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COMPETITION IN APPLE, AS INFLUENCED BY ALAR SPRAYS, FRUITING, PRUNING AND TREE SPACING

met een samenvatting:

CONCURRENTIE BIJ APPEL, ONDER INVLOED VAN ALAR-BESPUITINGEN, VRUCHTDRACHT, SNOEI EN PLANTAFSTAND

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1. INTRODUCTION

Around 1930 fruit growing in the Netherlands and in neighbouring countries became a specialized branch of agriculture. Since then fruit growing has been subjected to drastic changes, probably unparalleled in the field of agriculture. Tree density in apple orchards rose from about 100 trees per ha in 1930 to 1000–3000 in 1970, mainly due to the change-over to dwarfing rootstocks. In consequence changes in the planting system were necessary. Thus the old-time standard trees in grass, planted on the square, gave way to the filler system of bush trees in quincunxial patterns and this system was superseded by row cropping of spindlebushes.

These revolutionary changes have made many an orchard obsolete before it even came into bearing and they imperil the continuity of fruit holdings. To reduce these hazards a better insight in the influence of density and planting system on orchard performance is essential.

This need is emphasized by the continuing increase in tree density, which has given rise to proposals for new planting systems, such as the double row system (BLAAS, 1959), the bed system (VERHEIJ and DE VRIES, 1966) and – far more extreme – the ultrahigh density orchard (BIBLE and RIES, unpublished results) and the 'meadow orchard' (HUDSON, 1971).

It seems useful to distinguish 3 levels in the study of orchard design:

1. the *biological level*, concerning the relationship of orchard growth and fruiting with density, planting pattern, tree age, etc;
2. the *management level*, dealing with the influence of orchard design on the performance of men and machines;
3. the *economic level*, concerning input-output relations and investments.

The present study deals primarily with the biological aspects of orchard design, more in particular with the relation between tree density and orchard growth and yield. It has been pointed out (HOLLIDAY, 1969; VERHEIJ, 1970a) that the study of competition in perennial crops and particularly in fruit crops at varying density is much more complicated than in annual crops. Experiments with these crops demand large areas and have to be continued for many years. Dry matter determinations for tree crops are cumbersome and, if destructive methods are used, plot size is reduced at every sampling occasion. Erratic yields make it difficult to estimate the partitioning of dry matter over fruit and other tree parts at varying density. Fruit quality, which is of vital importance, is a complex and ill-defined aspect of yield. Moreover, arbitrary growing techniques such as pruning and fruit thinning strongly affect competition and should therefore preferably be included in the experiments as variable factors. An added complication with fruit crops is the great difference between varieties, further increased by the wide range of rootstocks.

Considering these complications it is not surprising that there are no experiments adequate to resolve yield-density relations for tree fruits. From a review by BASKERVILLE (1962) it appears that even in forestry adequate long-term experiments covering a wide range of density are scarce. Numerous spacing experiments with both tropical and temperate fruit crops contribute little to our knowledge because the range of densities is too narrow, or because density effects are confounded with effects of rootstock, tree shape, planting pattern, etc. Moreover, the value of several well-designed trials is limited because data on growth are lacking, making it difficult to interpret the yield data.

These considerations imply that inter-tree competition cannot be separated from intra-tree competition. A succession of a few heavy or light crops and manipulation of yield and growth by fruit thinning and pruning may greatly influence the results of spacing trials with fruit trees.

To elucidate the effects of various levels of intra-tree competition on inter-tree competition in orchards, a spacing experiment with Golden Delicious IX and James Grieve 'Lired' VII was laid out in which fruiting and pruning were introduced as variable factors one year after planting. Deblossomed plots were compared with cropping plots. Pruned sub-plots were compared with unpruned controls. To further extend the range of levels of intra-tree competition, annual sprays with the growth retardant Alar – in comparison with unsprayed controls – were superimposed on the treatments in the main trial.

Growth and yield per tree were measured each year, root studies on sample trees were carried out in the autumn of 1968 and 1969. At the end of 1969 one block of the trial was grubbed to collect data on tree weight and foliation; these data served to estimate dry matter yield in 1969, making it possible to compare the growth of the deblossomed trees with growth plus yield of the fruiting trees.

In this paper the results over the establishment phase of the experimental orchard, covering the 4-year period from 1966 to 1969, are presented.

2. MATERIALS AND METHODS

2.1. Lay-out of the trial; description of treatments.

In the spring of 1965 a spacing trial covering an area of 1.25 ha was planted on the experimental farm of the Institute of Horticultural Engineering at Wageningen. The soil is a heavy-textured river loam of marginal quality for intensive fruit growing. To improve growing conditions a supplementary drainage system has been installed and there are facilities for sprinkler irrigation. The soil under the tree rows is treated with herbicides; the alleyways are grassed down. The varieties in the trial are Golden Delicious on M IX and James Grieve 'Lired' on M VII. Two-year-old trees with 3 or more well-developed laterals were planted. The trees were left unpruned after planting and the flowers were removed.

One of the 3 blocks of the trial is depicted in illustration 1, to show the arrangement of the trees and the treatments. 'Lired' VII serves as a pollinator; for this variety there are only half as many plots as for Delicious IX.

In addition to tree spacing, pruning, deblossoming and – for Delicious IX only – Alar sprays were included in the trial as experimental treatments. These treatments were introduced in 1966 – the second year from planting – and continued for four years.

A factorial design was chosen with deblossoming and Alar in the main plots and pruning in the sub-plots. Each sub-plot consists of 4 tree rows with a systematic series of 8 tree spacings in the rows. In view of the complexity of the trial, the treatments were not randomized. Deblossoming and Alar application, both involving spraying, were situated in more or less contagious areas to limit the risk of spray drift. Pruned plots in each block were alternated systematically with unpruned plots.

Trunk size of the trees after the first growing season was analysed to determine the most favourable formation of the blocks. Calculations of trunk growth over several years revealed considerable heterogeneity of the residual and the higher-order-interaction sums-of-squares. Presumably this is due to the lack of randomization of the treatments. Consequently no further statistical analysis of the results was attempted, except for the relations between measurements of tree growth, to be presented in section 3.8.

Spacing. Nelder (1962) has proposed designs for spacing experiments consisting of a grid of systematically changing plant positions as an alternative to randomized block designs. The latter have the advantage of providing, in Nelder's words, 'an unbiassed estimate of the variance of treatment effects, as well as giving unbiassed estimates of the mean'. The principal advantage of the systematic designs is that the proportion of guard plants is greatly reduced. Freeman (1964) has considered the use of systematic designs for spacing trials

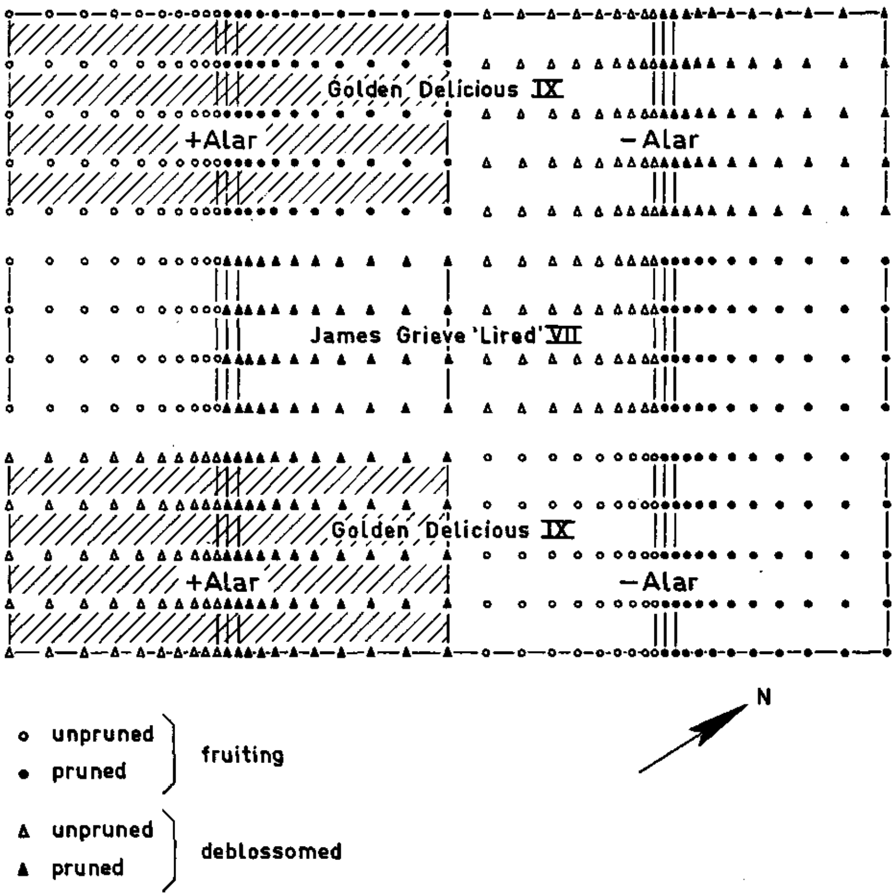

ILLUSTRATION 1. One block of the trial, showing the lay-out of the spacing sub-plots and the arrangement of the superimposed treatments. Trees linked by lines are guards.

with fruit crops in a paper describing such a trial with cocoa trees. Because of severe limitations to the number of trees per trial and far-reaching border effects in spacing experiments, there may be 2–4 guard trees for every experimental tree in a randomized block design. The systematic tree-to-tree variation in spacing in the trial described here, was adopted mainly because it resulted in one guard against 2 experimental trees, which is extremely favourable.

The range of intra-row spacings and the code denoting the 8 tree densities are indicated below:

320	276	236	200	168	140	116	96	80	cm
×	×	×	×	×	×	×	×	×	×
guard	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	guard

Inter-row spacing is 3.90 m. As shown above, density increases as intra-row spacing declines, from 860 trees per ha for the widest spacing (d_1) to 2915 trees per ha for the closest spacing (d_8). The rate of change of spacing is fairly high, in order to cover a sufficiently wide range of density with a limited number of trees. With increasing density the ratio inter: intra-row spacing increases. The high rate of change of intra-row spacing and the variation in planting pattern were accepted because the constant inter-row spacing greatly facilitates orchard management. For most calculations the series of 8 trees were divided into 4 groups of 2, giving mean densities of 925, 1275, 1820 and 2645 trees per ha.

Pruning. Pruned sub-plots were compared with unpruned controls. Pruning was carried out according to the prevailing concept of how trees at different spacings should be pruned to take advantage of the area available to them. Trees at wide spacings were shaped into spindles with 2 lateral leaders trained in the direction of the row; at closer spacing tree shape was gradually modified into a slender spindle with only light laterals. This pruning policy has the disadvantage that pruning effects are confounded with density effects. The alternative, however, – pruning trees at all spacings in exactly the same way – seemed unrealistic. The deblossomed trees were pruned to obtain the same tree shape and disposition of the branches as for the bearing trees. This required hard pruning due to the vigorous growth. Trees were not pruned in summer.

Deblossoming and fruit thinning. Completely deblossomed plots were compared with plots fruiting normally. In 1966 attempts to deblossom the trees with karathane and NAAM sprays failed. Therefore the trees were sprayed with carbaryl 0.3% to induce abscission of the fruitlets, while the remaining fruits were removed by hand in the second half of June. In 1967 and 1968 deblossoming was done by hand, but as the trees grew older this took too much time. In 1969 Na-DNOC in a concentration of 0.06% was applied twice with an interval of 8 days. This treatment was very effective; little additional manual labour was required. The sprays were not very damaging to the foliage, mainly because the deblossomed trees come into leaf very slowly, virtually all buds being flower buds.

Fruit thinning of bearing trees was essential to maintain tree growth. In order to limit the bias introduced by fruit thinning, it was attempted to retain the same numbers of fruit per unit leaf area at different spacings and for pruned and unpruned trees. It proved to be difficult to estimate leaf area visually, especially when comparing pruned and unpruned trees. As a result, the numbers of fruit per unit leaf area were generally higher on the unpruned trees.

Alar sprays. In recent years it has been demonstrated in numerous experiments that Alar (succinic acid 2.2. dimethyl hydrazide) can be used to check extension growth and to promote flowering and fruiting. Because of these effects on the competitive relations in the tree, Alar sprays were included in the trial. Plots sprayed annually with Alar were compared with untreated control plots. Alar was applied at 1750 ppm around June 1st, when the shoots had 4–6 leaves. Shoot growth was retarded in the deblossomed trees; in 1968 the difference was so prominent that the deblossomed trees were sprayed 9 days later than the fruit-bearing trees. In 1969 all Alar plots were sprayed on the same date, which was rather late for the fruit-bearing trees and rather early for the deblossomed trees.

Growing techniques. The trial is managed as a commercial orchard. The trees are tied to stakes; together with fruit thinning this has made it possible to maintain an acceptable tree shape for the unpruned trees. Fertilizers are spread uniformly over the orchard; 225 kg N is applied per ha annually. A mist blower is used to control pests and diseases. Canker necessitated some pruning of the 'unpruned' trees. During the first years some trees had to be replaced, but in total less than 3% of the trees had to be excluded in the calculations over the four-year experimental period. There has been no noticeable loss of fruit due to late frosts.

2.2. Records, measurements.

Annual measurements. Annual records per tree include: *trunk diameter*, measured 20 cm above the union in 2 directions at right angles, *tree height before and after pruning, weight of prunings, numbers and weight of fruit* at harvest. Data on trunk diameter were transformed into *trunk cross sectional area*, assuming a circular cross section. *Number and total length of shoots* longer than 10 cm were measured annually for trees at spacings d_2 and d_7.

Measurements of grubbed trees. Immediately after the 1969 harvest the experimental trees in one block were defoliated and all trees of this block (400 Delicious IX, 160 'Lired' VII) were grubbed. *Fresh weight of leaves* per tree and *fresh weight of the tree* (including a part of the root system) were determined. Together with the weight of the fruit these observations showed the distribution of fresh weight over the 3 major tree components. To estimate *dry matter yield in 1969* the dry matter content of samples of leaves and branches of Delicious IX was determined. Unfortunately, dry weight of the fruit was not measured; in consultation with dr. J. Tromp of the National Fruit Growing Research Station at Wilhelminadorp the dry matter content of the fruit was fixed at 16% for all treatments. During defoliation duplicated samples of 100 leaves were obtained from trees at the densities d_2, d_5 and d_8. These samples were weighed and subsequently leaf areas of the samples were determined by weighing punched discs of known area. *Weight and area per 100 leaves* for trees at the other densities were estimated by interpolation. These estimates were used to calculate *leaf area per tree* for all trees. Before grubbing, height and spread of the Golden Delicious trees were measured, in order to calculate *tree volume*.

Incidental measurements. Also in 1966, 1967 and 1968 samples of leaves were collected, but on a limited scale and only from the long shoots. *Area per 100 leaves* was determined; as the proportion of long shoots varied greatly for different treatments and in different years, the data do not permit conclusions in respect to the foliation of whole trees.

In 1967, 1968 and 1969 leaf analysis was carried out, using standard procedures.

In 1968 and 1969 root studies were conducted by Mr. J. LOETERS, soil scientist in the National Horticultural Advisory Service. *Root number and distribution* were recorded for sample trees at densities d_2 and d_7 in the various treatments. As there were indications that the growth rhythm of the trees varied with treatments, *forthnightly trunk girth increment* was measured for about 100 trees during the 1969 growing season. For this purpose aluminium measuring bands were fitted around the trunk as described by LIMING (1957); the bands were made according to specifications given by dr. J. GOODE of East Malling Research Station, England. At the end of 1969 the *total number of terminal buds,* on spurs as well as on long shoots, was recorded as a measure for the *complexity of the tree.* The diameter of the central leader at 1.20 m above the union was also measured; the ratio of cross sectional area at 1.20 and 0.20 m is used as a measure for the *slenderness of the trees.*

2.3. PRESENTATION OF RESULTS.

Because of the large number of variable factors and interactions, the relationships are considered from 2 aspects. In chapter 3 the results are grouped according to crop performance: tree habit, growth and yield per tree and per ha, etc. In this way a coherent picture of the crop can be build up. In chapter 4 on the other hand, the results are discussed according to experimental factors: Alar, fruiting, pruning, spacing. Since the various effects of each factor are dispersed through chapter 3, each section of chapter 4 commences with a brief resumé of these effects.

It should be added that the first and last sections of chapter 3 deviate from the pattern. The effects of Alar are singled out and considered first, in section 3.1, because they were relatively small; this made it convenient to present in the subsequent sections only the mean data for trees with and without Alar. In the last section of chapter 3, data on tree weight, foliation and shoot growth are related to trunk diameter, a common characteristic of tree size, to establish how close the relationships are and whether they are affected by the treatments or not.

Unless otherwise stated, the results refer to Golden Delicious IX, the principal variety in the trial. For James Grieve 'Lired' VII only the most important findings are presented.

3. RESULTS

3.1. Effects of Alar sprays.

The influence of Alar on mean length per shoot is shown in table 1. It appears that Alar generally reduces the mean length per shoot. The reduction is most prominent in the first year; in subsequent years Alar sprays are less effective, particularly on the deblossomed trees. The deblossomed trees from virtually only flower buds; shoot growth is delayed due to the absence of leaf buds. Perhaps the timing of the Alar sprays was not favourable for these deblossomed trees, but it is also possible that Alar is less effective on shoots that are already retarded. The effect of Alar does not seem to depend on tree spacing or on pruning, but the results shown in table 1 are more consistent for the pruned trees. The effect of the other factors on shoot length will be considered in section 3.2 on p. 9.

The reduction of shoot growth resulting from Alar sprays was reflected in slightly smaller trunk cross sectional areas, an effect that tended to accumulate over the years. It was more prominent in the fruiting trees. In the pruned trees the adverse effects of Alar on trunk growth have partly been compensated by lighter pruning; pruning weights were consistently lower for the treated trees than for the controls. Annual increment in tree height was reduced rather more by Alar than mean length per shoot, particularly for the pruned trees. This suggests that growth of the vigorous shoots in the top of pruned trees was retarded more than shoot growth in other parts of the tree.

Leaves of trees sprayed with Alar were smaller than leaves of control trees. Leaf weight per unit area also tended to be slightly reduced by Alar; the reduction in size and weight per unit area was strongest for the fruiting trees. Dry matter content of the leaves did not seem to be affected by Alar.

Table 1. Mean length per shoot in cm, for shoots longer than 10 cm.

Year	Spacing	Unpruned				Pruned			
		Deblossomed		Fruiting		Deblossomed		Fruiting	
		– Alar	+	– Alar	+	– Alar	+	– Alar	+
1966	$d_{1,2}$	21.0	16.5	18.8	15.2	26.6	24.3	23.2	21.6
	$d_{7,8}$	20.5	15.5	17.2	16.5	33.6	26.5	29.3	27.1
1967	d_2	22.1	22.5	21.2	17.9	30.0	24.9	27.1	22.1
	d_7	23.3	20.2	20.3	16.7	29.4	26.5	26.1	23.6
1968	d_2	21.5	20.4	22.2	16.3	28.0	27.6	24.8	21.4
	d_7	22.9	25.5	23.1	17.8	31.5	27.4	28.6	23.8
1969	d_2	17.5	18.3	19.9	18.3	23.5	22.1	23.9	24.5
	d_7	16.5	18.0	21.2	20.4	31.4	30.0	34.9	25.3

TABLE 2 Number of fruit per tree and (mean weight per fruit in g)

Year	Spacing	Unpruned Alar –		Unpruned Alar +	Pruned Alar –		Pruned Alar +
1966	d_{1-4}	9.5 (195)		13 (195)	5.5 (216)		8.5 (215)
	d_{5-8}	11 (195)		15 (186)	4.5 (217)		6 (225)
1967	d_{1-4}	68 (167)		70 (156)	40 (180)		42 (170)
	d_{5-8}	70 (156)		66 (151)	32 (178)		33 (174)
1968	d_{1-4}	80 (164)		78 (167)	58 (179)		52 (180)
	d_{5-8}	62 (166)		69 (165)	44 (176)		42 (184)
1969	d_{1-4}	176 (126)		155 (134)	104 (147)		86 (153)
	d_{5-8}	145 (121)		140 (120)	61 (143)		67 (149)

Table 2 shows that Alar increased the number of fruit per tree in the first year of application, which must be due to better fruit retention. In subsequent years there is no favourable effect on yield per tree, on the contrary: in 1968 and 1969 yields of sprayed trees tend to be somewhat lower, which is in keeping with a slightly smaller tree size.

Alar had no marked effect on mean weight per fruit, which is also shown in table 2. In 1967 only, fruit size seems to have been reduced by Alar. The influence of spacing, pruning and tree age on yield will be considered in section 3.4 on p. 20, the effects on mean weight per fruit in section 3.6 on p. 27.

Root studies in 1969 revealed a peculiar influence of Alar on root distribution. Root counts to a depth of 50 cm at distances of 45, 90 and 135 cm from the tree trunks came to 81, 70 and 73 roots respectively for widely spaced control trees; the corresponding figures for trees sprayed with Alar were 102, 72 and 42. Thus root density for trees treated with Alar decreased with increasing distance from the trunk, whereas the root density for the control trees remained virtually stable. The total number of roots per tree did not seem to be affected by Alar; also there was no evidence that Alar changed the vertical distribution of the roots in the layer from 0–50 cm.

3.2. TREE HABIT.

In the year after planting the trees grew fairly well. Since two-year-old trees had been planted, the framework branches were well-developed when trees were pruned for the first time, at the end of 1965. In the pruned plots these branches were removed at the closer spacings, as shown in illustration 2. This operation proved to be a mistake with lasting consequences. The unpruned controls showed that most of these strong branches could be accomodated in spite of the close spacing. Moreover, the pruned trees responded by vigorous and largely unwanted growth in the apical region, rather than by forming light laterals to replace the framework branches. Hence in the following years also pruning had

ILLUSTRATION 2. Pruned (left) and unpruned trees of Golden Delicious IX at close spacing, photographed in the summer of 1966 to show the effect of the removal of framework branches on tree shape.

to be fairly severe and the amount of fruiting wood increased only slowly.

The weight of prunings at the end of the first growing season (1965) was not recorded, but table 3 shows that until 1969 pruning weights for closely spaced trees were about as high as for the widely spaced trees. Also, the weight of prunings was much higher for the deblossomed trees than for the bearing trees. This is due to the more vigorous growth of the deblossomed trees and to the uneven distribution of growth over the tree. The excessive growth in the apical region of closely spaced trees was particularly prominent in the deblossomed treatments. Severe heading back became necessary to restrict the trees to a convenient height for pruning and picking from the ground. The top-heavy habit of these trees is demonstrated in table 4 by the extremely high ratio of trunk cross sectional area at 1.20 m above the union to that at 0.20 m above the union.

The ratios given in table 4 are a measure of tree slenderness. BYASS (1968) has

TABLE 3. Mean weight of prunings in g per tree.

Year	Spacing	Deblossomed	Fruiting
1966	$d_{1,2}$	152	132
	$d_{7,8}$	151	132
1967	$d_{1,2}$	365	243
	$d_{7,8}$	368	237
1968	$d_{1,2}$	891	405
	$d_{7,8}$	811	465
1969	$d_{1,2}$	1532	887
	$d_{7,8}$	1043	637

shown that trunk or branch cross section is a good measure of the size of the subtending branch system. Hence, a low slenderness ratio indicates that strong laterals emerge near the stem basis. By contrast, a high ratio indicates that a high proportion of lateral growth is borne in the upper region of the central leader. It is evident from table 4 that tree habit becomes more slender with diminishing tree spacing. For the pruned trees this effect may have been aggravated by the removal of the framework branches at close spacing, but the 50% increase in slenderness values with closer spacing for the unpruned trees indicates that inter-tree competition plays an important role too.

In comparison to slenderness, tree height is only mildly – though unmistakebly – affected by the treatments. Data on increment in tree height over a 3-year-period in table 5 show that pruning greatly stimulates height growth. However, the net gain is very small, as appears from the figures in table 5 on tree height at the end of the 1969 growing season. Close spacing leads to increased tree height, even for the unpruned trees which become only slightly taller in 3 years. This indicates that the accelerated height growth is a true effect of competition. On the other hand intra-tree competition between growth and fruiting reduces height growth, as shown by the inferior values for fruiting trees.

Treatment effects on the complexity of the tree, that is the extent of ramification, are presented in table 6 which gives data on the numbers of terminal buds per tree. These numbers are much smaller for the pruned trees, especially at close spacing. This is largely a consequence of the relatively hard pruning of the

TABLE 4. Slenderness of the trees at the end of 1969, expressed as the ratio between trunk cross sectional area at 1.20 m and at 0.20 m above the union.

	Unpruned		Pruned	
Spacing	Deblossomed	*Fruiting*	Deblossomed	*Fruiting*
$d_{1,2}$	0.22	0.22	0.28	0.26
$d_{3,4}$	0.20	0.24	0.32	0.30
$d_{5,6}$	0.29	0.27	0.43	0.41
$d_{7,8}$	0.33	0.33	0.56	0.48

TABLE 5. Total gross increment in tree height over 1967, 1968 and 1969 and mean tree height in October 1969, both in cm per tree.

Spacing	Unpruned		Pruned	
	Deblossomed	Fruiting	Deblossomed	Fruiting
	Height increment (cm) 1967 + 68 + 69:			
$d_{1,2}$	28	14	138	127
$d_{7,8}$	43	32	153	145
	Tree height (cm) October 1969:			
$d_{1,2}$	219	203	234	220
$d_{7,8}$	232	223	248	236

closely spaced trees. However, in the unpruned trees the number of terminal buds at close spacing is also depressed, and this can only be attributed to fiercer competition between trees. Fruiting clearly depresses the number of terminal buds on unpruned trees, especially as the trees get older, but it appears to have no effect on the complexity of pruned trees. Under-estimation of the need for fruit thinning in the unpruned tree is probably the main reason for this differential effect of fruiting.

The reduction in the numbers of growing points caused by pruning leads to increased vigour per growing point. This is shown by the high percentage of terminal buds on shoots longer than 10 cm, also listed in table 6. The effect of close spacing on the proportion of long shoots is inconsistent. Fruiting reduces the proportion of long shoots, although in the pruned trees the effect is not clear until 1969. The proportion of long shoots drops as the branches ramify with increasing age. The drop is small on pruned deblossomed trees, but in all other treatment combinations the percentage of long shoots is approximately halved from 1967 to 1969.

The data on mean length per shoot for shoots longer than 10 cm, already presented in table 1 on page 8, show that shoots on pruned trees reach a much greater length than on unpruned trees. Close spacing does not appear to affect shoot length of the unpruned trees, but in the pruned trees the shoots at close

TABLE 6. Mean number of terminal buds per tree at the end of the growing season and (mean percentage of shoots longer than 10 cm), in 1967 and 1969.

Year	Spacing	Unpruned		Pruned	
		Deblossomed	Fruiting	Deblossomed	Fruiting
1967	d_2	290 (49)	278 (28)	141 (59)	134 (51)
	d_7	242 (41)	215 (28)	87 (59)	96 (64)
1969	d_2	1075 (28)	730 (15)	411 (46)	413 (20)
	d_7	820 (23)	579 (16)	244 (54)	257 (30)

TABLE 7. Mean area per 100 leaves in dm^2 and mean weight per unit leaf area in g per dm^2; in 1967 for leaves on long shoots only, in 1969 for all leaves.

Year	Spacing	Unpruned		Pruned	
		Deblossomed	Fruiting	Deblossomed	Fruiting
			Area per 100 leaves (dm^2)		
1967	d_2	22.9	21.7	27.3	26.9
	d_7	24.5	23.1	27.6	26.0
1969	d_2	19.8	20.1	22.4	22.5
	d_7	19.7	20.0	24.9	23.1
			Weight per unit leaf area (g/dm^2)		
1967	d_2	3.44	3.23	3.67	3.39
	d_7	3.40	3.12	3.44	3.31
1969	d_2	2.91	2.76	3.16	2.90
	d_7	2.68	2.49	3.17	2.96

spacing are generally shorter than at wide spacing. Fruiting also tends to reduce mean length per shoot, but the results in table 1 are not very consistent.

Data in table 7 regarding the area per 100 leaves and weight per unit leaf area demonstrate that the sturdy shoots on pruned trees bear large leaves. Unpruned trees have smaller leaves with a lower weight per unit area. There is not much evidence that spacing and fruiting affect leaf size; on the other hand close spacing and fruiting both depress the weight per unit leaf area, although the effect of close spacing is smaller and not fully consistent.

That the overall effects of the treatments on tree habit were very prominent indeed, is indicated by the photographs in illustrations 3 and 4, taken in October 1967. Illustration 3 shows pruned and unpruned trees, both deblossomed and fruiting, at wide spacing; illustration 4 shows the corresponding treatments at close spacing. Characteristic for the pruned trees is the simple tree structure, composed of vigorous, upright shoots with large leaves. By contrast, the unpruned trees have a more complex pattern of ramification; the shoots are generally weaker and bear smaller leaves.

At this early stage there is no apparent influence of fruiting on the habit of the pruned trees. In the unpruned trees, however, the effects of fruiting are striking: the pendant branches, the absence of vigorous shoots and the high proportion of spurs on the fruiting trees are early symptoms of ageing. As the spurs are hard to distinguish, the photographs give the – largely false – impression that the ramification of these unpruned fruiting trees is less complex than that of their deblossomed counterparts.

Comparison of illustrations 3 and 4 shows that density is also beginning to influence tree habit. It appears that at close spacing the unpruned trees are more slender and that the structure of pruned trees is less complex, an effect that may be due to harder pruning. These effects of density became more obvious with increasing tree age.

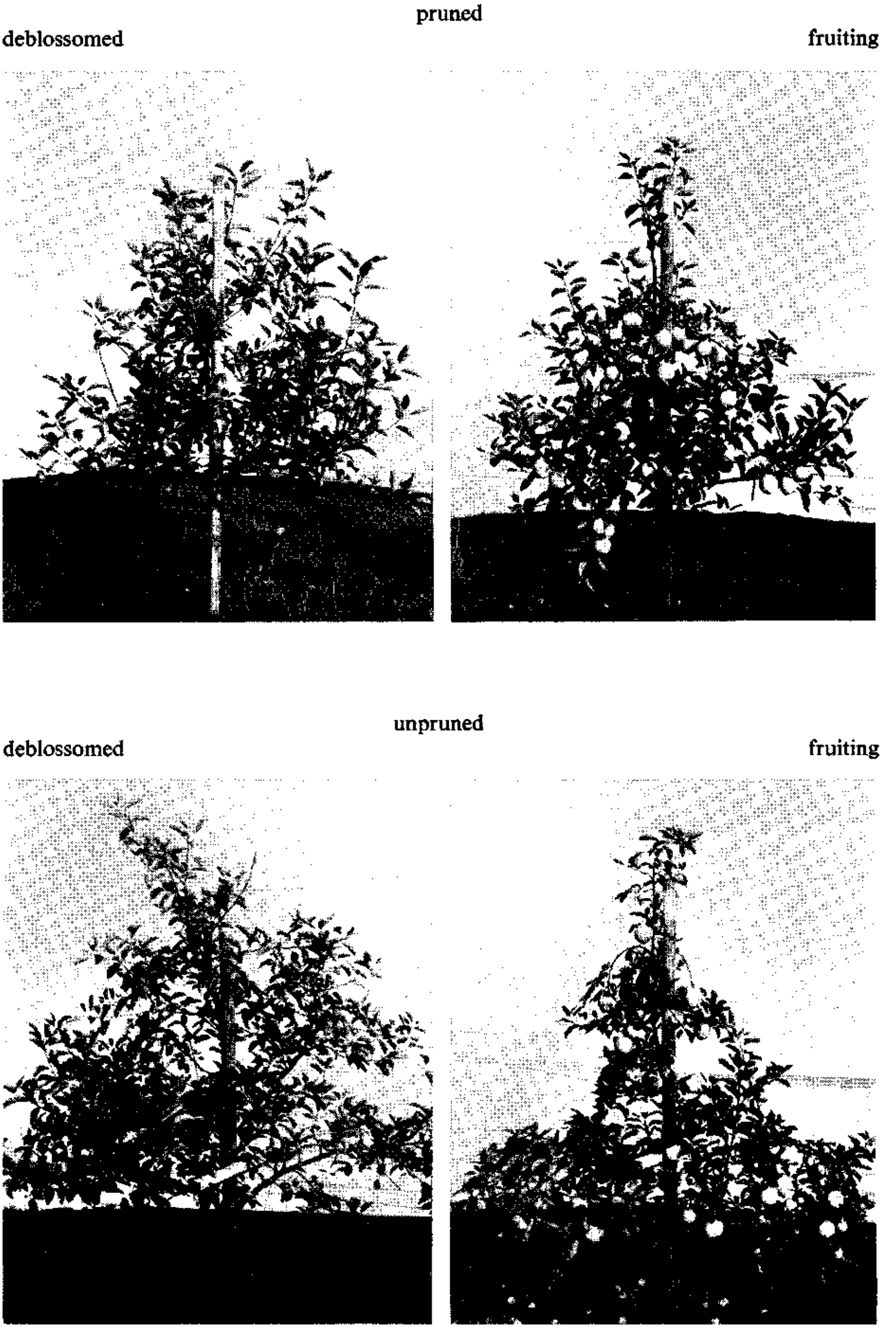

ILLUSTRATION 3. Typical widely spaced Golden Delicious trees on M IX in 1967, showing differences in tree size and habit as a result of pruning and deblossoming.

pruned

deblossomed | fruiting

unpruned

deblossomed | fruiting

ILLUSTRATION 4. Typical closely spaced Golden Delicious trees on M IX in 1967, showing differences in tree size and habit as a result of pruning and deblossoming.

On the assumption that the striking treatment effects on shoot growth and foliation should be reflected in the root system of the trees, root studies were carried out in September 1968 and 1969 by Mr. J. LOETERS, soil scientist in the National Horticultural Advisory Service. The best results were obtained in 1969, using a sampling technique described by LOETERS and NOTENBOOM (1969). In all plots of one block, soil samples made with a drain spade to a depth of 50 cm, were obtained from the vicinity of a selected tree at spacing d_2 and one at spacing d_7. The number and position of the roots in each sample were recorded. The sampling positions in relation to the trees are shown in illustration 5.

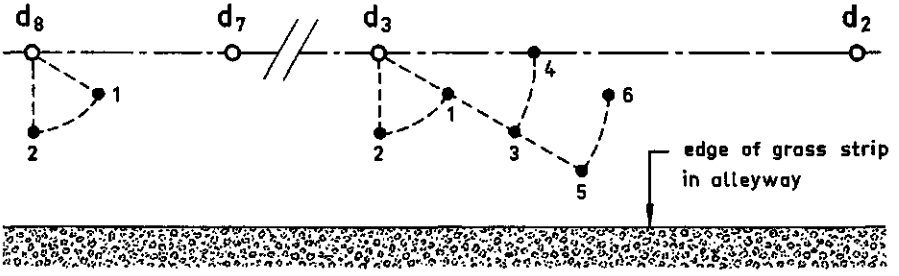

ILLUSTRATION 5. Sampling positions for the 1969 root study; all positions are within the herbicide-treated strip under the tree rows. d_n denotes tree position within the series of spacings. Sampling positions 1 and 2, 3 and 4, 5 and 6 are at 45, 90 and 135 cm respectively from the tree trunks; the distance within each pair of positions is 45 cm.

As has been pointed out in section 3.1 on p. 8, root density in 1969, defined as root number per unit soil volume, did not drop with increasing distance from the tree, except for trees treated with Alar. This applied to widely spaced trees; the near-equality of root numbers in both samples of closely spaced trees suggests that at high tree density also root density was fairly uniform. For trees not sprayed with Alar the mean number of roots per sample at 45 cm from the tree trunk was 40 and 59 for widely and closely spaced trees respectively, indicating that root density increased with tree density. Root density in 1969 was 2–3 times as high as in 1968.

It was hard to find close relationships between the root counts and aspects of above-the-ground tree habit. There was, however a convincing correlation between sampled root number per tree, adjusted for tree spacing, and the number of terminal buds per tree. This relationship is represented in illustration 6 by straight lines, one for the unpruned trees, the other – with a lower ratio of terminal buds to roots – for the pruned trees.

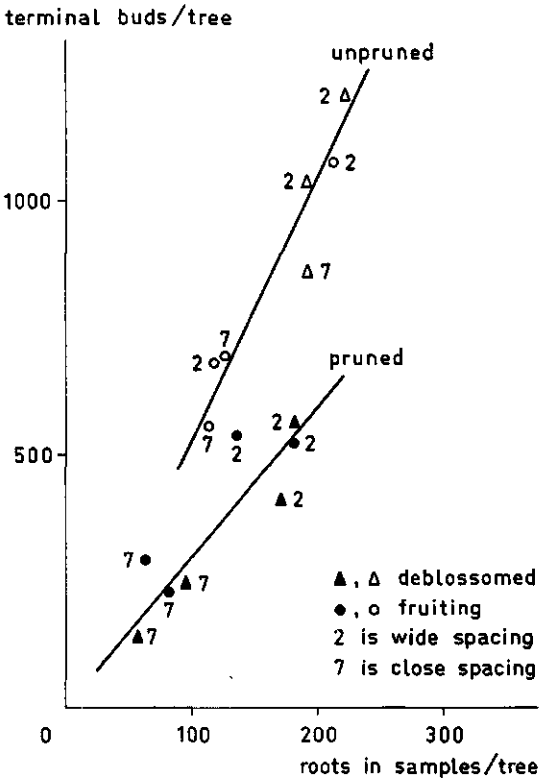

ILLUSTRATION 6. The number of terminal buds per tree in relation to the number of roots in the samples per tree, for the widely spaced trees multiplied by 0.8 ($= 3^{-1} \times 2.4$, there being 3 times as many sampling locations, whereas tree density is 2.4 times lower than for the closely spaced trees).

3.3 GROWTH RHYTHM, LEAF ANALYSIS, DISEASES.

The absence of fruit in the deblossomed trees stimulated flower initiation to such an extent that at blossom time in 1968 and 1969 these trees were completely white with bloom, there being virtually no leaf buds on the tree. The fruiting trees on the other hand were green at full bloom, since about 50% of the buds were leaf buds, although the percentage varied considerably. Consequently the deblossomed trees came into leaf several weeks later, when shoots developed at the base of the inflorescences. The complexity of the unpruned deblossomed trees is associated with the large number of such shoots on the one-year-old wood, an indication that correlative inhibition in these trees was much weaker than in the pruned trees.

The delayed shoot development of the deblossomed trees was not compensated by prolonged extension growth at the end of the season. On the contrary, leaf duration was adversely affected by early abscission in autumn. There were also indications that the foliage of the deblossomed trees did not function as well as on the fruiting trees, at least for the unpruned treatments. About the end of July, when extension growth stagnated, the leaves of the unpruned deblossomed trees folded up and autumn colours appeared. The symptoms aggravated with time and especially in August and September 1968 the trees looked very unhealthy, with symptoms similar to 'Cox-disease'.

The symptoms were slight or absent at close spacing and in the tree row adjacent to the poplar shelter belt. This suggests that the symptoms were caused by the inability of the tree to cope with the photosyntates produced by the leaves under favourable light conditions. Since symptoms were absent even in exposed parts of most closely spaced trees, it must be assumed that the appearance of symptoms depends on an excess of photosyntates for the tree as a whole.

For the pruned deblossomed trees light conditions were even more favourable and it is not easily explained why these trees showed no symptoms. The reason may be the prolonged growth of the pruned trees. Each year there was renewed extension growth in August, continuing into September and October and shoots on pruned trees – more in particular the most vigorous shoots – terminated extension growth several weeks later than shoots on unpruned trees.

The observations in respect of the pattern of growth within one year show clearly that annual deblossoming brings out the effects of fruiting on growth rather defectively. The differences in growth between fruiting and deblossomed trees, to be presented below in sections 3.4. and 3.5, could have been much greater if the deblossomed trees had not expended so much energy on flower bud formation and had come into leaf simultaneously with the fruiting trees.

The influence of the treatments on the seasonal rhythm of growth is reflected in trunk girth increment. Illustration 7 shows trunk girth at fortnightly intervals in 1969, as a percentage of the girth at the end of the growing season. The different shapes of the curves indicate differences in the distribution of growth over the season.

The curves for the fruiting trees are straight in comparison with those for the deblossomed trees; the same applies to the curves for closely spaced trees as compared with those for widely spaced trees. Thus intra-tree competition with fruit and inter-tree competition with neighbours both have a steadying effect on the growth rate (while reducing total growth). Whereas the fruiting trees attain their highest growth rate around the beginning of June, the deblossomed trees do not reach this stage until the end of June, probably as a result of the retarded foliation.

Leaf analysis was carried out in August 1967, 1968 and 1969. It is not surprising that the differences in growth rhythm were reflected in the composition of the leaves. The treatment effects were fairly persistent over the 3 years and can be summarized as follows. Whereas pruning, fruiting and close spacing

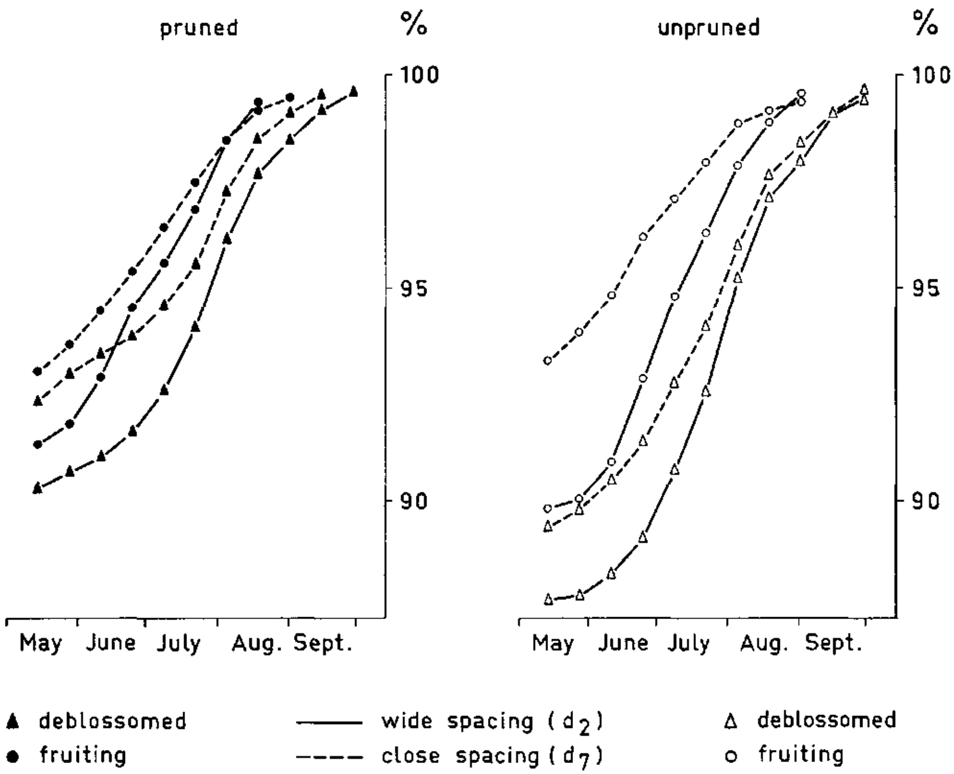

ILLUSTRATION 7. Trunk girth during the 1969 growing season as a percentage of girth at the end of the season, for pruned (left) and unpruned (right) treatments, showing differences in the relative growth and in the growth rhythm in response to spacing and fruiting.

reduced dry matter content, these treatments tended to raise the N-levels in the dry matter. Pruning and close spacing were generally associated with high K-levels, fruiting with low K-levels; Ca-levels were usually much higher in leaves of fruiting trees. The 1969 values are listed in table 8, to indicate the actual nutrient levels.

After the first few years canker became a problem in spite of intensive control measures, including treatment of wounds and one or two sprays with copper-mercury compounds during the period of leaf fall. Canker was notably rampant in the unpruned deblossomed plots, particularly at close spacing. In one 'Lired' plot most closely spaced trees were mutilated. The narrow crotch angles formed by the trunk and the lower laterals at close spacing were most vulnerable to infection. These crotches seemed to stay wet longer, favouring germination of spores; possibly fissures developed in the crotches during periods of rapid radial growth, giving the fungus a way to penetrate.

In 1969 scab control was inadequate, especially on 'Lired' trees. When trees

TABLE 8. Percent dry matter content and percent mineral content in the dry matter, for leaves of Golden Delicious IX in August 1969.

	Spacing	Unpruned		Pruned	
		Deblossomed	Fruiting	Deblossomed	Fruiting
Dry matter	d_2	41.5	38.3	39.5	37.8
	d_7	39.8	37.6	37.0	37.0
N	d_2	2.18	2.76	2.52	2.79
	d_7	2.32	2.66	2.66	2.76
K_2O	d_2	1.78	1.71	2.13	1.93
	d_7	1.84	1.71	2.20	1.93
CaO	d_2	1.77	2.07	1.79	2.04
	d_7	1.72	2.12	1.96	2.03

were defoliated in September, prior to grubbing, the proportion of leaves affected by scab spots was determined. The results for the major treatment combinations are listed in table 9. It appears that the incidence of scab was high; the dependence on the treatments is remarkable. Unpruned trees had the highest proportion of diseased leaves; pruning and to a lesser extent fruiting depressed the incidence of scab. In the unpruned plot wide spacing was also favourable. As for canker, the incidence of scab was highest in the unpruned deblossomed plots. However, whereas canker was not much of a problem in the other plots, scab infections were still numerous for the more favourable treatment combinations.

The relation between the 2 diseases and the treatments can be explained on the basis of differences in canopy structure, which influence the micro-climate and the efficacity of the control measures. Nevertheless the possibility cannot be ruled out that the variation in growth rhythm and in leaf composition have influenced the trees' defenses or have affected the suitability of the tissues as a substrate for the fungi.

TABLE 9. Percentage of leaves with scab spots; James Grieve 'Lired' VII, September 1969.

	Unpruned		Pruned	
Spacing	Deblossomed	Fruiting	Deblossomed	Fruiting
d_2	47.5	36.0	30.5	23.5
d_7	60.5	58.0	31.0	21.0

3.4. GROWTH AND YIELD PER TREE.

In the graphs of illustration 8A the growth of deblossomed trees over 1965–1969 is compared with growth and cumulative yield of fruiting trees; the graphs in illustration 8B show the annual values over the same period. The 4 curves in each graph refer to unpruned and pruned trees, at the extreme tree spacings

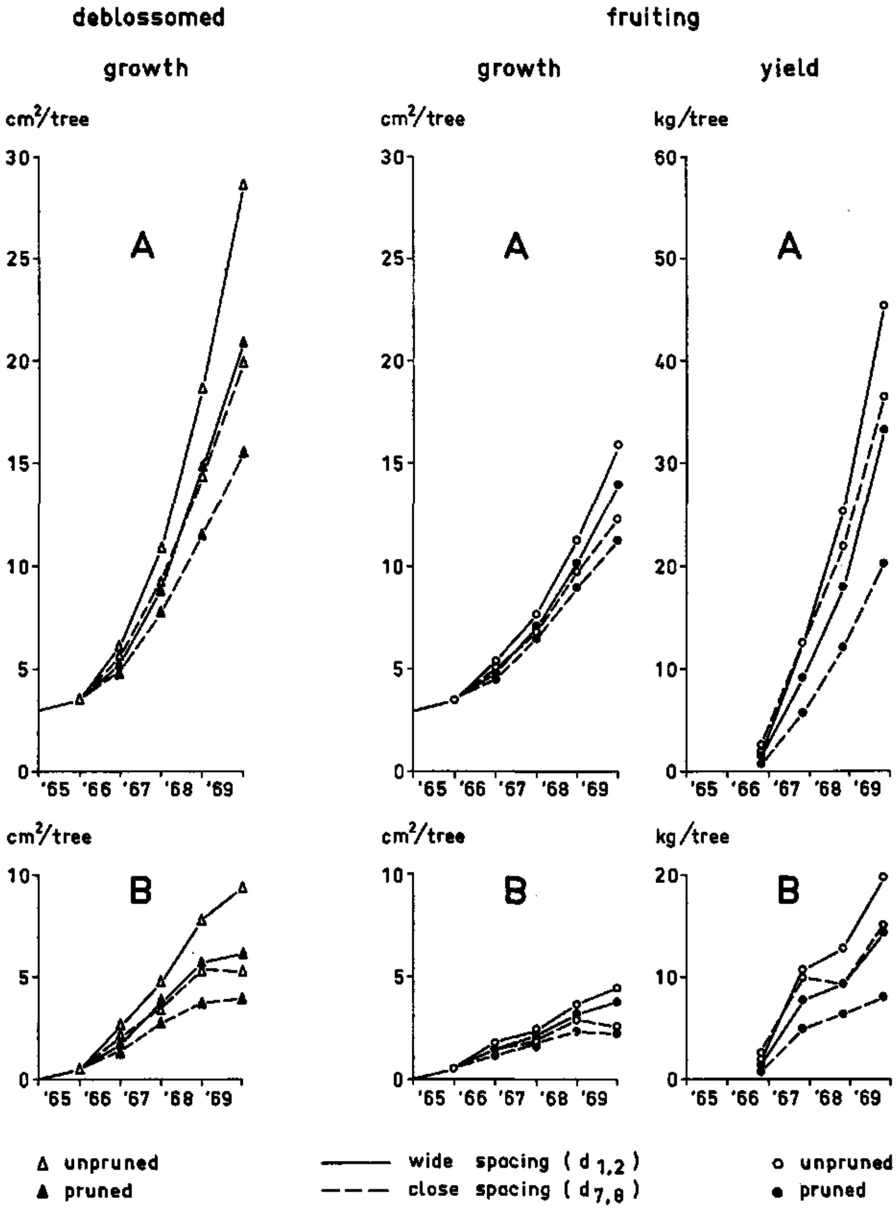

ILLUSTRATION 8. Growth and yield per tree in relation to age for Golden Delicious IX, represented by
upper series (A): tree size expressed as trunk cross sectional area and cumulative yield
lower series (B): annual increment in tree size and annual yield.

(mean data for d_1 and d_2 versus mean data for d_7 and d_8). Tree size is expressed as trunk cross sectional area, tree growth as its increment. Yield is expressed as kg fruit.

With increasing age the effects of the treatments clearly manifest themselves in the growth curves shown in illustration 8A. Fruiting strongly reduces the growth rate of the trees, but it does not reverse the order of the curves: unpruned trees grow faster than pruned trees and widely spaced trees grow faster than closely spaced trees. The influence of pruning and spacing is accentuated by deblossoming.

In 1969 there are signs that the pace of growth begins to waver; this is important as a symptom of mounting competitive stress. In both growth graphs in illustration 8B growth of the widely spaced trees in 1969 is still accelerating, but the growth rates of the closely spaced trees appear to be near or past their maximum, for the fruiting as well as for the deblossomed treatments. That this stage should be reached simultaneously for fruiting and deblossomed trees is remarkable. As the fruiting trees are much smaller, inter-tree competition cannot be nearly as strong as between the deblossomed trees. Hence the declining growth rate in the closely spaced fruiting trees must be due to the added intra-tree stress of the heavy 1969 crop.

The yield curves in illustration 8B show that yield per tree improved quickly from 1966 tot 1967, tended to stagnate in 1968 – especially for the unpruned trees – and was high in 1969. Yields are highest for the unpruned trees at wide spacing. Pruning and close spacing substantially reduce yield per tree, especially in combination. This is also demonstrated by the cumulative yield per tree in illustration 8A.

3.5. Growth and yield per ha.

In illustration 9 the information contained in illustration 8 is converted to a per ha basis. Hence the graphs in illustration 9A show basal growth – that is the mean trunk cross sectional area multiplied by the number of trees per unit area, in m^2 per ha – and cumulative yield of fruit in ton per ha, over the period 1965–1969. The annual increments in basal area and annual yields per ha are shown in illustration 9B.

It appears that the reduction in growth and yield *per tree* at close spacing is amply compensated by the nearly $3\times$ higher tree number *per ha* (2645, compared with 925 at wide spacing). Thus in each year growth and yield per ha are higher at close spacing (illustration 9B) and the cumulative effects on basal area and yield (illustration 9A) are spectacular.

Fruiting greatly depresses basal area growth, thus relieving inter-tree competition. For the fruiting treatments basal area growth at close spacing indeed proceeds almost $3\times$ as fast as at wide spacing, against about twice as fast for the deblossomed treatments. Nevertheless the yield curves point to substantial inter-tree competition for the fruiting treatments also: cumulative yield at close

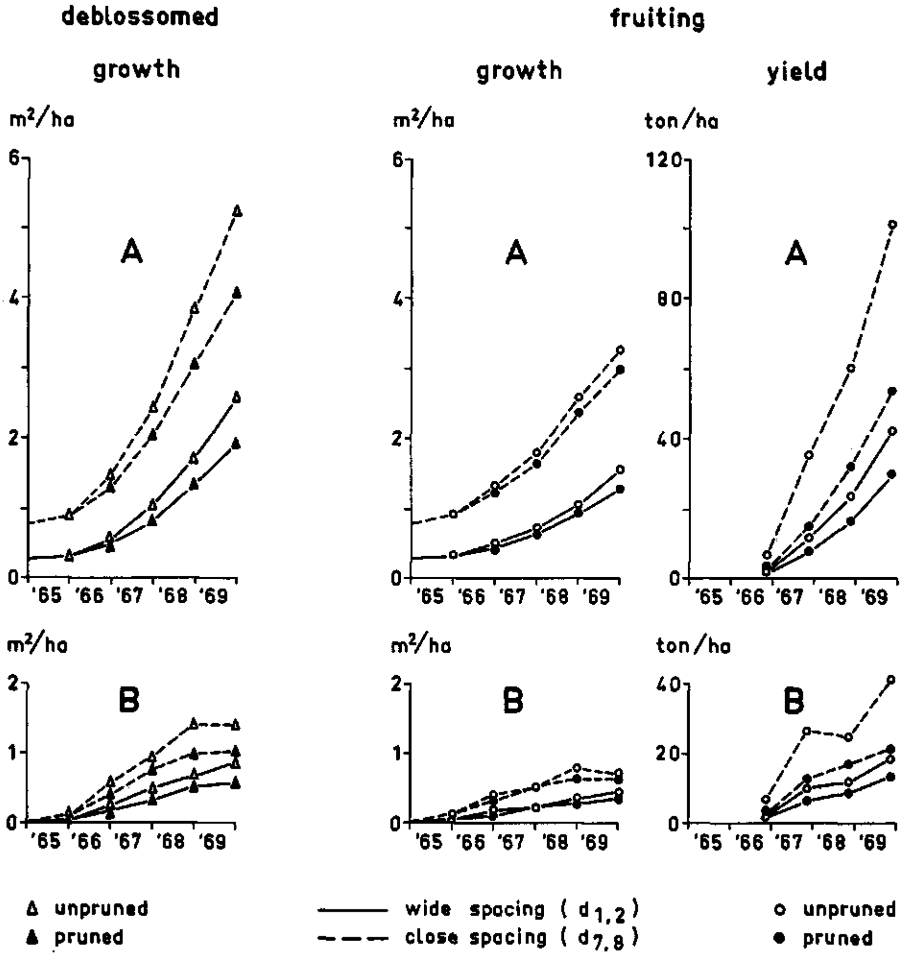

ILLUSTRATION 9. Growth and yield per ha in relation to orchard age for Golden Delicious IX, represented by
upper series (A): basal area and cumulative yield
lower series (B): annual increment in basal area and annual yield.

spacing is approximately twice, not thrice, as high as at wide spacing.

Pruning resembles close spacing, in that it also has a more prominent effect on yield than on growth. For the fruiting trees, the growth reduction caused by pruning is surprisingly small, but it is matched by alarming yield depressions. By the end of 1969 the superiority of cumulative yield for the unpruned treatments is striking, especially at close spacing.

The results obtained with 'Lired' VII agree well with those for Delicious IX as appears from illustration 10.

The superior vigour of the M VII rootstock finds expression in a higher

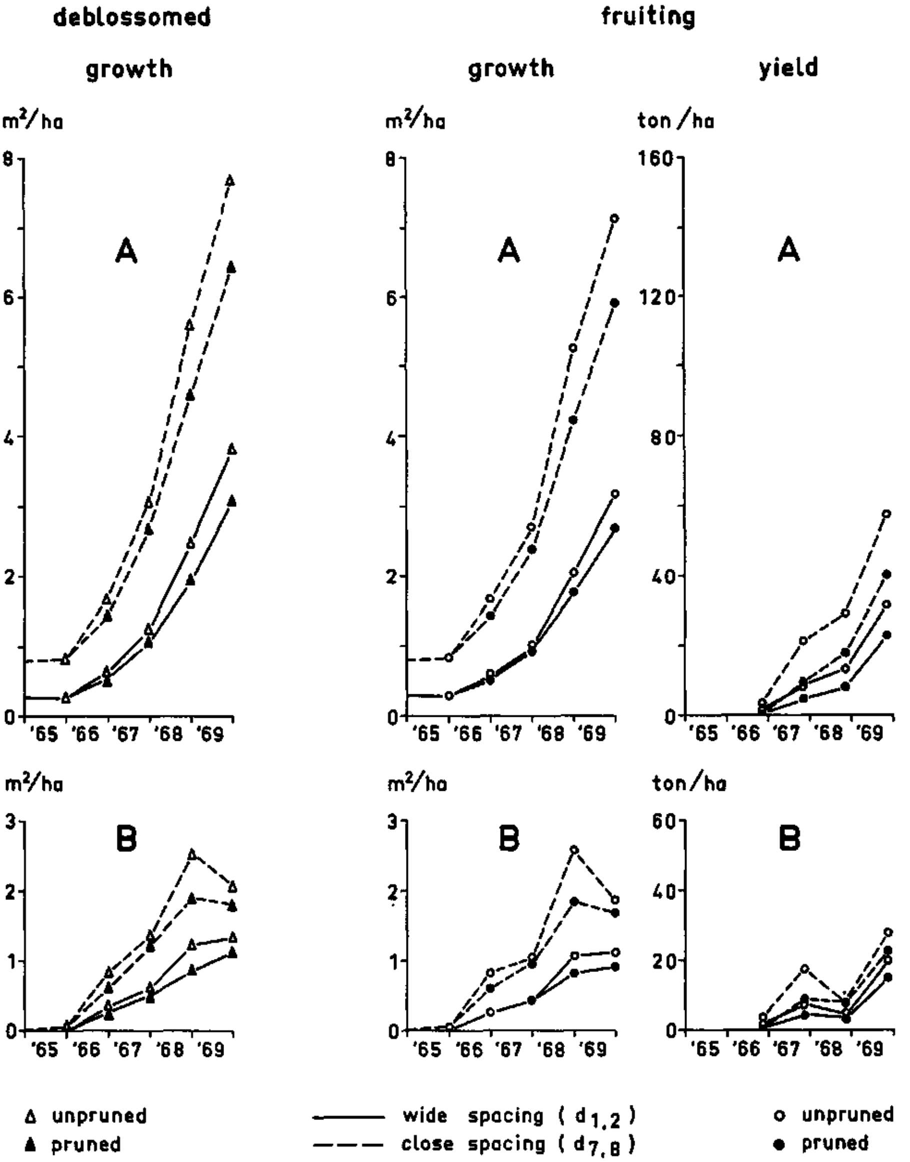

ILLUSTRATION 10. Growth and yield per ha in relation to orchard age for James Grieve 'Lired' VII, represented by
upper series (A): basal area and cumulative yield
lower series (B): annual increment in basal area and annual yield.

growth rate and larger basal areas than for the trees on M IX. To some extent this vigour seems to be generated at the expense of fruiting: yields of 'Lired' are lower and fluctuate much more than the Delicious yields. It is important to note that these yields hardly affect growth (cf. the growth graphs for deblossomed and fruiting treatments), whereas the heavy yields of Delicious IX approximately halve the growth rate. This difference is not purely a rootstock effect; the 'Lired' strain does not bear as heavily as the common James Grieve and is no match for Golden Delicious.

Whether or not the close spacing is anywhere near the optimum tree density for yield and growth, can be assessed from illustration 11 and 12. Illustration 11 depicts biennial basal area growth in m^2 per ha, illustration 12 biennial fruit yield in ton per ha, for both Delicious IX and 'Lired' VII, at the intermediate densities as well as at the extreme densities. It appears that the optimum density changes with age. During 1966 and 1967 basal area growth is almost linearly related to density. Only in the most vigorously growing treatment, i.e. unpruned deblossomed 'Lired' VII, the proportionality of basal area growth with density cannot be kept up towards the highest density. During 1968 and 1969 the linearity of the relationship is clearly broken for both varieties and for all treatments. This indicates that inter-tree competition checks the growth rate of trees at high density rather more than at low density. Nevertheless the graphs suggest that a somewhat stronger basal area growth per ha could have been obtained by a further increase in density.

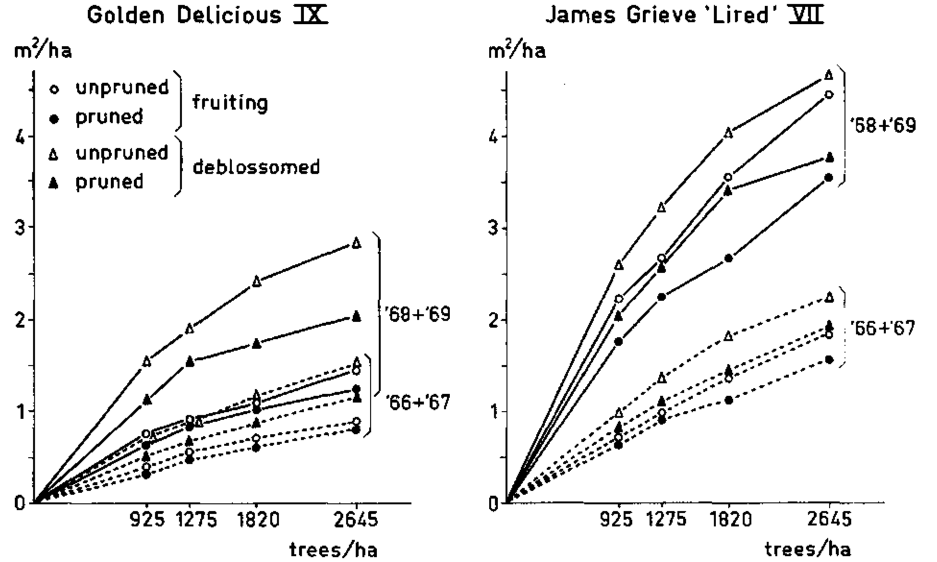

ILLUSTRATION 11. Biennial basal area increment in m^2 per ha in relation to density, for the 4 main treatment combinations.

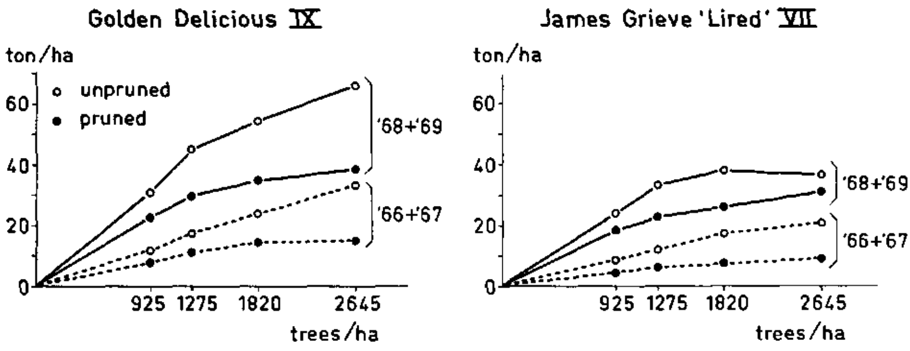

ILLUSTRATION 12. Biennial yield in ton per ha in relation to density, for pruned and unpruned treatments.

The yield aspect is more complicated and differs for the 2 varieties. From the curves for unpruned Delicious IX it appears that over 1966–67 yield is virtually proportional to density. During the next biennial period the proportionality cannot be sustained at densities exceeding 1275 trees per ha, but the curve suggests that at densities over 2645 trees per ha still higher yields could have been obtained. This is not so for the vigorous 'Lired' VII: for the unpruned treatments of this variety the proportionality is broken for the very first yields already and over 1968 and 1969, that is during the 4th and 5th year from planting, the yield curve shows an optimum at 1820 trees per ha.

For the pruned treatments the yields do not improve so much with increasing density, probably due to the severe initial pruning of the closely spaced trees and the subsequent problems in controlling tree habit, reported in section 3.2. For Delicious IX the yield gap between unpruned and pruned treatments becomes very wide indeed at the highest density. For 'Lired' VII this is not so, because the unpruned trees at the highest density are relatively poor croppers too, due to fierce inter-tree competition.

The large treatment effects on both growth and yield pose the question as to what extent the yield per unit growth is affected. There are many ways to express the relation between yield and growth, but perhaps the most straightforward method is to plot yearly yield per ha against basal area per ha at the beginning of each year. In the graphs in illustration 13 this has been done for Delicious IX and 'Lired' VII at the 4 mean densities of 925, 1275, 1820 and 2645 trees per ha.

Virtually all yields for Delicious IX are above the 45° line, which represents a yield of 10 ton per m^2 basal area, that is 1 kg per cm^2. The unpruned trees yield more per unit growth than the pruned trees. Also, the yield per unit growth for the unpruned trees remains fairly stable with increasing density. This indicates that the mounting inter-tree competition at high density does not reduce fruiting much more than it does growth. By contrast, the markedly curved lines for the pruned trees, indicating a decline in yield per unit growth with increasing

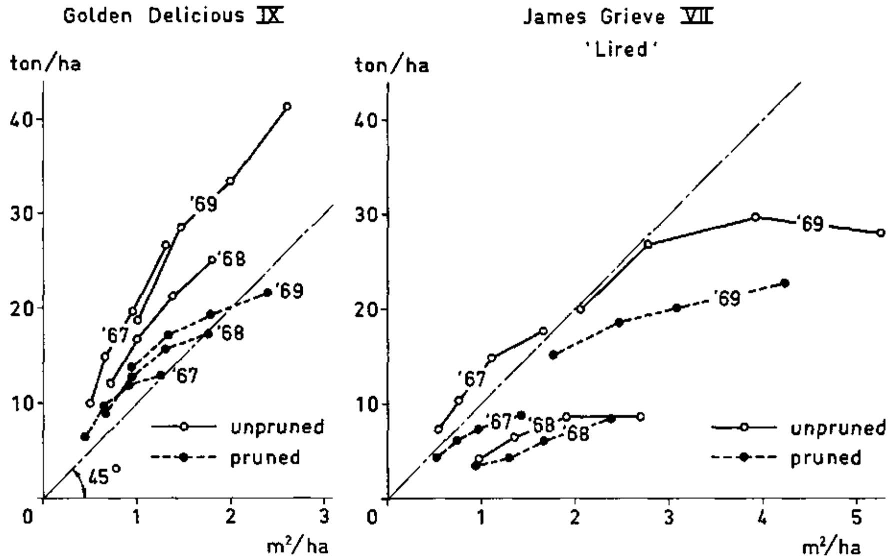

ILLUSTRATION 13. Yield per ha in 1967, 1968 and 1969 against basal area per ha at the beginning of each year, for Golden Delicious IX and James Grieve 'Lired' VII. The 4 points on each curve represent 4 density levels; for each curve density increases from left to right.

density, point to another adverse effect of the relatively hard pruning at high density.

A comparison of both graphs clearly shows the vigorous growth and relatively low yield of 'Lired' VII; all curves but one remain below the 45° line. The year-to-year variation in yield level is much greater too. Again pruning tends to reduce yield per unit growth, but – contrary to the situation for Delicious IX – the curves for the pruned trees are straighter than those for the unpruned trees. In the curves for the unpruned trees the influence of spacing is evident. At high density fruiting suffers more under the competitive stress than does growth. In other words, in the overcrowded condition of the closely spaced unpruned 'Lired' VII, tree growth is maintained at the expense of fruiting, a condition that in a more extreme form is typical for forestry. Pruning counteracts overcrowding, thus relieving inter-tree competition. This explains why the effect of spacing in the curves for the pruned trees is smaller than for the unpruned trees, as opposed to the situation for the more dwarfed trees of Delicious IX.

3.6. FRUIT QUALITY.

An important aspect of yield is fruit quality. Data on mean weight per fruit, already listed in table 2 on page 9, show that fruit becomes smaller as the trees get older. In some instances in 1968 this trend is interrupted, because of the light crop in that year. It appears that spacing also influences mean weight per fruit. In years with a heavy crop (1967, 1969) mean weight per fruit at close spacing is generally lower than at wide spacing. Pruning greatly improves fruit size; without exception the weight per fruit of the pruned treatments is superior to that of the unpruned treatments. However, this may (partly) be due to fruit thinning being inadequate on the unpruned trees.

For the Delicious trees grubbed in 1969, fresh weight of leaves per fruit was 18.1 g for the pruned treatments against 12.4 g for the unpruned treatments, showing that on average the unpruned trees carried almost 50% more fruit per unit foliage. If trees are grouped in classes of increasing leaf weight per fruit, as in table 10, it appears that mean weight per fruit is indeed better in the higher classes.

This strongly suggests that more rigorous fruit thinning would indeed have improved the fruit size of the unpruned trees. Nevertheless, even within a class, mean weight per fruit is superior for the pruned trees. Therefore it seems that fruit size benefits more from the removal of flower buds (and competing vegetative growing points) during winter pruning than from the removal of fruitlets in early summer.

The fruit of pruned trees was also of better appearance; russetting in particular was less severe than on unpruned trees. Apparently the unpruned trees are taxed to the limit of their bearing capacity so that any disturbance in growing conditions must affect fruit quality.

To supplement data on mean weight per fruit in 1969, fruit samples were graded. Each sample consisted of the fruit from 8 trees. The influence of pruning and spacing on fruit size distribution of these samples is show in illustration 14. The frequency distribution is nearly symmetrical for fruit from unpruned trees, but rather skew – with nearly 70% of the fruit in the 2 largest size classes – for fruit from pruned trees. Close spacing shifts the distribution towards the smaller size classes, especially for unpruned trees.

With 'Lired' VII fruit size of unpruned trees was not inferior to that of pruned trees until 1969 and even then the difference was only 10–15 g per fruit. Leaf weight per fruit measured in 1969 was much higher for the pruned trees, but for the unpruned trees it still appeared to be sufficient, i.e. there were no

TABLE 10. Mean weight per fruit (g), for trees classified according to fresh weight of leaves in g per fruit, for Golden Delicious trees in 1969.

Leaf weight/fruit (g) ranging from	Mean weight/fruit (g)	
	Unpruned	Pruned
7,5–10	119	no data
10 –12,5	123	few data
12,5–15	136	144
15 –20	142	151
> 20	few data	160

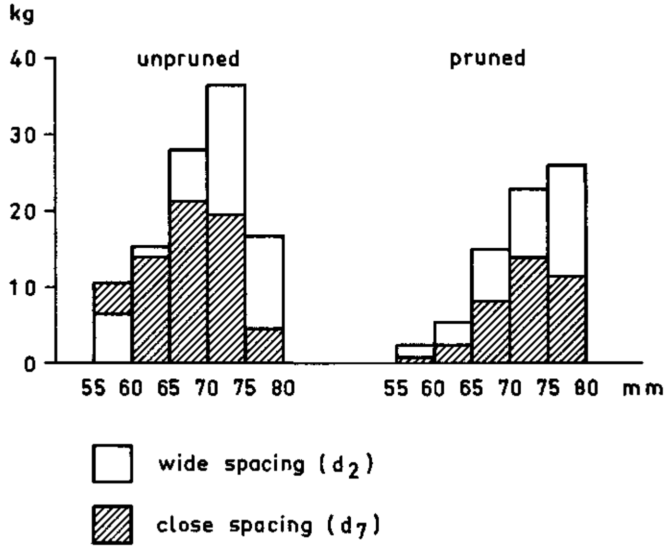

ILLUSTRATION 14. Size distribution of Golden Delicious fruit in 1969, as influenced by pruning and spacing.

indications that the higher values were associated with a higher mean weight per fruit. As for Delicious IX, mean weight per fruit in 1967 and in 1969 declined with closer spacing.

3.7. DRY MATTER YIELD IN 1969.

The fresh weights of fruit, leaves and defoliated trees, recorded for the grubbed trees, were used to estimate dry matter production in 1969. Dry matter determinations of leaves showed that dry matter content ranged from 37.0 to 41.5%, depending on treatment. Leaf samples were obtained only for trees at the widest and the closest spacings; dry matter content of leaves on trees at intermediate spacings was estimated by linear interpolation. Drying of samples of branches showed little variation in dry matter content, which was therefore fixed at 52% for all treatments. Dry matter accumulated in the tree frame during 1969 was estimated from the increment in tree weight over the year; fresh tree weight at the beginning and the end of the year was calculated from the regression equations on trunk diameter, to be presented in section 3.8. To estimate fruit dry weight, the dry matter content was assumed to be 16% for all treatments.

In illustration 15 the resulting estimates of dry matter yield in g per m^2 are shown in relation to density for different treatment combinations. The distribution of dry matter over the perennial tree frame, leaves and fruit is also shown, as well as the amount of dry matter removed by pruning at the end of 1969. Losses in the course of the growing season – notably those due to the removal of flowers in the deblossomed trees and to fruit thinning in the fruiting trees – are not included in the estimates.

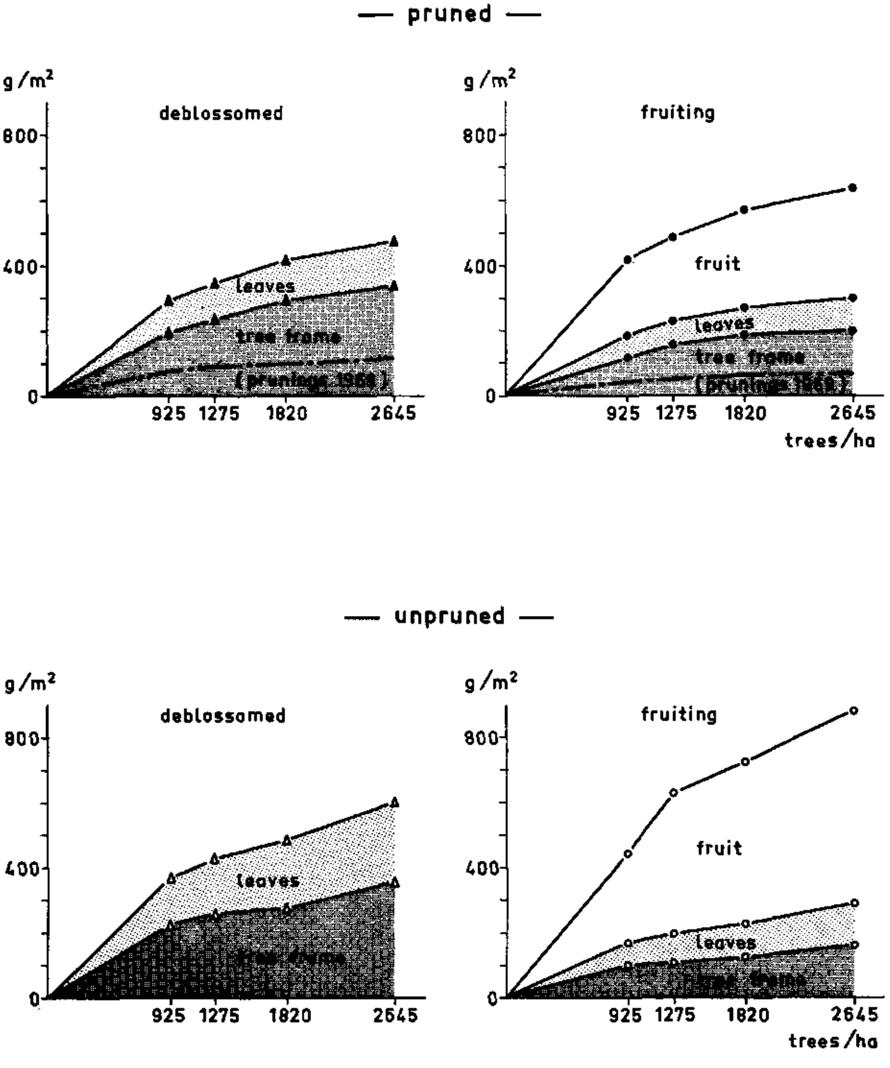

ILLUSTRATION 15. Estimated dry matter yield per m² in 1969 in relation to density for the main treatment combinations. The distribution of dry matter over fruit, leaves and tree frame increment and the proportion of dry matter yield removed by pruning at the end of 1969 are also shown.

Total dry matter yield increases with density, the increase being strongest for the unpruned treatments. The main reason is that at closer spacing the unpruned trees penetrated further into the inter-row space and thus intercepted a higher percentage of incident light than trees at wider spacings. In the pruned plots total dry matter yield increases only moderately towards the highest density. This suggest that in the near future annual dry matter yield per unit area will tend to level off over an increasing range of high density, dry matter yield per tree over this range having become inversely proportional to density. This is in accordance with the prevailing theory (BLEASDALE, 1966; DONALD, 1963).

By far the highest total dry matter yield is produced in the fruiting plots and the high proportion of dry matter recovered in the fruit – more than 50% – is striking. Pruning enhances the share of dry matter yield in the tree frame, reducing the share of both fruit and leaves. However, as indicated, a large part of this dry matter increment in the tree frame is removed when the trees are pruned, even though pruning might seem light in relation to dry weight of the tree as a whole. There is no conclusive evidence that fruiting and spacing modify the distribution of dry matter yield over tree frame and leaves.

In illustration 16 the dry matter yield per m^2 is depicted in relation to leaf area per m^2. This makes it possible to compare the dry matter production and its distribution over the 3 major tree components for equal 'leaf area indices'. It should however be borne in mind that due to differences in tree spacing and tree size, a given 'leaf area index' may stand for entirely different canopy structures.

Total dry matter yield per m^2 of fruiting trees, for mean densities of 925, 1275, 1820 and 2645 trees per ha, is presented in the 2 top curves in illustration 16. It appears that there is not much difference in total dry matter yield per unit foliage between pruned and unpruned trees. Comparison with the 2 following lower curves, which represent total dry matter yield for the deblossomed treatments, shows that the fruiting trees produce much more dry matter per unit foliage than the deblossomed trees. The most likely explanation, supported by findings of HANSEN (1970) and several other workers, is that the fruit serves as a ready sink for assimilates, whereas in the deblossomed trees photosynthesis is hampered because the transport of assimilates stagnates. On the other hand, excessive flowering and retarded foliation may have substantially depressed dry matter yield of the deblossomed trees.

The group of curves marked 'trees + leaves' shows that both deblossoming and pruning raise the dry matter yield per unit leaf area in the vegetative parts, particularly in the tree frame, since differences in leaf dry matter are relatively small. The low position of the curve for unpruned fruiting trees is striking. Apparently competition from the fruit has strongly reduced the amount of dry matter available for growth. In the same way it can be argued that fruit on the pruned trees has only mildly competed with growth for dry matter, because the level of the curve for 'trees + leaves' does not differ much from that of the corresponding curve for deblossomed trees.

From the group of curves marked 'leaves' it appears that dry matter yield per

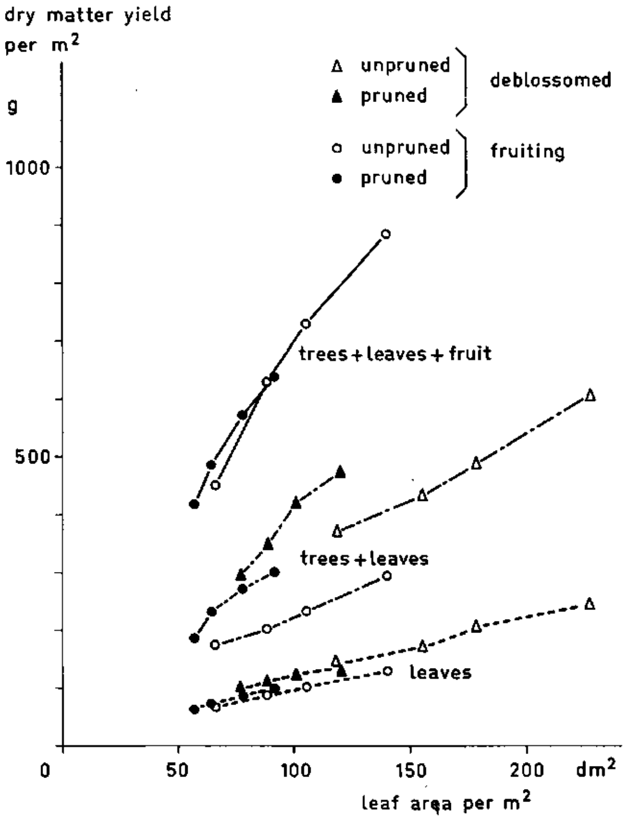

ILLUSTRATION 16. Estimated dry matter yield per m^2 in 1969 in relation to estimated leaf area per m^2 in the same year for grubbed Golden Delicious trees.
The 4 points on each curve represent the 4 mean densities of 925, 1275, 1820 and 2645 trees per ha; for each curve density increases from left to right.

unit leaf area is somewhat higher for the deblossomed treatments. These curves also show clearly that the leaf areas per m^2 and their increments with density are much larger for the unpruned and for the deblossomed treatments. For instance, the 'leaf area index' for the most closely spaced pruned bearing trees is much smaller than that for the most widely spaced unpruned deblossomed trees.

Most curves in illustration 16 are fairly straight, as opposed to the curves in illustration 15. This implies that the effect of density on dry matter yield in illustration 15 is largely due to the fact that the *amount* of foliage does not increase in proportion with density, a decline in the *efficiency* of the foliage with increasing density playing a less important role.

The above findings show that for Delicious IX in the fifth year after planting, estimated dry matter yield still increases with density, largely as a result of increasing 'leaf area indices'. Fruiting greatly enhances dry matter yield per unit foliage and more than 50% of dry matter yield is recovered in the fruit. Pruning also tends to stimulate dry matter yield per unit leaf area; it raises the share of dry matter accumulated in the tree frame, at the expense of the share for leaves and fruit. A large proportion of dry matter increment in the tree frame is removed by pruning.

3.8. TRUNK DIAMETER IN RELATION TO OTHER TREE MEASUREMENTS.

Trunk measurements are commonly used to characterize tree growth. Analyses by PEARCE (1952) for apple and TELFER (1969) for woodland vegetation confirmed earlier findings that trunk diameter or trunk circumference are closely correlated with tree weight. Generally the correlation is at its best if trunk diameter is raised to powers between 2 and 3, depending in part on whether or not leaves and roots are included in tree weight.

Close correlations have also been established between other measures indicative of tree size – such as amount of foliage, shoot growth, tree volume calculated from tree height and spread – and trunk diameter. In a trial with Cox's Orange Pippin, BARLOW (1969) found for branch systems of increasing complexity that log leaf area was linearly related to log branch diameter, the slope of the line being given by the regression coefficient $b = 2.59$. MOORE (1966) raised trunk girth of apple trees at the beginning and the end of a one- or two-year period to a series of powers and correlated the increment in powered girths with total length of shoot growth produced during the period. The correlation coefficients were very high if trunk girth was raised to powers between 2 and 5; at higher and particularly at lower powers the correlation became much weaker.

The data collected in 1969, when one block of the trial was grubbed, provided an excellent opportunity to determine the relationships between trunk diameter and other tree measurements and to examine whether these relationships are influenced by the treatments. Differential treatment effects on the relationships could not be ruled out, the more so since the treatments greatly affected tree growth. PEARCE (1952), for instance, found that in manurial trials trunk girth was an adequate measure for estimation of tree weight, but in variety, rootstock and pruning trials the relationship depended on the treatments.

Trunk diameter was related to fresh tree weight, to fresh weight of the leaves, to calculated leaf area per tree and to calculated tree volume. For all trees at densities d_2 and d_7 in the trial as a whole, data on shoot growth were available over the years 1966, 1967, 1968 and 1969. Total number and total length of shoots longer than 10 cm, over the 4-year period and over 1969 only, were related to trunk diameter at the end of 1969. A linear relationship was assumed between the natural logarithms of trunk diameter and of the other measurements. Regression equations per treatment combination and overall regression equations were calculated by Mr. A. A. M. JANSEN at the Institute for Mathematics, Information Processing and Statistics (IWIS-TNO) at Wageningen; analyses of variance were carried out to establish whether slope and intercept of the regression lines differed significantly for different treatment combinations. Some of the results obtained with Delicious IX are listed in table 11. In interpreting these results it should be borne in mind that the analyses of variance do not carry their usual weight, because of the systematic arrangement of the treatments.

The relation between fresh tree weight and trunk diameter is very close indeed, as shown by the high coefficient of correlation (R = 0.93) in table 11. Nevertheless the levels of significance P indicate that there are differences between treatment combinations in respect of intercept ($P_{en\ a}$). It appeared that tree weight is relatively low for pruned trees in comparison with unpruned trees. The levels of significance for the regression equations for pruned and unpruned trees suggest that all pruned treatments can be pooled; the same applies to all unpruned treatments. More detailed analysis indeed confirmed that neither deblossoming, nor Alar application or spacing have significant effects on the relationship. The scatter diagram for tree weight versus trunk diameter is shown in illustration 17; as expected the values for pruned and unpruned trees respectively are situated predominantly below and above the curve representing the overall regression.

The close correlation between trunk diameter and tree weight and the fact that the relationship is not affected by such important factors as fruiting and spacing, confirms the usefulness of trunk diameter as a measure of tree size. In sections 3.4 and 3.5 tree size has been expressed as trunk cross sectional area,

TABLE 11. Coefficients of regression equations on trunk diameter of Golden Delicious trees, according to the function $\ln y = b \ln x + \ln a$; coefficients of correlation (R) for these regressions; standard error (S) of the regression coefficients and levels of significance P referring to the hypothesis that the regressions for the treatments do not differ.

y	Coefficients		R	S_b	$S_{\ln a}$	P_b	$P_{\ln a}$
	b	ln a					
Fresh tree weight	2.33	−7.02	0.93	0.06	0.22	0.32	0.00
Do, pruned trees only	2.37	−7.24	0.91	0.10	0.36	0.81	0.29
Do, unpruned trees only	2.22	−6.56	0.95	0.07	0.26	0.12	0.61
Leaf weight	2.35	−1.45	0.89	0.08	0.30	0.38	0.00
Leaf area	2.23	−2.05	0.85	0.09	0.35	0.28	0.00
Shoot number 1966–1969	2.14	−2.38	0.87	0.11	0.43	0.20	0.00
Shoot length 1966–1969	2.22	+0.44	0.84	0.13	0.51	0.63	0.00
Shoot number 1969	2.78	−5.80	0.85	0.15	0.59	0.09	0.00
Shoot length 1969	2.51	−1.69	0.75	0.20	0.77	0.33	0.00

ILLUSTRATION 17. Scatter diagram for fresh tree weight (after defoliation, before pruning) against trunk diameter for individual Golden Delicious trees grubbed in 1969; the curve corresponds to the overall regression equation in table 11.

ILLUSTRATION 18. Scatter diagram for leaf area against trunk diameter for individual Golden Delicious trees; the curve corresponds to the regression equation in table 11.

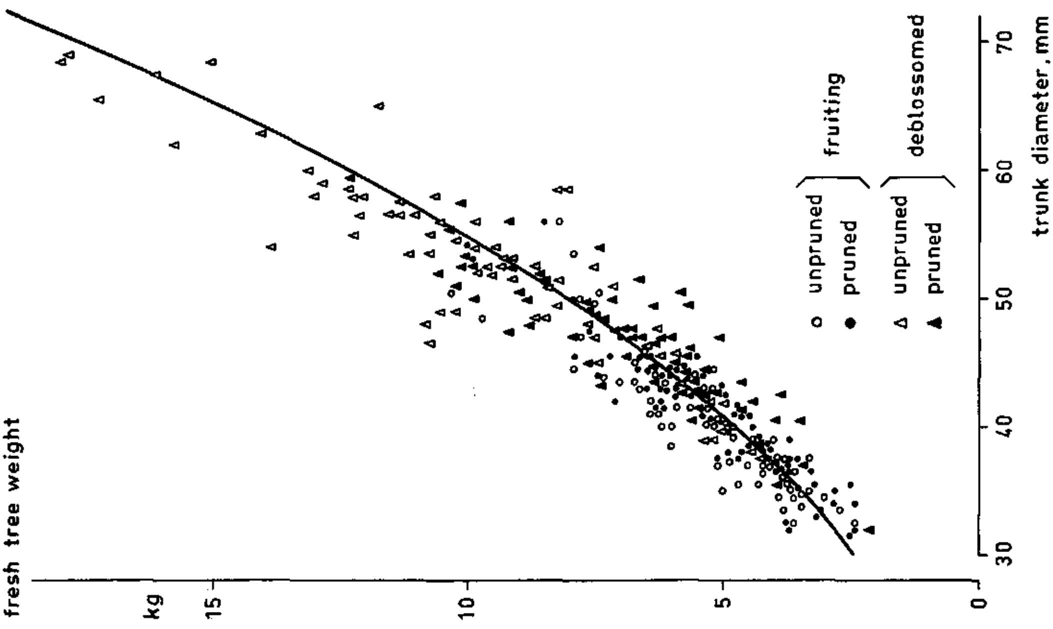

Illustration 17

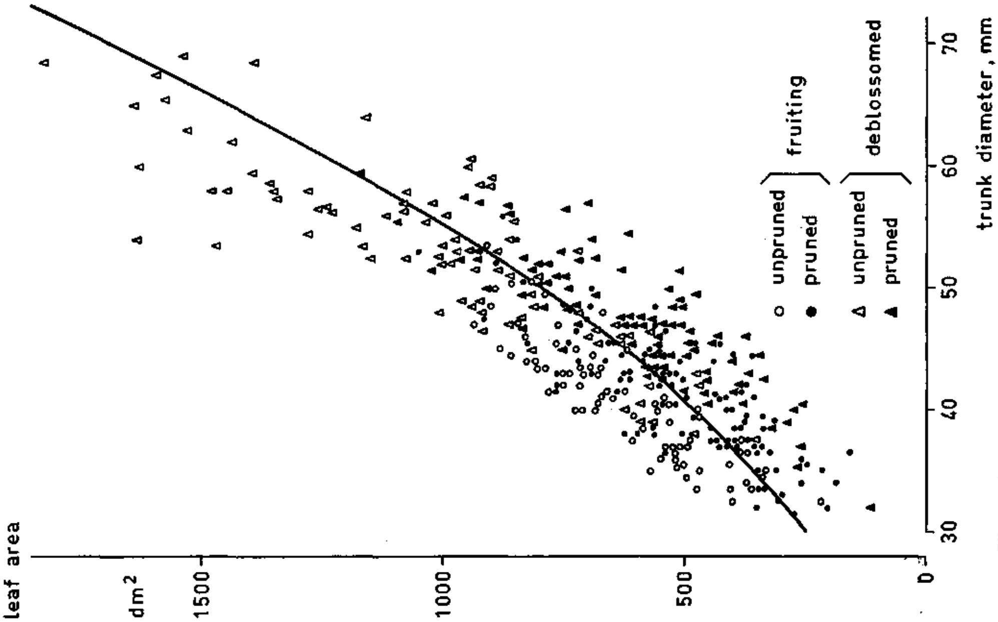

Illustration 18

tree growth as its increment. This involves raising trunk diameter to the power 2, which is close to the values 2.37 and 2.22 of the coefficient b in the regression equations for pruned and unpruned trees respectively. The power 2 is preferred to the actual values of coefficient b, because of its simplicity and because trunk cross sectional area as such is a meaningful characteristic. It is only natural that pruning depresses tree weight in relation to trunk size and it is well to bear in mind that if tree size and growth had been expressed on a fresh weight basis, the lead of the unpruned treatments would have been accentuated.

Measurements of tree foliation and shoot growth are time-consuming and if trunk diameter were a good estimator for these tree characteristics, this would greatly simplify experimental procedures. However, from the analysis emerged a complicated pattern of relationships, due to significant differences between groups of treatment combinations, deblossoming and pruning being the most influential factors. The correlation coefficients shown in table 11 for the overall regression equations for trunk diameter versus leaf weight ($R = 0.89$) and versus leaf area ($R = 0.85$) are high, but the levels of significance show that treatment combinations differ in respect of intercept. The scatter diagram for the relation trunk diameter – leaf area, presented in illustration 18, shows that unpruned trees have a relatively large leaf area, in agreement with their relatively large tree weight. Thus trunk diameter may be an acceptable estimator for leaf weight or leaf area, but the actual relationship should be determined for each set of data.

The same applies to the relationship between trunk diameter and shoot number or shoot length, over the period 1966–1969 as well as over 1969. Table 11 gives the overall regression equations. Just as for leaf weight and area, the regression equations. Just as for leaf weight and area, the regression lines for various treatment combinations differ significantly in respect of intercept. The pattern of these differences was similar to that for leaf weight and leaf area.

Tree volume was calculated on the basis of measurements of tree height and spread. The scatter diagram showed that trunk diameter was poorly correlated with tree volume. Difficulties in defining the tree perimeter, aggravated by the overlapping of trees at close spacing, may partly explain the lack of correlation. The effects of competition on tree shape, reported in section 3.2 on p. 9, strengthen the impression that it is extremely difficult to properly asses tree volume in spacing trials.

For 'Lired' VII no data on shoot growth and tree volume were available. The relationships between trunk diameter and tree weight and tree foliation were similar to those for Delicious IX, but they were not so well defined, due to the smaller numbers of trees measured. As a result fewer significant differences between regression lines for different treatment combinations could be traced. As for Delicious IX, all differences which were significant referred to the intercepts of the regression lines, not to the slopes.

4. DISCUSSION

4.1. Effects of Alar sprays.

The effects of Alar agreed fairly well with the findings of other workers. The reduction of shoot length on treated trees has been well-established. The small leaf size of treated trees is in agreement with the results obtained by SCHUMACHER and FANKHAUSER (1967); however these workers found no effect on leaf thickness. In another paper (1968) these authors also report a reduction in the weight of prunings of treated Golden Delicious trees. This is probably due to the most vigorous shoots – often concentrated near the tree top – being most retarded, so that on treated trees these shoots could partly be retained. For young trees grown in containers with glass panes, SCHUMACHER, FANKHAUSER and SCHLÄPFER (1967) showed a substantial depression in the extension growth of the roots of treated trees. If this effect accumulates over the years, it may explain the declining root density with increasing distance from the trunk of treated trees.

There are few reports on the cumulative effect of Alar on trees treated annually over a series of years. In a trial with Winston IX, WERTHEIM (1970, 1971) showed that Alar sprays a few weeks after full bloom for 4 consecutive years substantially retarded shoot growth in each year; increased flowering and reduced June drop resulted in higher yields per tree up to the fourth year, when the control trees yielded equally well.

There are several indications in the literature that Alar is most effective on vigorously growing, poorly cropping trees and most trials are carried out with trees in this condition. Golden Delicious on a dwarfing rootstock does not come in this category. Moreover, the experimental treatments such as deblossoming and leaving trees unpruned, do not leave much scope for promoting fruiting at the expense of extension growth. Thus it is not surprising that the cumulative effect of Alar was slight in comparison with WERTHEIM's findings for the less precious Winston trees. Nevertheless the Alar spray in the first year substantially improved the balance between growth and yield. The principal benefit of annually repeated Alar treatment was the reduction in the weight of prunings, which seems to reflect more balanced competitive relations between shoot growth in various parts of the tree.

4.2. Effects of fruiting.

The effects of fruiting cannot be accurately assessed because of increased flowering and delayed foliation of the deblossomed controls. Nevertheless, comparison of fruiting and deblossomed trees yields valuable information. The main effects of fruiting were the influence on tree habit as shown in illustration

3 and 4 on p. 14 and 15, the depression of tree growth (illustration 8 on p. 21) and the greatly enhanced dry matter increment per unit leaf area (illustration 16 on p. 32). Effects on tree habit include the reduction of tree height (table 5 on p. 12), of percentage of long shoots (table 6 on p. 12) and of leaf weight per unit leaf area (table 7 on p. 13).

There has been a number of experiments in which some of these effects of fruiting have been observed. BARLOW (1966) and AVERY (1969) found that cropping depressed the number and length of extension shoots. MAGGS (1963) observed that leaves were slightly smaller on cropping trees, but did not report a reduction of weight per unit leaf area.

That fruiting depresses growth has been well established. In a long-term experiment involving deblossoming, BARLOW (1964) found that the decrease in trunk thickening and in shoot growth on fruiting trees was correlated with the weight of the crop, above a 'threshold'. The existence of a 'threshold' is also suggested by the data for 'Lired' VII, which showed (illustration 10A on p. 24) that the size of the cropping trees was only slightly inferior to that of the deblossomed trees, although the cumulated yield of the cropping trees amounted to 20–60 tons on a per ha basis. In the off-year 1968, a yield of about 8 tons per ha for the closely spaced cropping trees did not depress trunk thickening (illustration 10B on p. 324).

That trees can carry some fruit without repercussions on growth is explained by the higher net assimilation rate of the leaves of cropping trees. MAGGS (1963) and AVERY (1969) calculated increments in the overall efficiency of the leaves of fruiting trees of 16 and 21 % respectively, in comparison with the leaves of deblossomed controls. Illustration 16 on p. 32 suggested much higher increments of foliar efficiency of the cropping trees, but the delayed foliation of the deblossomed trees depressed leaf area duration, precluding a fair comparison.

Data of CHANDLER and HEINICKE (1926), MAGGS (1963) and AVERY (1969) indicate that only very little dry matter is removed by deblossoming, but substantial dry matter losses may have been incurred by the metabolic activity of the numerous flowers on the deblossomed trees. Thus it is likely that in addition to the late start of shoot growth on these trees, the growth rate of the shoots was also slowed down, due to the depletion of reserves. In both 1968 and 1969 it was observed that following deblossoming the leaves developed slowly and were pale green. The dry matter increment of the deblossomed trees and consequently the increment in tree size could presumably have been much larger in the absence of excessive flowering.

4.3. EFFECTS OF PRUNING.

Pruning had a dramatic effect on tree habit, as shown in illustrations 3 and 4 on pp. 14 and 15. Pruning also reduced tree size (illustration 8 on p. 21) and, more important, yield per unit growth (illustration 13 on p. 27), but it improved mean weight per fruit (table 2 on p. 9).

The effects on tree habit are inherent to the dual function of pruning: to eliminate undesired growth and to stimulate desirable growth. A tree in winter rest can be considered as a collection of growing points, concentrated near the extremities, and a store of reserves, concentrated in the framework of the tree. Pruning inevitably reduces the number of growing points, while increasing the quantity of reserves per remaining growing point. The effect is a more forceful development of the activated growing points. The experimental results showed that pruned trees indeed had longer shoots (table 1 on p. 8) with bigger leaves (table 7 on p. 13) and per shoot a larger number of roots were available than in unpruned trees (illustration 6, p. 17).

The removal of undesired growth simplified the pattern of branching, an effect that presumably was reinforced by a strengthening of correlative inhibition, because on pruned trees relatively few buds formed a shoot (table 6 on p. 12). Moreover, pruning accentuated the dominating position of the tree top, as evidenced by greatly stimulated height growth (table 5 on p. 12) and increased slenderness ratios (table 4 on p. 11). This points to a change in the pattern of correlative inhibition in pruned trees.

The reduction in the size of pruned trees depended on fruiting. If yields severely check growth, as in the unpruned Delicious IX, the yield reduction brought about by pruning allows for compensatory growth. Thus pruning only slightly reduced the size of fruiting Delicious IX, because the loss of prunings was largely compensated by more vigorous growth, generated at the expense of yield. If yields are too low to markedly check growth, as in the unpruned 'Lired' VII, pruning – although depressing yields – will not lead to compensatory growth. Consequently pruning greatly depressed the size of both fruiting and deblossomed 'Lired' trees.

The reduction of tree size led to lower estimates of dry matter yield for the pruned trees in 1969 (illustration 15, p. 30). On the other hand estimated dry matter yield per unit leaf area was slightly increased by pruning (illustration 16, p. 32).

The reduction in the yield per unit growth was probably due to the removal of flower buds by pruning, to poorer fruit retention due to competition from vigorously growing shoots and to the formation of fewer flower buds as a consequence of the continuation of extension growth till late in the season.

The increase in the size of fruit due to pruning was not only borne out by a higher mean weight per fruit, but also by a substantial improvement in the frequency distribution of fruit size of Delicious IX (illustration 14, p. 29). As trees get older, mean weight per fruit declines and pruning becomes indispensable to ensure that a high percentage of the fruit will reach the desired size. For 'Lired' VII pruning did not affect fruit size convincingly until 1969, when the first heavy crop was produced. Fruit size is also increased by fruit thinning, but thinning appeared not to be quite as effective as pruning (table 10 on p. 28).

A study of individual trees in the trial by Mr. A. SCHOUTEN, student at the Agricultural University, Wageningen, showed that fruit size was not noticeably influenced by pruning intensity, defined as weight of prunings per cm^2 trunk cross section. This strengthens the impression that the fruiting trees in the trial have been pruned rather hard. Judged by the weight of prunings (table 3 on p. 11) the deblossomed trees have been pruned even harder. The reason is that the growth response to pruning in the deblossomed trees was rather unbalanced and unpredictable, necessitating further hard pruning and bending of branches to maintain an acceptable tree shape. Apparently fruiting moderates the growth response to pruning, an effect which is similar to that of Alar sprays.

The results are in agreement with the literature on pruning, as reviewed by JONKERS (1960). JONKERS also lists more vigorous extension growth, larger leaves and fruits and a reduction in tree size and yield per tree as major effects of pruning. The overall pruning effects in the trial are rather unfavourable. This may have been due to relatively hard pruning, especially at close spacing. If the framework branches at close spacing had not been removed in the beginning, the problems in respect of tree shape would probably not have developed so early in tree life. Another measure to slow down height growth, nowwidely applied, would have been to set the central leader back on a two-year-old lateral, rather than on a shoot. A two-year-old branch does not adjust so quickly to the role of central leader and if it bears fruit the growth response is generally moderated.

It appears from these findings, that young trees should not be pruned hard. The sole reason for pruning young trees is to shape the tree in order to set the pattern for future expansion. In high density orchards there is little need for formative pruning since trees remain small. In low density orchards tree shape is important; however if the vigorous non-bearing trees in such orchards react to pruning in a similar way as the deblossomed trees in the trial, the price for a well shaped tree is rather high. The reduction in tree size delays the expansion of the cropping volume and the adverse effects of pruning on yield per unit growth further retard the onset of fruiting. Moreover, the unbalanced growth response of non-bearing trees frustrates the efforts to shape the tree.

This conclusion is in agreement with WERTHEIM's (1970) recommendations for pruning high density orchards, based on practical experience in the Netherlands during the last few years. Light pruning is advised and the emphasis is on renewal pruning. Formative pruning is largely restricted to slowing down height growth in varieties which have a prominent central leader.

As the orchard gets older, pruning becomes essential to rejuvenate the fruiting wood and to improve fruit size. The results have shown that trees on a dwarfing rootstock may show prominent symptoms of ageing within a few years from budding. This is probably associated with the extremely short period of purely vegetative growth on these rootstocks. In this situation the principal function of pruning is to prolong the productive life span of the tree.

Whereas the young trees in the trial presumably would have responded much better to lighter pruning, especially at close spacing, it is to be expected that nevertheless the adverse effects of pruning on growth distribution over the tree and particularly on yield per unit growth, would have eventually become manifest.

4.4. Effects of tree spacing.

The study covers only the first 5 years from planting, too short a period to fully clarify the effects of tree spacing on orchard growth and yield. However, as the close spacings were fairly extreme, inter-tree competition clearly affected tree size, tree habit, yield and fruit quality.

That competition at close spacing reduces plant size is a well-known phenomenon. In the trial the effects of inter-tree competition soon became manifest. As early as 1966, the second year after planting, tree growth at close spacing was lagging behind (illustration 8B on p. 21) and by the end of 1969 the differences in tree size were substantial (illustration 8A). From the regression equations in section 3.8 it can be inferred that if tree weight or leaf area per tree had been used as measures of tree size instead of trunk cross section, the differences between closely and widely spaced trees would have been even larger.

The effect of inter-tree competition on tree habit found expression in a top-heavy appearance (illustration 4, p. 15) and marked increases in tree slenderness (table 4, p. 11), associated with stimulated height growth (table 5, p. 12) and a simpler pattern of ramification (table 6, p. 12). Most reports on spacing trials give little information regarding plant habit. A slender habit, due to the suppression of lateral growth, has been observed in peppers (Verheij, 1970 a). It has a parallel in the suppression of tillering in cereal crops (Bruinsma, 1966) and reduced sucker formation in bananas (Ahmed and Mannan, 1970) at high density. Substantial increases in plant height at close spacing have been reported for oil palm (Smith, 1960), bananas (Ahmed and Mannan, 1970) and Brussels sprouts (Verheij, 1970 b), all plants with a dominating apical meristem.

Presumably the favourable position of the plant apex in respect of light interception supports apical growth and strengthens apical dominance. This explanation implies that light is the main factor competed for, at least for a part of the experimental period, which seems to be a reasonable assumption.

It is to be expected that flowering and fruiting suffer from these changes in tree habit at close spacing. For top-heavy trees growth in the apical region is too vigorous and in the shaded basal region it is too weak for optimal flowering and fruiting. Yield per tree was indeed more depressed at close spacing than growth, so that yield per unit growth declined with increasing density (illustration 13, p. 27). In the more extreme conditions of a dense forest stand, the lower branches are not even capable to sustain their own growth: the leaves fall early and the branches die back. Such conditions were also observed in the high density plots of a planting system experiment with Jonathan IV in Hungary (Verheij, 1969). The trial was planted in 1953. Over the period 1959–1962 yield per unit growth was much the same at all densities, but for the next 4-year period yield per unit growth at 1110 trees per ha was reduced to two-third of the value for plots with 120 to 740 trees per ha. Similarly, in a spacing trial with Golden Delicious on M IX and on M II planted in 1962, Verheij and Verwer (1972) found that from 1967 onwards yield per unit growth at close spacing for both stocks fell below the levels for plots with widely spaced trees. Larsen (1967) working with black currants and LE ROUX (1967) working with grapes, also found lower yields per unit growth at high density.

Spacing also affected fruit size. In 1969 mean weight per fruit of Delicious IX was lower at close spacing (table 2 on p. 9), associated with a substantial change in fruit size distribution (illustration 14 on p. 29). For 'Lired' VII the effect of spacing on mean weight per fruit was observed already in 1967 and in 1969 it was more prominent than for Delicious IX. Smaller fruit size at high density has been reported for field tomatoes (LOUGHTON, 1968), pine-apples (NIJENHUIS, 1967), black currants (LARSEN, 1967), pear (UITTERLINDEN, 1965) and apple (VERHEIJ, 1969).

From the fruit grower's point of view the effects of close spacing on tree habit and yield are unfavourable. Increased tree height and a top-heavy tree habit are undesirable; the reduction of yield per unit growth and of fruit size obviously are disadvantageous. On the other hand the grower is interested in the orchard rather than in the individual tree. The results confirm that – in spite of the reduction in growth and yield per tree – growth and yield per ha initially increased with density. The worldwide trend towards closer tree spacing is based primarily on this advantage.

However, comparison of the findings for Delicious IX and 'Lired' VII showed that the superiority of yield at high density was much greater and persisted longer for Delicious IX. Cumulative yields for unpruned Delicious IX over 1966–1969 amounted, to 43, 63, 79 and 100 tons per ha for mean densities of 925, 1275, 1820 and 2645 trees per ha respectively and the lead of the highest density was still increasing in 1969. The corresponding figures for unpruned 'Lired' VII were 33, 45, 56 and 58 tons per ha and yields over 1968 and 1969 were slightly higher at 1820 than at 2645 trees per ha.

The yield depression for 'Lired' VII at the highest density is a logical consequence of the adverse effects of close spacing on growth and yield per tree. As trees get older and competitive stress increases, serious problems in respect of growth control and inferior yields are to be expected over an increasing range of high densities. Overcrowding and a drop in yield at close spacing below the level at wider spacings have indeed been observed in the Hungarian planting system trial with apple (VERHEIJ, 1969) and in a similar large scale trial with oranges (BOSWELL, LEWIS, MC CARTY and HENCH, 1970). This last trial was planted in 1961 and comprises 11 spacings, ranging from 90 to 440 trees per acre. In 1964/65 the yield was highest at the closest spacing, but by 1966/67 it had fallen to the lowest level.

4.5. HIGH DENSITY ORCHARDS.

On the basis of the discussion in the previous section a high density orchard can be defined as an orchard with such a large number of trees per ha that in due course an orchard with a lower tree number per ha would give the same or higher yields. In view of the yields for 'Lired' VII in 1968 and 1969, it is to be expected that within a few years the highest yield will be attained at 1275 trees per ha, bringing all higher tree numbers per ha under the definition of high density orchards. For Delicious IX, on the other hand, there was no indication that yield at the highest density will soon be equalled or surpassed at lower densities. Thus, according, to the definition even 2645 trees per ha may prove to be a low density.

Results reported by HILKENBÄUMER and ENGEL (1969) suggest that the lower limits of high density under the conditions of their experiments were about 1000 trees per ha for Golden Delicious and Jonathan on M IV and over 2000 trees per ha for these varieties on M IX. In a trial on a sandy soil with trees growing rather weakly, VERHEIJ and VERWER (1972) concluded that less than 2000 and more than 3000 trees per ha were required for maximum yield of Golden Delicious on M II and on M IX respectively. More work needs to be done to establish the figures for other stock-scion combinations and for different growing conditions.

Two key questions emerge from the definition of high density orchards:

1. which factors govern the initial yield advantage of high density orchards;
2. what can be done to control tree growth and to maintain the yield level in high density orchards as trees mature?

Starting with the second question, the reduction of tree growth brought about by fruiting, makes fruiting the ideal means for relieving inter-tree competition. However, all growing techniques are already aimed at promoting regular and heavy cropping, irrespective of tree spacing. In precocious trees, such as Delicious IX, growth may be checked by reducing the degree of fruit thinning, but the dangers of deteriorating fruit quality and inducing biennial bearing severely limit this possibility. In the high density plots of a spacing trial with Golden Delicious on M IX and on M II (VERHEIJ and VERWER, 1972) for instance, heavy crops reducing the rate of trunk thickening, were associated with an unacceptable loss of tree vigour and poor fruit quality. Consequently, the yield level had to be lowered and the initial growth rate was resumed. Evidently tree growth has to be adequate to sustain the production of heavy crops of good quality. Moreover, once inter-tree competition begins to build up, the yield per unit growth declines, leaving less scope for regulating growth by fruit thinning.

On the other hand the risk of crop failure is the principal stumbling-block for the success of high density orchards. Chemical growth regulators may be applied to improve the balance between yield and growth. The effects of Alar on Delicious IX in the trial were small, but the literature regarding the influence of Alar on poorly cropping trees suggests that incidental use of Alar may be very effective in high density orchards.

Growers who plant high density orchards mainly rely on pruning to cope with overcrowding. However, the experimental results strongly suggest that pruning is not an effective means of relieving inter-tree competition in bearing trees, because the reduction of tree size was associated with a more than proportional reduction of yield. Moreover, both close spacing and pruning strengthened the domination of the tree top over the basal tree parts. Thus it will be rather difficult to redress overcrowding and a top-heavy tree habit by pruning without serious yield depressions. If hard pruning is required to check growth in the tree tops and to improve light conditions in the canopy, this indicates that tree spacing is too close in relation to tree vigour.

As an alternative to drastic pruning, grubbing of part of the trees should be considered. In several trials the response to tree thinning in overcrowded plots has been remarkably favourable. In the Hungarian experiment referred to before, thinning of part of the plots of 3 × 3 m tree spacing to 6 × 3 or 6 × 6 m greatly improved yield and fruit quality in comparison with the unthinned controls and restored yield per unit growth to the high level found in all low density plots. HILKENBÄUMER and ENGEL (1969) obtained better yields from Golden Delicious and Jonathan on M IV following thinning from 3 × 1,5 to 3 × 3 m, than from the trees which had been spaced at 3 × 3 m throughout. In the spacing trial with oranges in California, BOSWELL, LEWIS, Mc CARTY and HENCH (1970) recorded somewhat higher yields following removal of half the trees in the plots with 11 feet row spacing, than following hard pruning of the plots with 15 feet row spacing, in spite of the lower tree numbers per acre in the thinned plots.

It follows from this discussion that promotion of regular, heavy cropping – if necessary with the help of chemical growth regulators – can greatly slow down but not prevent severe inter-tree competition. Excessive growth can be removed and fruit quality can be improved by corrective pruning, but it is doubtful that pruning can restore yields to the level attained at wider tree spacings. This leaves tree thinning as the main remedy against the adverse effects of close spacing. The excellent response to tree thinning seems to justify the conclusion that it is indeed possible to control growth and to maintain equal yield over a wide range of high (initial) densities. This yield level represents the ceiling crop for orchards of a given planting system and age.

Attainment of ceiling crop is not limited to densities producing ceiling dry matter yield. For the production of ceiling dry matter yield considerable inter-tree competition, with a resulting drop in crop per unit growth, is inevitable. Hence the range of densities producing ceiling crop per ha also includes those lower densities for which the reduction in dry matter yield is compensated by increased crop per unit growth.

The answer to the first question, regarding the factors governing the initial yield advantage of high density orchards, is simple. The sooner growth is slowed down by fruiting, the longer it will take before inter-tree competition equalizes yield at different density and the greater will be the superiority of cumulative yield at high density over the early years of orchard life. High density orchards obviously are unattractive for stock-scion combinations which come into bearing after inter-tree competition makes itself felt. For such fruit crops the lower limit of high density represents the optimum tree number per ha. For stock-scion combinations which during their youth do not crop appreciably above the threshold level, the yield advantage of high densities is slight, not only because the crops are light but also because they do not check growth and therefore cannot retard the building-up of inter-tree competition. As the results for 'Lired'

VII show, the initial yield advantage at high densities for such fruit crops can hardly justify the investment in the extra trees. For precocious stock-scion combinations such as Delicious IX, however, a wider range of high densities deserves consideration, because of the cumulative effect of the high yields per tree and the delayed development of inter-tree competition. In this case tree number per ha depends mainly on the cost of buying and raising additional trees in relation to the value of the extra fruit produced.

The conclusion is that for intensive fruit growing only a limited range of high densities deserves consideration, particularly if trees come into bearing slowly, so that inter-tree competition becomes apparent before appreciable crops have been produced. In due course equal crops – ceiling yield – will be attained over this trajectory of high densities. If other measures fail, tree thinning must be relied upon to prevent a drop in yield at the higher densities of the range as the orchards get older.

It should be realized that the lower limit of high density and ceiling yield level depend on the planting system. The planting system determines to what extent the trees can exploit the environment. In the prevailing single row planting system a large proportion of the orchard is taken up by alleyways, required for the passage of machines; the proportion of alleyway space increases as more dwarfed trees come into use. As the trees cannot take full advantage of the alleyway space, inter-tree competition at equal density will be stronger and ceiling crop will be lower in the single row system than in multiple row systems, such as the bed system. In multiple row systems the number of alleyways is reduced and the trees are more evenly distributed over the orchard so that the incoming radiation and the soil factors can be more fully exploited. However, it remains to be shown whether – even for the smallest trees now in use, such as Golden Delicious IX – the increase in ceiling crop for bed system orchards is worthwhile in relation to the more complicated management techniques.

The possible need for tree thinning in overcrowded orchards brings up another consideration regarding the planting system. The response to tree thinning depends largely on the resulting canopy structure. Therefore flexible planting systems, allowing for favourable tree arrangements after (varying degrees of) tree thinning, are desirable. The argument for planting systems suited to tree thinning is strengthened by the fact that tree vigour of a newly-established orchard cannot be accurately predicted. If trees grow more vigorous than anticipated, tree thinning may be necessary even though this was not foreseen when the orchard was planted. The inability to predict tree vigour is one of the major obstacles for the practical application of results of yield-density studies.

5. SUMMARY

In the spring of 1965 a trial was planted with Golden Delicious IX and James Grieve 'Lired' VII, in which tree spacing, deblossoming, Alar sprays and pruning were variable factors. Results are presented over the period 1966–1969.

At the end of 1969, the 5th year from planting, 400 Delicious trees and 160 'Lired' trees were grubbed to measure tree weight and foliation. Tree weight was closely correlated to trunk diameter; for a given diameter pruned trees weighed slightly less than unpruned trees. The relations of leaf weight and leaf area per tree with trunk diameter were less well defined and varied more for different treatment combinations; the same applied to the relations of shoot number and total shoot length over 1966–1969 with trunk diameter at the end of 1969.

The grubbed trees were also used to collect data on dry matter yield for Delicious IX. Estimated dry matter yield per unit area in 1969 still increased with density, largely as a result of increasing 'leaf area indices'. Fruiting greatly enhanced dry matter yield per unit foliage and more than 50% of dry matter yield was recovered in the fruit. Pruning also tended to stimulate dry matter yield per unit leaf area; it raised the share of dry matter accumulated in the tree frame, at the expense of the share for leaves and fruit. A large proportion of dry matter increment in the tree frame was removed by pruning.

Inter-tree competition at close spacing manifested itself in reduced growth and yield per tree, in lower yields per unit growth, in a reduction of mean weight per fruit and in the tendency of the trees to become top-heavy as a result of accelerated height growth and suppressed growth in the basal portion of the trees. These effects became more prominent with increasing age, suggesting that at the closest spacings it will be difficult to control growth and to prevent yield depressions as the trees get older. This leaves the superiority of yield during the early years of orchard life as the main advantage of close spacing.

Initially yield per ha was indeed higher at close tree spacings. Cumulative yields of unpruned Delicious IX over 1966–1969 amounted to 43, 63, 79 and 100 ton per ha for mean densities of 925, 1275, 1820 and 2645 trees per ha respectively; in 1969 yield still increased with density. The corresponding figures for 'Lired' VII were 33, 45, 56 and 58 ton per ha and in 1968 and 1969 yield tended to level off at densities beyond 1275 trees per ha. Yields of Delicious IX virtually all exceeded 1 kg per cm^2 trunk cross section and greatly reduced growth in comparison with the deblossomed controls. Yields of 'Lired' VII generally remained well below this level and only slightly reduced growth. In spite of the large growth reduction caused by the heavy Delicious crops, symptoms of inter-tree competition were still evident at close spacing. For the less precocious 'Lired' trees fierce inter-tree competition led to serious problems in respect of growth control at close spacing by the end of the period under study.

Alar was sprayed only on Delicious IX. In the first year of application it

reduced shoot growth and improved fruit retention. Continued application in subsequent years did not affect yield but slightly reduced growth and changed root distribution; pruning weights of treated trees were much smaller, suggesting a more balanced distribution of growth over the tree. Although the effects of Alar on Delicious IX were small, incidental use of Alar on poorly cropping stock-scion combinations may be much more effective in checking inter-tree competition.

Relieving inter-tree competition by winter pruning had very unfavourable side effects. It did reduce tree size, especially at low yield levels, but yield was reduced even more. Moreover, pruning strengthened the dominating position of the tree top; hence it was extremely difficult to correct the top-heavy habit of closely spaced trees by pruning. Nevertheless some pruning was necessary to rejuvenate the fruiting wood and to increase fruit size, especially for Delicious IX. Fruit thinning was not quite as effective as pruning for improving fruit size and quality. Pruning of deblossomed trees had only adverse effects: it kept the trees much smaller and the growth response was unbalanced, necessitating further pruning and bending of branches to maintain an acceptable tree shape. These findings confirm that pruning is a useful instrument for regulating competitive relations within the tree, at least for fruiting trees, but they also indicate that pruning is of little value for reducing competitive stress between trees.

A high density orchard is defined as an orchard with such a large number of trees per ha that in due course an orchard with a lower tree number per ha would give the same or higher yields. It is concluded that for intensive fruit growing only high densities deserve consideration. For stock-scion combinations such as 'Lired' VII, which do not produce substantial crops before inter-tree competition makes itself felt, the optimum tree number per ha is close to the lower limit of high density. For precocious stock-scion combinations such as Delicious IX, a wider range of high densities may be attractive, depending mainly on the cost of buying and raising additional trees in relation to the extra fruit produced in the early years. In due course equal yield, representing the ceiling crop for orchards of a given planting system and age, will be attained over this range of densities.

Tree thinning is recommended to prevent overcrowding and yield depressions at the higher densities of the range, in case other measures – such as promotion of regular heavy cropping and judicious pruning – are inadequate.

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7. SAMENVATTING:

(CONCURRENTIE BIJ APPEL ONDER INVLOED VAN ALAR-BESPUITINGEN, VRUCHTDRACHT, SNOEI EN PLANTAFSTAND)

Proefopzet

In de lente van 1965 werd een proefboomgaard ingeplant met tweejarige bomen van Golden Delicious IX en James Grieve 'Lired' VII. De behandelingen behelsden een factoriële combinatie van een reeks plantafstanden (gemiddelde plantdichtheden van 925, 1275, 1820 en 2645 bomen per ha), al dan niet snoeien, al dan niet ontbloemen en al dan niet bespuiten met Alar. De resultaten over de periode 1966–1969 worden besproken.

Relaties tussen groeikenmerken

Na de oogst van 1969 werden 400 Delicious bomen en 160 'Lired' bomen gerooid om boomgewicht en bebladering te meten. Er bleek een nauw verband te bestaan tussen boomgewicht en stamdoorsnee; bij gelijke stamdoorsnee wogen gesnoeide bomen iets minder dan ongesnoeide bomen. De relaties van bladgewicht en bladoppervlak met stamdoorsnee lagen minder duidelijk vast en verschilden meer voor diverse behandelingen; hetzelfde gold voor het verband van aantal scheuten en totale scheutlengte over 1966–1969 met de stamdoorsnee eind 1969.

Droge-stof-produktie in 1969.

De gegevens van de gerooide Delicious bomen werden ook gebruikt om de droge-stof-produktie in 1969 – het 5e groeijaar – te schatten. Op deze leeftijd nam de droge -stof-produktie nog steeds toe met hogere plantdichtheid, voornamelijk dank zij het toenemende bladoppervlak per m^2 grondoppervlak. Vruchtdracht leidde tot een sterke toename van de droge-stof-produktie per dm^2 bladoppervlak en meer dan de helft van de totale droge-stof-produktie bleek in de vruchten te zitten. Bij gesnoeide bomen was ook een tendens tot hogere droge-stof-produktie per eenheid blad waarneembaar; snoei verhoogde het droge -stof-aandeel van het boomgestel, ten koste van het aandeel van bladeren en vruchten. Een groot deel van de droge-stof-toename in het boomgestel werd bij de snoei weggenomen.

Invloed van de plantafstand; problemen bij 'hoge' plantdichtheden.

In onderstaand overzicht zijn de waargenomen invloeden van dicht planten op de jonge boom (A) en de op grond hiervan op den duur te verwachten invloeden op de boomgaard (B) samengevat.

A	B
Invloeden van dicht planten op de jonge boom:	Te verwachten effecten op de boomgaard over een toenemend trajekt van hoge plantdichtheden:
a. achterblijvende groei en vruchtdracht;	gelijke droge-stof-produktie;
b. minder vertakkingen onder- en bovengronds; versterkte hoogtegroei; slankere boomvorm;	problemen t.a.v. de groeibeheersing;
c. lagere vruchtdracht per eenheid groei;	kleinere oogst per ha;
d. kleinere vruchten;	problemen t.a.v. de vruchtkwaliteit.

De gewasreakties bij nauwe plantafstanden zijn een gevolg van concurrentie tussen de bomen onderling; de invloeden op de boomvorm duiden op concurrentie om licht.

Een plantdichtheid is gedefinieerd als hoog, wanneer het aantal bomen per ha zo groot is dat op den duur gelijke of grotere oogsten kunnen worden behaald met een lager aantal bomen per ha.

De definitie houdt in dat zich bij hoge plantdichtheid problemen betreffende de groeibeheersing en de oogstgrootte voordoen als de bomen ouder worden en dat het voordeel vooral moet worden gezocht in de meerproduktie van fruit gedurende de jeugd.

Middelen ter beheersing van groei en produktie bij 'hoge' plantdichtheden.

Vruchtdracht is uiteraard het meest effektieve middel om de groei – en daarmee de concurrentie tussen de bomen onderling – te remmen, althans boven een zekere 'drempelwaarde'. De oogsten van 'Lired' VII lagen in het algemeen ruim onder het niveau van 1 kg per cm^2 stamdoorsnee en remden de groei maar weinig in vergelijking met de ontbloemde controles; de oogsten van Delicious IX lagen vrijwel alle boven dit niveau en remden de groei sterk. Daarbij moet in aanmerking worden genomen dat de groei van de ontbloemde bomen ook geremd werd, namelijk door een uitputtende bloei en vertraagde bladontwikkeling.

Ongesnoeide Delicious IX leverde veruit de grootste oogsten, maar ook bij deze behandeling traden symptomen van concurrentie tussen de bomen aan het licht. Om jaarlijks een volwaardige oogst te produceren, moet de groeikracht toereikend zijn. Vruchtdracht kan dus de toename van de concurrentie tussen bomen bij hoge plantdichtheden wel vertragen maar niet voorkomen.

De groeiremmer *Alar* was in de proef opgenomen om de concurrentie tussen bomen te verminderen, mede door bevordering van de vruchtdracht. Alar werd alleen toegepast op Delicious IX. In het eerste jaar remde Alar de scheutgroei en vergrootte het de vruchtdracht dank zij verminderde rui. Toepassing in volgende jaren beïnvloedde de oogst niet, maar remde wel de groei enigszins en leidde bovendien tot veranderingen in de bewortelingsdichtheid. De snoeihoutgewichten van met Alar bespoten bomen waren veel lager, hetgeen een evenwichtiger verdeling van de scheutgroei over de boom suggereert. De invloed van Alar was klein, maar de mogelijkheid blijft open dat Alar – of een andere groeiregulerende stof – bij minder vruchtbare ras-onderstam-combinaties een veel gunstiger effekt op de concurrentieverhoudingen heeft.

Fruittelers vertrouwen vooral op de *snoei* om de groei in dichte beplantingen te beheersen. Snoei beperkte inderdaad de boomgrootte, vooral bij ontbloemde bomen en lage produktie-niveau's ('Lired' VII). De neven-effecten waren echter zeer ongunstig: snoeien verminderde de vruchtdracht per eenheid groei en versterkte de dominerende positie van de boomtop. Het bleek daarom uitermate moeilijk om de topzware boomvorm bij de nauwste plantafstanden door snoei te corrigeren en dit ging gepaard met aanzienlijke produktieverliezen.

Niettemin was snoei bij dragende bomen noodzakelijk om het vruchthout te verjongen en daarmee de groeikracht en de vruchtgrootte te verbeteren. Vruchtdunning had een minder gunstig effect op vruchtgrootte en -kwaliteit dan snoei. De vruchtgrootte hing niet samen met de mate van snoei, hetgeen er op wijst dat met een lichtere snoei had kunnen worden volstaan. Snoei van ontbloemde bomen had een averechtse uitwerking: de bomen bleven veel kleiner en de groeireaktie was onevenwichtig, zodat nog meer snoei en uitbuigen nodig waren om een acceptabele boomvorm te krijgen.

De snoei is derhalve een goed middel om de concurrentiedruk binnen de boom te regelen, maar is weinig geschikt om de concurrentiedruk tussen bomen onderling te verlichten. Waar bevordering van de vruchtdracht, eventueel met groeiregulatoren, en snoei falen, is men aangewezen op het rooien van een deel der bomen. Blijkens de literatuur zijn met boomdunning in te dichte boomgaarden inderdaad uitstekende resultaten bereikt. Dit wettigt de conclusie dat het mogelijk is om de groei te beheersen en gelijkwaardige oogsten te verzekeren over een aanvankelijk breed trajekt van hoge plantdichtheden.

Meerproduktie in de jeugd bij hoge plantdichtheden.

De meerproduktie bij hoge plantdichtheden gedurende de jeugd wordt vooral bepaald door de mate waarin de concurrentie tussen vruchtdracht en groei per boom de toename van de concurrentie tussen de bomen onderling vertraagt. De cumulatieve oogst over 1966–69 voor ongesnoeide Delicious IX bedroeg 43, 63, 79 en 100 ton per ha bij gemiddelde plantdichtheden van respectievelijk 925, 1275, 1820 en 2645 bomen per ha. Deze oogsten beperkten de concurrentie tussen de bomen onderling zodanig dat ook in 1969, het 5e groeijaar, de oogst nog het grootst was bij de hoogste plantdichtheid. De overeenkomstige oogsten voor ongesnoeide 'Lired' VII bedroegen 33, 45, 56 en 58 ton per ha. In het 4e en 5e jaar na planten was de oogst bij 1820 bomen per ha al iets hoger dan bij 2645 bomen per ha en het valt te verwachten dat op wat hogere leeftijd alle boomaantallen groter dan 1275 per ha onder de definitie van hoge plantdichtheid zullen vallen.

Conclusie.

De conclusie luidt dat voor intensieve fruitteelt slechts hoge plantdichtheden in aanmerking komen. Voor ras-onderstam-combinaties zoals 'Lired' VII, die zo traag in produktie komen dat de concurrentie tussen bomen onderling zich doet gelden vóór aanzienlijke oogsten zijn geproduceerd, ligt het optimale aantal bomen per ha dicht bij de ondergrens van de als hoog gedefinieerde plantdichtheden. Voor vroeg vruchtbare ras-onderstam-combinaties zoals Delicious IX verdient een ruimer trajekt van hoge plantdichtheden overweging; de keuze hangt vooral af van de verhouding tussen de waarde van de meerproduktie en de kosten van de extra bomen. Na verloop van tijd worden over dit trajekt van plantdichtheden gelijke oogsten geproduceerd, die het produktie-plafond voor boomgaarden van die leeftijd vertegenwoordigen. Als andere maatregelen falen, is boomdunning het aangewezen middel om als de bomen ouder worden oogstdepressies over het dichtere deel van dit trajekt te voorkomen.

Het produktie-plafond hangt mede af van het plantsysteem, omdat dit bepalend is voor de mate waarin de bomen de milieu-faktoren kunnen benutten. Bij de gangbare rijenteelt kunnen de bomen slechts ten dele profiteren van de bodemfaktoren en het binnenvallende licht in de rijpaden. Dit bezwaar wordt ernstiger naarmate de boomgrootte afneemt; voor zeer kleine boomvormen bieden daarom plantsystemen met minder rijpaden, zoals de beddenteelt, voordelen. Overigens is het van belang dat intensieve plantsystemen zich lenen voor het rooien van een deel der bomen, temeer omdat de groeikracht van nieuwingeplante boomgaarden onvoldoende nauwkeurig kan worden voorspeld.

8. LITERATURE

AHMED, K. and MANNAN, A. (1970). Effects of size of pit and spacing on the performance of Amritsar banana. Punjab Fruit J. **32**, (110/111): 7–13.

AVERY, D. J. (1969). Comparisons of fruiting and deblossomed maiden apple trees, and of non-fruiting trees on a dwarfing and an invigorating rootstock. New Phytol. **68**: 323–336.

BARLOW, H. W. B. (1964). An interim report on a long-term experiment to assess the effect of cropping on apple tree growth. Rep. E. Malling Res. Stn. for 1963: 84–93.

BARLOW, H. W. B. (1966). The effect of cropping on the number and kind of shoots on four apple varieties. Rep. E. Malling Res. Stn. for 1965: 120–124.

BARLOW, H. W. B. (1969). The relation of leaf area to stem cross-section. Rep. E. Malling Res. Stn. for 1968: 117–119.

BASKERVILLE, G. L. (1962). Production in forests. Canada Dept. of Forestry, Maritime Region, Fredericton, N.B.: 85 pp. (mimeo).

BIBLE, B. B. and RIES, S. K.: Theoretical considerations for culture of ultra high density apple plantings. *Michigan Agric. Exp. Stn., J. Article No 4738, unpublished.*

BLAAS, H. J. (1959). (A new planting system.) Fruitteelt **49**, (4): 91–93 (Dutch).

BLEASDALE, J. K. A. (1966). Plant growth and crop yield. Ann. appl. Biol. **57**: 173–182.

BOSWELL, S. B., LEWIS, L. N., Mc CARTY, C. D. and HENCH, K. W. (1970). Tree spacing of 'Washington' Navel orange. J. Amer. Soc. Hort. Sci. **95**, (5): 523–528.

BRUINSMA, J. (1966). Analysis of growth, development and yield in a spacing experiment with winter rye (Secale cereale, L). Neth. J. of agric. Sci. **14**, (8): 198–214.

BYASS, J. B. (1968). Equipment and methods for orchard spray application research. II. The geometry of apple trees. J. agric. Engng. Res. **13**, (4): 358–369.

CHANDLER, W. H. and HEINICKE, A. J. (1926). The effect of fruiting on the growth of Oldenburg apple trees. Proc. Amer. Soc. Hort. Sci.: 36–45.

DONALD, C. H. (1963). Competition among crop and pasture plants. Advances in Agronomy **15**: 1–118.

FREEMAN, G. H. (1964). The use of a systematic design for a spacing trial with a tropical tree crop. Biometrics **20**, (1): 200–203.

HANSEN, P. (1970). ^{14}C-studies on apple trees. VI. The influence of the fruit on the photosynthesis of the leaves, and the relative photosynthetic yields of fruits and leaves. Physiol. Plant. **23**: 805–810.

HILKENBÄUMER, F. and ENGEL, G. (1969). Dichtpflanzungen mit Kernobst. Erwerbstobstbau **11**, (7): 1–23.

HOLLIDAY, R. (1969). Theoretical aspects of plant population and crop yield. Proc. Seminar on Intensification of Coffee Growing in Kenya, Nairoby 1968: 19–26.

HUDSON, J. P. (1971). Meadow orchards. Agriculture, **78**, (4): 157–160.

JONKERS, H. (1960). (Backgrounds of the pruning of fruit trees.) Meded. Dir. Tuinb. **23**, (12): 793–801 (Dutch, Engl. summ.).

LARSEN, F. (1967). (Spacing trial with black currants.) Årsskrift Kon. Vet. og Landbohøjskole 1968: 49–58 (Danish, Engl. summ.).

LIMING, F. G. (1957). Homemade dendrometers J. of Forestry **55**, (8): 575–577.

LOETERS, J. W. J. and NOTENBOOM, L. (1969), (Simple method for root sampling.) Spons, Meded. RTC Bodemaangelegenheden Wageningen (10): 7–8 (Dutch).

LOUGHTON, A. (1968). Effects of plant density on yields of field tomatoes. Rep. Hortic. Res. Inst. Ontario 1967: 35–37.

MAGGS, D. H. (1963). The reduction in growth of apple trees brought about by fruiting. J. Hort. Sci. **38**: 119–128.

MOORE, C. S. (1966). The relationship of increment in trunk girth with shoot growth in apple trees. Rep. E. Malling Res. Stn. for 1965: 115–119.

NELDER, J. A. (1962). New kinds of systematic designs for spacing experiments. Biometrics **18**: 283–307.

NYENHUIS, E. M. (1967). Espacement experiment with Queen pineapples in Natal. Agric. Res., Dept. of Agric. Techn. Serv., South Africa, part I: 140–141.

PEARCE, S. C. (1952). Studies in the measurement of apple trees. I. The use of trunk girths to estimate tree size. Ann. Rep. E. Malling Res. Stn. for 1951: 101–104.

ROUX, M. S. le, (1967). Comparison of different types of trellises for table grapes. Agric. Res., Dept. of Agric. Techn. Serv., South Africa, part I: 74.

SCHUMACHER, R. and FANKHAUSER, F. (1967). Einflusz des Schnittes und Auswirkungen von Hemmstoffspritzungen auf die Blatt- und Triebentwicklung der Apfelbäume. Schweiz. Landwirtsch. Forsch. **6**, (2): 131–147.

SCHUMACHER, R. and FANKHAUSER, F. (1968). Untersuchungen über die Schnittholzmenge bei Apfelbäumen nach Anwendung des Hemmstoffes Alar. Schweiz. Landwirtsch. Forsch. **7**, (2): 148–160.

SCHUMACHER, R., FANKHAUSER, F. and SCHLÄPFER, E. (1967). Einflusz des Hemmstoffes Alar auf Fruchtentwicklung, Wurzelwachstum und Triebaufbau der Apfelbäume. Schweiz. Landwirtsch. Forsch. **6**, (2): 148–169.

SLY, J. M. A. and CHAPAS, L. C. (1963). The effect of various spacings on the first 16 years of growth and production of the Nigerian oil palm under plantation conditions. J. of WAIFOR **4**, (13): 31–45.

TELFER, E. S. (1969). Weight-diameter relationships for 22 woody plant species. Can. J. Bot. **47**: 1851–1855.

UITTERLINDEN, L. (1965). (Plant spacing, yield and fruit size for pears.) Fruitteelt **55**, (45): 1320–1322 (Dutch).

VERHEIJ, E. W. M. (1969). Yield-density relations in apple; results of a planting system experiment in Hungary.)Publ. 37, ITT Wageningen: 31 p.

VERHEIJ, E. W. M. (1970a). Plant spacing and mechanisation in horticulture. Span **13**, (3): 161–164.

VERHEIJ, E. W. M. (1970b). Spacing experiments with Brussels sprouts grown for single-pick harvest. Neth. J. agric. Sci. **18**: 89–104.

VERHEIJ, E. W. M. and VERWER, F. L. J. A. W. (1972). Yield-density relations for apple trees on a dwarfing and a semi-dwarfing rootstock. Neth. J. agric. Sci., in the press.

VERHEIJ, E. W. M. and VRIES, H. C. P. de, (1966). (Is there scope for a bed system in fruit growing?) Meded. Dir. Tuinb. **29**, (8): 338–343 (Dutch, Engl. summ.).

WERTHEIM, S. J. (1970a). The training of the slender spindle of four apple varieties. Meded. 10, Proefst. Fruitteelt, Wilhelminadorp: 158p.

WERTHEIM, S. J. (1970b). (Research work with tree fruits.) Jaarverslag Proefst. Fruitteelt, Wilhelmina dorp 1969: 29–41 (Dutch, Engl. summ.); see p. 35–37.

WERTHEIM, S. J. (1971). (Research work with tree fruits.) Jaarverslag Proefst. Fruitteelt, Wilhelminadorp 1970: 35–54 (Dutch, Engl. summ.); see p. 45–47.