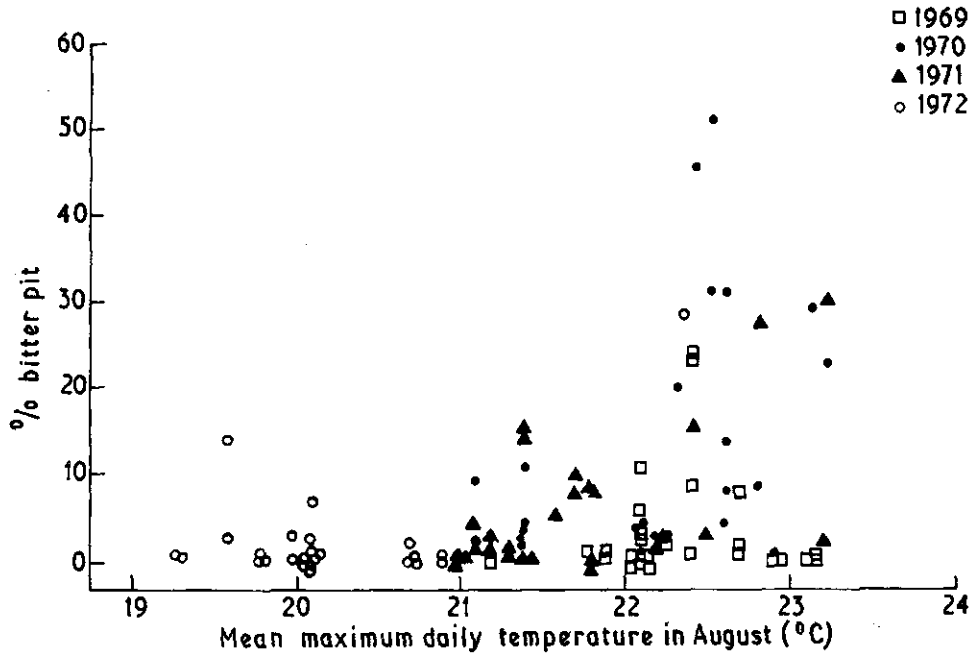

FIG. 1.
Relationship between bitter pit (%) and mean maximum daily temperature in August in 26-28 orchards during a 4-year period.

28 sets of data (Table II) showed that the mineral composition of the fruit at harvest was a better indicator of fruit quality than that of the leaves sampled early or late. Moreover, the correlation coefficient between leaf composition and bitter pit was progressively lower as leaf sampling was brought forward in August. The highest correlation coefficient was obtained for the (K+Mg)/Ca ratio in the fruit at harvest, followed by the same ratio in the leaf, also at harvest time. The Ca level in the fruit was more clearly related to the incidence of bitter pit than the K level. In con-

TABLE II
Simple correlation coefficients between incidence of bitter pit (1969–72) in cv Cox's Orange Pippin apples and the mineral composition (% dry weight) of the leaves and fruit.

Mineral composition	Correlation coefficients				
	External pit				Internal pit
	1969	1970	1971	1972	1972
Fruit at harvest					
Ca	−0.41*	−0.66***	−0.64***	−0.34	−0.57**
K	0.12	0.27	0.42*	0.20	0.09
(K+Mg)/Ca (eq/eq)	0.60***	0.75***	0.72***	0.35	0.58**
Leaf (early August)					
Ca	−0.49**	−0.28	0.07	−0.07	−0.15
K	0.14	0.30	0.52**	−0.01	−0.09
(K+Mg)/Ca (eq/eq)	0.49**	0.44*	0.42*	−0.08	0.05
Leaf (late August)					
Ca	−0.40*	−0.53**	−0.26	−0.02	−0.23
K	0.36	0.44*	0.62***	0.08	0.02
(K+Mg)/Ca (eq/eq)	0.49**	0.60***	0.57**	−0.06	0.17
Leaf (harvest)					
Ca	−0.46*	−0.43*	−0.19	0.04	−0.17
K	0.48**	0.55**	0.61***	0.10	0.02
(K+Mg)/Ca (eq/eq)	0.57**	0.63***	0.61***	−0.09	0.13

Correlations significant at $P<0.05$*, $P<0.01$** and $P\leq 0.001$***

trast, in the leaf data, K was more frequently a better indicator than Ca. In 1972, when external pitting was generally low, no relationship was found between external bitter pit and leaf or fruit composition. Internal bitter pit symptoms were somewhat more closely related but the correlation only reached significance for fruit Ca and the (K+Mg)/Ca ratio.

Fruit/leaf ratio

The fruit/leaf ratio was more closely related to bitter pit incidence than was the yield per tree, and also bitter pit was more severe in fruit from orchards made up of trees bearing variable crop loads (Table III). No doubt this latter effect occurs because light and moderately bearing trees produce apples which are considerably more susceptible to bitter pit. Other tree factors did not show a clear relationship with bitter pit occurrence.

Predicting bitter pit incidence

Regression equations obtained from data from the survey of 28 orchards were extrapolated to find the threshold values at which no bitter pit would occur. The (K+Mg)/Ca ratio in the fruit showed the closest agreement in the four years with a value between 10.5 and 12.5 (eq/eq). The threshold Ca level in the fruit was between 42 and 54 mg/100 g (dry matter). However, the slope of the fitted regression line between percentage bitter pit and the nutrient element content or (K+Mg)/Ca ratio in the leaf or fruit differed from year to year, even when a correction was applied for cropping level.

The raw data for the sample plots were also subjected to multivariate analysis. Multiple correlation coefficients (Table IV) were obtained by including the fruit/leaf ratio and the index for regularity in fruit cropping as independent variables with the leaf and fruit composition data. The correlation coefficients for leaf composition were almost as high as those for fruit composition when the two tree factors were included in the analysis. In particular, this treatment of the data markedly improved the relationship between leaf composition in early August and the incidence of bitter pit after storage. In 1972 internal bitter pit incidence also showed fairly high multiple correlation coefficients with leaf and fruit composition, but those for external bitter pit were low and are therefore excluded from Table IV.

Correlation coefficients were also calculated for the data from experiments on the control of bitter pit conducted between 1961 and 1975. A clear correlation was found between storage quality and the mineral composition of the fruit (correlation coefficient between percentage healthy fruit and fruit Ca concentration=0.57***). The unfavourable influence of high temperature in summer was less distinct (correlation coefficient between percentage healthy fruit and the daylight temperature in August=−0.35***). When the data were also subjected to factor analysis with varimax rotation, the factor with the highest sum of squared loadings showed high loadings for percentage healthy fruit, bitter pit and breakdown, fruit Ca and fruit (K+Mg)/Ca; this result agrees with the findings of Martin *et al.* (1975). However, no factor was found which included distinct loadings for weather variables as well as for storage quality attributes.

DISCUSSION

Analysis of four years' data from the sample

TABLE III
Correlation coefficients between cropping factors and bitter pit (%).

Cropping factor	Correlation coefficients				
	External pit				Internal pit
	1969	1970	1971	1972	1972
Yield per tree (kg)	−0.29	−0.36	−0.30	−0.07	−0.25
Fruit/leaf ratio†	—	−0.58**	−0.44*	−0.14	−0.36
Uniformity of cropping index‡	—	−0.55**	−0.63***	−0.23	−0.49**

† Fruit/leaf ratio was assessed visually in the orchard on a 1–5 scale. 1 = very low yield with large numbers of leaves per fruit, 5 = too heavy a yield with few leaves per fruit
‡ Uniformity of cropping between different trees was assessed visually on a 1–5 scale. 1 = irregular cropping of the 20 selected trees in the sample plot, 5 = uniform cropping of all trees
Correlations significant at $P<0.05$*, $P<0.01$** and $P<0.001$***

TABLE IV
Multiple correlation coefficients between bitter pit (%) and fruit/leaf ratio, uniformity of cropping and selected leaf and fruit nutrients (% dry matter)

Mineral composition	Multiple correlation coefficients			
	External pit			Internal pit
	1969	1970	1971	1972
Fruit at harvest				
Ca	0.48	0.81***	0.71***	0.62**
K	0.41	0.75***	0.71***	0.49
(K+Mg)/Ca (eq/eq)	0.69***	0.81***	0.77***	0.63**
Leaf (beginning of August)				
Ca	0.55*	0.75***	0.65**	0.50
K	0.48	0.75***	0.76***	—
(K+Mg)/Ca (eq/eq)	0.58*	0.76***	0.69**	0.49
Leaf (end of August)				
Ca	0.45	0.79***	0.65**	0.51
K	0.57*	0.76***	0.78***	—
(K+Mg)/Ca (eq/eq)	0.53*	0.80***	0.71***	0.49
Leaf (harvest)				
Ca	0.53*	0.75***	0.64**	0.52
K	0.59*	0.75***	0.80***	—
(K+Mg)/Ca (eq/eq)	0.62**	0.76***	0.75***	0.50

Multiple correlation coefficients significant at $P<0.05$*, $P<0.01$** and $P<0.001$***

plots in the survey and 15 years' data from the experimental trial orchards confirmed that the most reliable indicators of susceptibility to bitter pit are the (K+Mg)/Ca ratio and Ca concentration of the fruit at harvest. A threshold fruit (K+Mg)/Ca ratio of 12 (eq/eq) and a threshold fruit Ca content of 47 mg/100 g (dry matter) were established. The latter value is higher than that of 20 mg/100 g given by Shear (1972), but agrees more closely with the 5.5 mg/100 g fresh weight (equivalent to 40 mg/100 g dry matter) proposed by van Goor (1971) and Perring and Preston (1974).

Sampling leaves or fruits relatively early in the growing season is necessary if the analytical data are to be of value to the grower in taking remedial action and in organizing his storage programme. Fruit samples taken at harvest are therefore of limited value. Moreover, such samples are bulky and therefore inconvenient to handle in practical, advisory situations. There is at present insufficient knowledge of the value of analysis figures for fruit sampled early and, although Chiu and Bould (1977) did not consider the Ca level of the leaf to be a reliable index for the prediction of bitter pit, such a sample would appear to be more practicable. The results obtained here suggest that the (K+Mg)/Ca ratio of the leaf may be a better guide than leaf Ca alone and that, when combined with the fruit/leaf ratio and regularity of cropping, the leaf at the beginning of August may provide a good basis for forecasting the risk of this disorder.

In the sample plots, larger fruits were more susceptible than smaller ones and the fruit/leaf ratio was consistently related to bitter pit in the four years of the study. Assessing the fruit/leaf ratio may give a better guide to competition for Ca and water between leaves and fruit than yield of the tree alone.

Apples from lightly cropping trees showed high susceptibility to the disorder, and regularity in fruit bearing between the 20 selected trees in the orchard was also found to be a distinct factor in determining bitter pit susceptibility. By combining these cropping indexes with leaf composition data it is possible to account for as much of the variation in bitter pit incidence as by the fruit Ca concentration at harvest. Although the two tree factor indexes were only rough estimates, their influences were clearly established. However, improvement and standardization of the assessments will be necessary if these methods are to be utilized generally. The application of a modified method of Winter (1967) failed to provide a better relationship with the physiological disorders.

Both sets of experimental data indicated the relationship between bitter pit and the daily maximum temperature in August. However, the relationship was less marked than that with fruit composition and it is evident that more information on the mechanism by which weather conditions influence susceptibility will be necessary before this index can be used in practice.

It was noted that at high leaf (K+Mg)/Ca ratios, wide variation in bitter pit occurred between orchards and especially between years. For example, in 1972, which was a cool humid year in Holland, bitter pit was generally infrequent in Cox. Under similar weather conditions in 1972, bitter pit was rare in Baldwin apples grown in the north-east USA, even at leaf Ca levels which had been associated with severe bitter pit in the preceding year (Drake *et al.*, 1974). This suggests that drought itself can adversely affect Ca uptake by the fruit or even cause the withdrawal of Ca from it (van der Boon, 1973; Wilkinson, 1968), and that the unfavourable effect of warm summers may be due to excessive water tensions in the fruit caused by high rates of transpiration from the leaves. Under such conditions the cells at the end of the vascular bundles in the fruits may be damaged by the high water stress, especially where Ca concentrations are low, thereby predisposing cell membranes to excessive permeability (van Goor, 1971). This suggestion is supported by the results of Schumacher *et al.* (1976) who found that spraying trees with anti-transpirants diminished the occurrence of bitter pit.

REFERENCES

BOON, J. VAN DER (1973). Influence of K/Ca ratio and drought on physiological disorders in tomato. *Netherlands Journal of Agricultural Science,* **21,** 56-67.

BOON, J. VAN DER, DAS, A. and SCHREVEN, A. C. VAN (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. (1977). Stip en weersomstandigheden in Nederland 1949-76. *Instituut voor Bodemvruchtbaarheid Rapport* 16-77.

DRAKE, M., BRAMLAGE, W. J. and BAKER, J. H. (1974). Correlation of calcium content of 'Baldwin' apples with leaf calcium, tree yield and occurrences of physiological disorders and decay. *Journal of the American Society for Horticultural Science,* **99,** 379-80.

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

HARMAN, H. H. (1967). *Modern factor analysis.* University of Chicago Press, 2nd Ed.

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

PERRING, M. A. and PRESTON, A. P. (1974). The effect of orchard factors on the chemical composition of apples. III. Some effects of pruning and nitrogen application on Cox's Orange Pippin fruit. *Journal of Horticultural Science,* **49,** 85-93.

SCHUMACHER, R., FANKHAUSER, F. and STADLER, W. (1976). Versuche mit Calciumchlorid, Antitranspiranten und Borsäure zur Verminderung der Stippebildung. *Schweizerische Zeitschrift für Obst- und Weinbau,* **112,** 300-4.

SHEAR, C. B. (1972). Incidence of cork spot as related to calcium in the leaves and fruit of 'York Imperial' apples. *Journal of the American Society for Horticultural Science,* **97,** 61-4.

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.

WILKINSON, B. G. (1968). Mineral composition of apples. IX. Uptake of calcium by the fruit. *Journal of the Science of Food and Agriculture,* **19,** 646-7.

WINTER, F. (1967). Studie über methodische Untersuchungen zur Ertragsprognose bei Kernobst. Statistisches Amt der Europäische Gemeinschaft. *Agrarstatistik* St/2687/67-D.

(Accepted 7 Febuary 1980).