NITROGEN REQUIREMENT OF BELLE DE BOSKOOP APPLE TREES AT DIFFERENT DENSITIES GROWN UNDER DRY CONDITIONS

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Abstract

Amongst the various factors considered in determining nitrogen dressings in apple orchards, the moisture condition of the soil is one of the major ones. In The Netherlands under average moisture conditions 50-100 kg N per ha is given annually, but on dry soils dressings range from 100-150 kg N. On extremely good soils quite a few growers do not fertilize at all, although some nitrogen is then supplied by calcium nitrate and urea sprays.

Of late, more and more evidence is being accumulated on the relative drought-susceptibility of trees growing at narrow spacings. In single-row systems where grass strips are applied, this susceptibility may be further worsened by enhanced competition as row distance and width of the herbicide strip decrease. Since nitrogen uptake and the efficiency of nitrogen dressings are much influenced by moisture supply and competition for nitrogen, and besides, an increased need of nitrogen can be expected on account of the greater number of trees and a higher production per ha, it seems obvious to assume a relationship between fertilizer response and plant density. Such a relationship was found in a field experiment with Belle de Boskoop apples on M.9 on a shallow-rooted, rather dry soil. There were four plant densities and five nitrogen rates. In the initial years, growth and production of the trees were strongly influenced by dry periods in most of the years whereas the whole growing season of 1976 was extremely dry. The following preliminary conclusions have been drawn.

1. Aiming at minimum nitrogen dressings or even omitting fertilization in grass strip orchards carries a far greater risk of biennial bearing in dense, than in wide plantings. Reduced flower initiation brought about by nitrogen deficiency is especially to be feared when high cropping coincides with drought.
2. In seeming contradiction with the foregoing is the observation that the highest nitrogen requirement was not found in the densest planting system. High dressings promoted tree growth in the widest planting but had no effect or even reduced growth in the densest systems, the latter possibly as a consequence of excessive salt concentrations in the root zone during dry periods.
3. Therefore, in the two densest plantings a rather low nitrogen dressing was required for maximum production in the first six rather dry years. Under more normal, moist conditions possibly a higher optimum dressing would have been found, compared with the widest planting.

Introduction

In the past 30 years many changes have taken place in the cultivation of apples in The Netherlands. Concurrent with an almost complete change-over from vigorous and semi-vigorous rootstocks to the dwarfing M.9, plant densities increased from an initial 400 or less, to 800 trees per ha (orchards planted before 1950), through 400-1600 (1950-1970) to 800-1600 or more after 1970. At least 50 per cent of new orchards are at present planted with more than 1600 trees. Some growers even plant 3000-5000 trees per ha.

In the past, in many orchards on more or less heavy soils, the development of apple trees was hampered by competition because overall grass and weeds was the current soil management system at the time. This particularly applied to apples on M.9. Trees on more vigorous rootstocks were less affected. In order to cope with competition and to get a well-closed planting, the trees were vigorously pruned and nitrogen dressings between 1960 and 1966 compared with the period 1950-1960, were about doubled to an average of some 220 kg N per ha. However, the necessity of such high dressings was rendered out of date because the change-over to M.9 was soon followed by the introduction of chemical weed control. This made it possible to keep wide strips along the tree rows free from competitive vegetation and to maintain the grass in the alleyways. On dry soils the entire surface was treated with herbicides. The new grass strip system was readily accepted. It became, and to this day still is, the predominant soil management system, but since the dry year 1976 a further shift to the less competing overall herbicide treatment is apparent.

New fertilizer experiments showed a much lesser need of high nitrogen dressings in orchards with grass strips compared with overall grass. Therefore, after 1966 the fertilizer quantities were again drastically lowered to a level of 50-100 kg N per ha for soils with average moisture conditions. There even is a tendency to limit fertilization to critically low dressings to improve fruit quality.

In the past, inadequate juvenile growth resulting in lasting under-sized trees, was one of the main limiting factors for productivity in wide plantings. Trees sometimes did not fill the available space for several reasons: besides competition the soil could be too heavy, too wet or too dry. Sometimes too many dry periods occurred in the initial years, or replant disease played a role. The soil has much more influence on the size of the tree crown than on the production of fruit per m^2 of crown projection (van Dam 1973). Therefore, all these influences could more or less successfully be eliminated by planting more densely. It resulted in a substantial advancement and increase of productivity per ha, but more trees per ha also require more moisture. The coincidence that dense planting is particularly practised on soils where restricted tree growth is expected on account of inadequate moisture supply, has accentuated the relative susceptibility of dense plantings to drought.

Since nitrogen uptake is so much dependent on the moisture condition of the soil, the question was raised whether in determining fertilizer dressings, differences in tree numbers per ha should be taken into account. For that reason an experiment was started in Wilhelminadorp, in which nitrogen quantities were applied to apple plantings in different spacings.

Materials and methods

One-year old apple trees Belle de Boskoop on rootstock M.9 were planted by the end of February 1972. There are three single-row systems at 395 x 205, 355 x 136 and 300 x 102 cm distances (between and in the rows respectively), and six-row beds, with 1110, 1860, 2930 and 3330 trees per net ha (0.9 ha), respectively. The shortest distance between the trees in the beds is 125 cm. There are three replicates.

In between the single rows, smooth-stalked meadow grass (*Poa pratensis*) was sown in the summer of 1972 and herbicides are being applied on tree strips 200, 180 and 150 cm wide, respectively. The rotary-mown grass is mulched on the weed-free strips. In the beds the entire area of soil under the trees is treated with herbicides.

Each replicate is sub-divided into plots differently fertilized with annual broadcast spring dressings of 0, 70, 140, 210 or 280 kg N per ha. The number of trees per plot is 6, 10, 10 and 12 in the order of planting-systems mentioned before.

The soil consists of 50-60 cm marine silt loam with 22 per cent clay (particles 2) overlying medium fine sandy loam (7 per cent clay) which apple roots do not penetrate. Because of the shallow root system the trees are rather drought-sensitive. The ground-water level fluctuates between 80 and 120 cm below the surface in winter, and between 130 and 180 cm by the end of the summer. Capillary supply of ground-water in the shallow root zone is negligible when the ground-water table drops below 140 cm.

From 1972 to 1979, extensive observations were made on tree growth, production and quality of the fruits. Moreover, leaves were annually sampled and analysed on N, whereas in 1979 the vertical transport of fertilizer nitrogen in the soil was followed up by extensive soil testing. Tensiometers were placed near the stem to registrate moisture tensions in different planting-systems.

Results

Nitrogen status of leaves

Basal leaves from the third to the fifth position on current-year shoots were sampled early in August. Figure 1 represents average contents of six experimental years. For the variety Belle de Boskoop, 2.3 % is considered an adequate nitrogen content. The data show that in the single-row system denser planting resulted in lower values. The differences were more pronounced, and N deficiency in denser plantings was more severe at low dressings. The influence of spacing is also accentuated by a relative increase of competition: the decrease of the row distance from 395 to 300 cm involved a decrease of the width of the herbicide strips from 200 to 150 cm.

Although the 300 x 102 cm single rows and the beds comprise almost equal numbers of trees per ha (2930 and 3330 respectively) the latter show higher nitrogen contents at low levels of fertilization. This may be explained by the complete absence of competing vegetation and by a somewhat larger area of weed-free soil per tree. In the beds all experimental trees are surrounded by other trees. The shortest distance between the diagonally planted trees is 125 cm, and the area of weed-free soil is 1.95 m^2 per tree. In the single rows the distance is 102 cm and in-between the grass strips 1.40 m^2 of weed-free soil is available per tree when some border effect of the grass (5 cm) is accounted for.

Growth

In the initial years the trees were differently pruned in order to achieve differences in growth vigour adapted to the plant densities. For instance, right after planting, the central leader in the 395 x 205, 355 x 136, 300 x 102 cm rows, and in the beds was pruned away at an average height above the ground of 73, 87, 94 and 99 cm, respectively. However, in spite of these measures the trees in the 395 x 205 cm planting system, and to some extent also in the 355 x 136 cm system, dit not fully succeed in filling their space in the rows. This was largely due to lack of moisture in the shallow-rooted soil, aggravated by dry periods in 1973, 1974, 1975 and 1978, whereas in 1976 the whole growing season was far too dry. Moreover, under these conditions the grass strip was probably too competitive.

To assess treatment effects upon growth, stem girth measurements were carried out each spring. In 1978 tree crown volumes were estimated by visual ratings on a scale of 0-10 (figures 2 a and b). It should be remarked that within one planting system differences in crown volumes can be established reasonably well by estimation, but differences between plant densities are probably influenced by shifts in the estimation. For instance, figure 2 a shows that without nitrogen dressing, stem growth increased with wider plantings, but such a better growth was, incorrectly, not confirmed by the estimations in figure 2 b, unfertilized. Although irregular because of soil fertility variability, both figures show a positive influence of fertilization upon tree growth in the widest single-row system but little or no favourable effect, or even retarded growth in the denser systems, particularly in the beds.

Flower initiation

Until 1977 abundance of flowering was not, or only unobtrusively influenced by the treatments. In 1976 flowering and cropping were very good and regular but the whole season was unusually dry. Evaporation in excess of rainfall in April-August amounted to 536 mm, whereas in this area 269 mm is the average. Nitrogen percentages in the leaves were much lower than usual 1.89 % and 2.09 % N as an average of all unfertilized plots and plots with 280 kg N per ha, respectively; cf Figure 1). Fruit size remained far below normal and many fruits cracked after some rain fell by the end of August. This was particularly true for the dense plantings. As a consequence of differences in nitrogen fertilization, plant density, and possibly competition by grass strips, substantial differences in flowering appeared in the spring of 1977. In particular, nitrogen deficient trees at narrow spacings blossomed very poorly (Table 1). Rainfall in 1977, however, was quite well distributed and dry periods were only short and not pronounced. Therefore the trees could recover from earlier drought effects. Consequently flower initiation in 1977 was again normal, as was concluded from abundant and regular blossoming in 1978. In this year, however, the crop was once more affected by drought. A short dry period occurred in the middle of June and a much longer one from the end of July till the end of September. Estimations of blossoming in the spring of 1979 again showed distinct treatment effects (Table 1), although in the three densest systems less pronounced than in 1977. In the beds, flower initiation was not even at all affected by omission of fertilization, possibly because here the trees are less subject to inter-tree and grass competition compared with the densely planted single-row sytems.

Fruit weight

At picking, fruits were counted and weighed per tree. Average weights per fruit are presented in Figure 3. Tree age, cropping level (biennial bearing), drought (extreme in 1976, moderate in 1975 and 1978), and plant density were the main factors that caused variations in fruit size. Nitrogen dressings influenced fruit weights mainly through the numbers of fruits per tree. In years with good, more or less regular bearing (1974, 1975, 1976, 1978) fruits were somewhat smaller as plantings were denser, but in 1977 this trend was reversed by biennial bearing, the more so as plant densities were higher and more in particular in plots without nitrogen dressings. To some extent uneven flowering and bearing, as a consequence of nitrogen deficiency and spacing, has also influenced differences in fruit weights in 1979. For instance, the lower level of flower initiation in the 355 x 136 and 300 x 102 cm single rows (cf. Table 1) may have given comparatively large fruits and thus the fruit size of the widest planting was attained.

Yield in successive years

Figure 4 demonstrates that the much higher production level of dense compared with wide plantings renders the former more susceptible to drought. The severe drop in production in the dry year 1976 was mainly caused by retarded fruit growth but June drop may also have played a role (not recorded). Moreover, in the dense planting systems many fruits dropped just prior to picking. This was most severe in the 300 x 103 cm rows and in the beds. In the 395 x 205 cm single rows fruit drop was of no importance. Although at picking these fruits were roughly counted and included in the yield, the part of dropped fruits in the total yield may nevertheless have been somewhat underestimated particularly in the beds. Another factor that may have interfered with the unequal drop in production in 1976, is the different increase in productivity of the planting systems as a consequence of different increase of the tree size in the preceding years. For instance, in 1974 and 1975, total stem girth increase in the 395 x 205 cm single rows, and in beds averaged 3.0 and 2.2 cm respectively. Therefore, drop in production in 1976 as brought about by small fruits and fruit drop will have been more masked by increasing productivity in the 395 x 205 cm rows than in the beds.

The relatively low production in 1977 for the 355 x 136, 300 x 102 cm rows and the beds was caused by poor blossoming and poor fruit set resulting in extremely large fruits. This particularly applied to unfertilized trees (cf table 1).

Index of biennial bearing

The data presented in figure 4 suggest that as a consequence of heavy bearing and inadequate moisture supply, yield in dense plantings may show larger year-to-year fluctuations than in wide plantings. This irregularity can be expressed by an index of biennial I (Hoblyn et al., 1936). I is calculated as 100 x (difference between two subsequent crops): (sum of the two crops) and can vary between 0 in the case of regular bearing and 100 (absolute value) in the case of extreme biennial bearing. The indices have been calculated for three pairs of successive years (Table 2). In the three densest planting systems irregularity of bearing was considerably enhanced by drought in 1976 and 1978, and by omitting nitrogen fertilization, but dressings higher than 70 kg N per ha did not result in lower indices. In the 395 x 205 cm rows, drought also caused somewhat higher indices, but here fertilization resulted in slightly higher values rather than the reverse. This phenomenon may be explained by the favourable effect of fertilization upon tree growth (Fig. 2). Indices of biennial bearing may somewhat increase due to the sheer fact that trees get bigger and produce more as years advance. On the other hand, in the 395, 205 cm rows omission of fertilization had almost no effect upon flower initiation (Table 1).

Yield and nitrogen dressings

Figure 5 gives the relationships between the average yield in the first six production years and the nitrogen dressings. The four curves show more or less distinct positive, although statistically not equally significant responses to nitrogen fertilization. There is a tendency that the four planting systems require different dressings for maximum production but there is no statistical evidence for an interaction between nitrogen requirement and planting system.

In the 395 x 205 cm rows only 70 kg N was required and yield reductions, brought about by either omitting fertilization, or applying an excessively high dressing (280 kg N per ha), were rather small, 11 % and 5 %, respectively.

In the 355 x 136 cm rows, 210 kg N was the optimum dressing, whereas no nitrogen and 280 kg N per ha resulted in more conspicuous yield reductions of 21 % and 9 % respectively, compared with the highest yield. Evidently a futher increase in plant density again involved lower optimum dressings. In the 300 x 102 cm rows 140 kg N was required and the above-mentioned yield reductions were 19 % and 9 %, respectively. In the beds 70 kg N was the optimum dressing and yield reductions were only 9 % and 10 %, for trees without nitrogen and with 280 kg N per ha respectively. It is obvious to assume that the lower optimum dressings in the two densest systems a great deal resulted from the negative influence of high dressings on the growth of the trees (cf Figure 2).

Discussion

The question whether denser planting necessitates an increase in nitrogen dressings cannot be answered simply from the results of this still young experiment. The analysis of crop responses showed that the nitrogen status of the leaves, flower initiation (biennial bearing), and tree growth, responded differently to fertilization depending on plant spacing. It could have been the same with fruit set and June drop. The reponses jointly determine the optimum dressing but under the condition of the experiment they were influenced by drought. This was very much the case with flower initiation and probably with tree growth.

In an average orchard, conditions diverging from the experiment will in general prevail. Not only the weather (precipitation) will be more normal and moisture availability in the soil will be better, but a difference in soil management system (e.g. mulching grass clippings on the grass alley instead of on the herbicide strip; less competitive grass, or overall herbicide treatment), and even a difference in sensitivity of the apple variety to biennial bearing could also influence the requirement of nitrogen fertilization. Nevertheless it seems justified to draw a few tentative general conclussions.

When trees are planted more densely, the contribution of nitrogen fertilization to productivity shifts from promotion of tree size by shoot growth (probably enhanced by invigorative pruning) to support of flower initation and possibly fruit set under conditions of drought. The importance of ample nitrogen supply for flower initiation under dry conditions has been repeatedly observed in earlier fertilizer experiments and in growers' orchards: on good soils omission of fertilization, or application of low dressings, apparently does not necessarily affect the productivity of the crop for several years (apart from a lowering of the nitrogen status of the leaves, and improvement of fruit keepability and colour), but a dry year is then often followed by a severe drop in production brought about by reduced flowering. The experiment under discussion has shown that this phenomenon will appear more severely in dense than in wide plantings. It is probably the consequence of drier soil conditions and reduced uptake of soil nitrogen in dense plantings although less favourable exposure to light and less vigorous growth of shoots and roots may also be involved.

In our experiment the influence of plant density on the moisture content was investigated by repeated moisture determinations in soil samples, and by tensiometer readings. The porous pots were placed 50 cm from the stem and 25 cm deep. The readings showed that in dry periods, starting from field capacity, the moisture tensions systematically went up more quickly as plant densities increased, and these differences in drying up were confirmed by the moisture determinations. They were probably brought about by higher root concentrations in the vicinity of the stem of closely-planted trees. Verhey (1972), in comparing root concentrations at 45 cm from the stem of Golden Delicious trees planted at 90 and 230 cm in a row, found a 50 per cent higher root concentration with the first group.

Judging from the higher susceptibility of unfertilized trees to reduced flowering (Table 1), drier soil conditions and the resulting hampered uptake of nitrogen (Figure 1), and the much higher productivity per ha, it could be expected that dense plantings require higher nitrogen dressings for maximum production compared with wide plantings. In particular this applies to single-row orchards with grass strips where competition increases as a consequence of reduced row distance and width of the weed-free soil area. This competition could possibly be further accentuated when trees try to compensate for reduced root development in the direction of adjacent trees, by more extended root growth across the direction of the rows.

However, evidence for an increased need of nitrogen fertilization is only weakly demonstrated by the curves for single rows in Figure 5 and not at all by the curve for beds. The explanation is that a favourable effect of fertilization was increasingly counteracted by retarded tree growth as plant density increased (Figure 2). Whether this effect is attributable solely to excessively high salt concentrations in the root zone is hard to say. Possibly, other factors such as reduced light conditions, inter-tree competition and high root densities also interfered.

In 1979, with a wet rather than a dry spring, an extensive soil testing program was carried out to follow up the vertical movement of fertilizer nitrogen in the soil. It comprised repeated sampling of successive soil layers and determination of nitrate and ammonium contents. The conclusion was that in the beds, and to some extent also in the tree strips of the 300 x 102 cm rows, fertilizer nitrogen initially leached more slowly into deeper soil layers, compared with the 395 x 205 cm rows. It resulted in temporary higher concentrations of soluble nitrogen in the 0-5 and 5-10 cm layers. By the end of the season however, the total quantity of soluble nitrogen in the 0-60 cm layer was lowest in the two densest planting systems. The phenomenon of retarded downward movement of fertilizer nitrogen in the densest planting systems could have been far more pronounced in a dry spring resulting in excessively high nitrate concentrations in the soil solution. Since dry periods occurred in most of the initial years,retarded tree growth could very well be explained by too high nitrate concentrations in the top soil. It may therefore be expected that under more moist soil and weather conditions retarded growth will not turn up within the limits of fertilizer dressings of this experiment. Planting more densely, in particular when grass strips are used, could then more distinctly require higher nitrogen dressings for maximum production, compared with wide plantings.

Literature

Hoblyn, T.N. et al.,1936. Studies in biennial bearing I. J.Pomol. Hort.Sci., 14:39-76.

Verhey, E.W.M., 1972. Competition in apple, as influenced by Alar sprays, fruiting, pruning and tree spacing. Thesis Agric.Univ. Wageningen, 54 p.

Table 1 - Intensity of flowering in per cent of abundant flowering.

Planting system (cm)	1977 kg N per ha		1979	
	0	70-280	0	70-280
395 x 205	54	53	55	41
355 x 136	14	29	17	29
300 x 102	6	17	16	33
beds	7	17	21	21

Table 2 - Indices of biennial bearing.

Planting system (cm)	Production years	Kg N per ha					av.
		0	70	140	210	280	70-280
395 x 205	1976-77	7	10	7	9	6	8
	1977-78	9	13	15	17	15	15
	1978-79	3	5	15	18	10	12
355 x 136	1976-77	24	4	2	14	10	8
	1977-78	45	26	22	39	31	30
	1978-79	27	10	8	21	14	13
300 x 102	1976-77	40	4	1	14	4	6
	1977-78	58	28	30	45	31	34
	1978-79	39	12	4	25	13	14
beds	1976-77	24	1	1	16	7	6
	1977-78	61	40	40	29	38	37
	1978-79	20	10	15	8	12	11

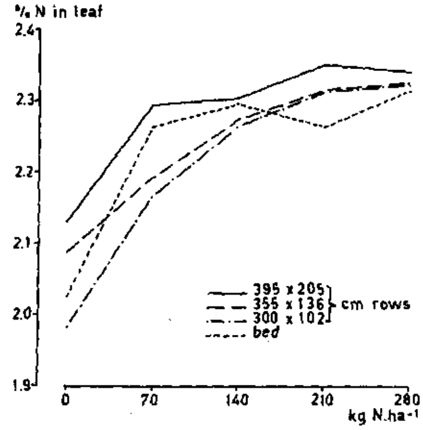

Fig. 1 - Nitrogen percentage in basal shoot leaves of Belle de Boskoop apples as related to treatments. Mean values of 1973-1978 samplings in early August.

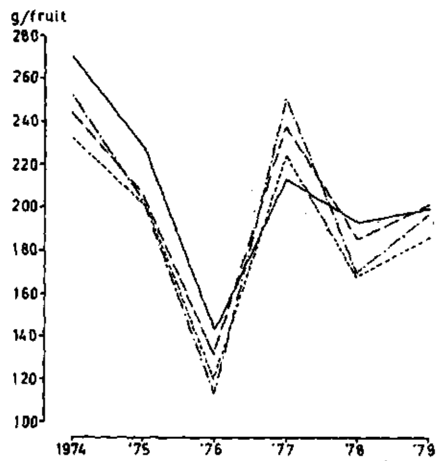

Fig. 3 - Fruit weights in gram per fruit in six successive years as an average of five nitrogen dressings. For identification of lines see Figure 1.

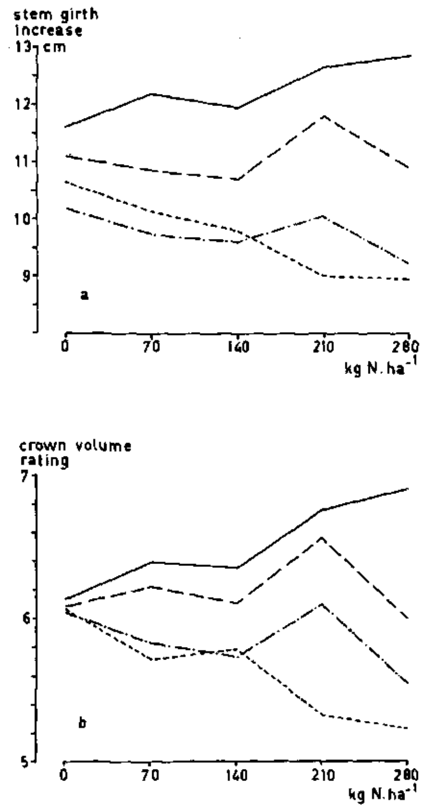

Fig. 2 a, b - Stem girth increase in 1972-1979 (8 years) and estimated crown volume in the fall of 1978 as related to treatments. For identification of lines see Figure 1.

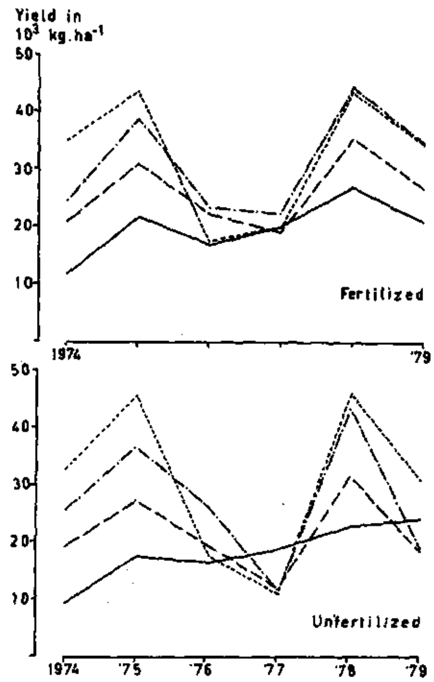

Fig. 4 - Yield per net ha (0.9 ha) for fertilized (70-280 kg N per ha) and unfertilized plots. For identification of lines see Figure 1.

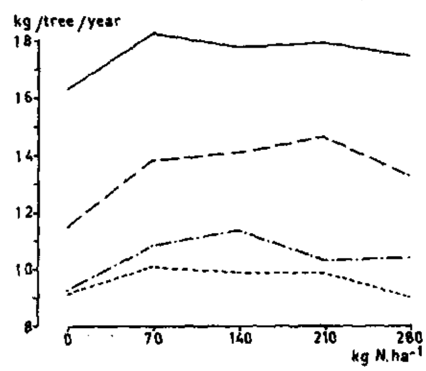

Fig. 5 - Yield per tree as an average of yields in 1974-1979. For identification of lines see Figure 1.