Fruitlets of Nijiseiki (Pyrus pyrifolia) on P. betulaefolia
pear trees were thinned to various crop density (CD) levels of 3-
16 fruit cm^{-2} trunk cross-sectional area (TCSA) in 1986 and 4
levels of CD (1, 3, 5, and 7 fruit cm^{-2} TCSA) in 1987.

CD influenced trunk growth, leaf size of non-fruiting spur,
terminal shoot growth and fruit growth. They correlated negatively
to CD. The effect of CD on fruit growth was cumulative during the
growing season.

There was a positive linear correlation between CD and biomass
of fruit and the total of leaves and fruit but a negative
correlation with leaf weight. CD affected the partitioning of
biomass between leaves and fruit also. There was no effect of CD
on leaf size of terminal shoots and fruiting spurs, fruit shape,
return bloom, or flower size.

CD decreased leaf B concentration of non-fruiting spurs in
1986, increased leaf Mg of terminal shoots in 1986, and decreased
leaf K of fruiting, non-fruiting spurs and terminal shoots in 1986

and 1987. CD influenced fruit K concentration at harvest and fruit P, S, K, and Mg concentration only one month before harvest. All fruit correlations were negative. K was the element which was affected most by CD in leaves and fruit.

CD had significant effect on the nutritional content of all elements analyzed for leaves except Zn and for fruit except Fe. Negative correlations were found between CD and total N, K, S, Ca, and Mn contents in 1986 while CD had significant effect on total N, P, K, Mg, and B contents in 1987. Linear correlations were found between crop density and the partitioning of nutrients (% of total) except Fe between leaves and fruit in 1986. Crop density influenced nutritional partitioning of all elements in 1987. The differences of nutritional partitioning was principally due to the biomass.

Effect of Crop Density on Vegetative and Fruit Growth
and on Mineral Status in Nijiseiki Pear (<u>Pyrus pyrifolia</u>)

by

Sanliang Gu

A THESIS

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TO MY WIFE AND MY SON,

XIUMEI LI AND FEI GU.

APPROVED:

_____

Professor of Horticulture in Charge of Major

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Head of Department of Horticulture

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Dean of Graduate School

Date thesis is presented _____ December 14, 1987

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AND ON MINERAL STATUS IN NIJISEIKI PEAR (Pyrus pyrifolia)

Chapter 1. INTRODUCTION

There is increased interest in growing Asian pears in U. S. A. in recent years. Generally, Asian pear trees are thinned to increase the rate of fruit growth and improve 'pack-out' size at harvest. Since Nijiseiki is the prominent Asian pear cultivar, it is important to understand how growth and development of the trees are affected by thinning, which is the change in crop density of the entire tree or branch.

A large volume of literature has established that cropping is important in growth, flowering, and fruiting of fruit crops, especially apples. Previous studies considered the effect of cropping by comparing fruiting and non-fruiting trees, or by thinning treatments after removing a certain percent of blossom or fruitlets. Some researchers used leaf:fruit ratio (LFR) to study the effect of crop load, which had certain advantages over other methods. But the disadvantage of LFR was the use of it before the total leaf canopy developed on a tree (Forshey, 1980). Thus it underestimated leaf area, particularly of shoot leaves which were found to be important contributors to fruit size late in the season (Rom and Ferree, 1986a).

Trunk size, especially the trunk cross-sectional area (TCSA),

has been considered as an important parameter of tree size, and is a reasonably measure of the tree performance (Yeager and Latimer, 1940). However, various expressions of trunk size have been used in many studies. Trunk circumference has been found to be correlated to top weight (Anthony, 1941; Sudds and Anthony, 1929; Uriu and Lilleland, 1959), tree weight (Anthony, 1941; Holland, 1959; Pearce, 1952; Sudds and Anthony, 1929), canopy volume (Miller and Lightner, 1987), bearing area (Overholser, et al., 1941) and shoot enlongation (Sudds and Anthony, 1928) of fruit trees. TCSA has been found to bear a close relationship with total top weight (Westwood and Roberts, 1970), canopy volume (Westwood, 1978; Miller and Lightner, 1987), pre-existing structure and total dry weight (Forshey and Weires, 1983), shoot growth (Khatamian and Hilton, 1977), leaf area (Forshey and Weires, 1983) and root growth (Head, 1969). Westwood and Roberts (1970) suggested trunk measurements can be used to estimate the potential bearing surface. So the fruit number or weight per unit trunk size seems to be a good measure of the fruiting condition. Since trunk size is often expressed as TCSA (Westwood and Roberts, 1970), crop density can be expressed as fruit number per unit of trunk or branch cross-sectional area (Lombard, 1987).

The objective of this study was to determine the effect of crop density (CD) by thinning Nijiseiki pear trees to different levels on:

1. the vegetative growth (trunk, leaves and shoots);

2. the flowering, fruit growth, development and quality;

3. the dry matter production and partitioning between leaves and fruit; and

4. the mineral uptake and distribution between leaves and fruit in Nijiseiki pear trees.

CHAPTER 2. LITERATURE REVIEW

A. EFFECT OF CROPPING ON THE VEGETATIVE GROWTH OF FRUIT TREES

In horticultural practice it is widely accepted that cropping influences growth to the extent that very heavy cropping reduces vegetative growth excessively while failure to crop leads to excess vigor (Avery, 1969; Barlow, 1964; Jackson, 1984; Singh, 1948). Increased cropping is usually accompanied by decreased vegetative growth in the same year, with reduced dry weight increment of leaves, stems, trunks and roots. The effect of cropping on the vegetative growth were well reviewed by Jackson (1984). Landsberg (1980) outlined a simple model, which completely defined dry weight gain (dW) and partitioning by an apple tree:

$$dW/dt = dW/dt(Pl + Ps + Pr + Pf) \qquad (eq. 1)$$

In this l, s, r and f denote leaves, frame (stem etc.), roots and fruit and Pl + Ps +Pr + Pf = 1. On this model any increase in cropping must reduce vegetative growth correspondingly. Some data, usually from relatively short term experiments can be interpreted in this way, for example, Hansen (1980) found fruiting trees to produce a similar total dry matter as non-fruiting trees with the dry matter increment of leaves, shoots, branches, trunks and roots being reduced by an amount approximately equal to the dry matter increment in the form of fruit. Even in this case, however, the actual effects were more complex than a simple change in partitioning of relative increment. In most other cases the

results can only be interpreted using more complex model, involving feed-back and feed-forward effects, in which dW itself is clearly recognized as a function of the relative allocation of dry matter increment to leaf, stem, root and fruit. A schematic outline of this (Fig. 2-1) was given by Jackson (1984) and used in his paper as the conceptual framework for discussing effect of cropping on growth.

There have been many conflicting reports of the influence of cropping on vegetative growth. Results from several experiments involving deblossoming (Barlow, 1964, 1966; Preston, 1954), early fruitlet thinning (Quinlan and Preston, 1968) and relative studies indicated that there is competition between the different growth centers for infusable substants, and that competition is particularly severe during blossoming and the following 3-4 weeks. Fruit thinning during this period results in an increased rate of fruit growth and, as in the case of complete deblossoming, an increased rate of tree growth. The dual nature of the relationship between yield of fruit trees and tree growth is well known in quantitative terms. Growth and yield are competitive and negative related (Ljones and Nesdal, 1954). Several workers have established that a reduction in apple tree growth is brought about by fruiting (Maggs, 1963; Avery, 1969, 1970). Predictably, cropping has a negative influence on vegetative growth of fruit trees (Avery, 1975; Jackson, 1984). Erf and Procter (1987) found 54% less vegetative growth was found in cropping trees than noncropping apple trees. Decreased vegetative growth suggested

that assimilates were partitioned to developing fruit at the expense of other tree components.

1. Trunk Growth

Quantitative estimates of the effect of cropping on the tree growth have been derived by comparing growth of fruiting and deblossomed trees (Avery, 1975). Significant relationship was established between the crop and the reduction in TCSA increment. Barlow (1964) reported a linear negative relationship between crop weight (above a threshold value) and TCSA increase of apple trees.

Reduced rate of increase in TCSA of fruiting or heavy cropping trees compared with non-cropping or lighter cropping trees were reported from many thinning experiments (Avery, 1975; Webster and Brown, 1980). The effect of the crop was considered as the difference in TCSA increament between cropping and deblossomed trees (Barlow, 1964). Increase in mean trunk circumference of individual 8- to 17- year old 'McIntosh'/M7 apple trees was a linear function of mean crop load (kg cm^{-2}). A linear relationship between them implies that, for a given initial tree size, increase in TCSA will be nearly linear with yield (Webster and Brown, 1980).

With 'Sunset'/M9 apple, Quinlan and Preston (1968) reported that all thinning treatments increased TCSA compared with the unthinned trees, an effect that was detected at the end of the first year of treatments. Only little difference among thinning times were found but the two earliest ones tended to have the

greatest effect. They suggested that the effect of thinning in increasing the rate of trunk thickening also indicates a stimulation of cambial activity. Lenz (1979) found stem growth was reduced by fruiting in 'Golden Delicious'/M9 apple also. Erf and Procter (1987) reported that defruited trees had greater TCSA than those not defruited in 11 year old 'Golden Delicious'/M26. Trees with less fruit tended to have more trunk growth than trees with more fruit. Mochizuki (1962) also found the thickening of the trunk was less in fruiting trees compared with non-fruiting ones. Barlow (1964) concluded the decrease in trunk thickening on fruiting trees was correlated with weight of crop above a 'threshold' value. As the crops increases in size so does the divergence in TCSA increments of the cropping and deblossomed trees, in 'Worcester Pearmain', 'Cox's Orange Pippin' 'Miller's Seedling', and 'Laxton's Superb' apples (Barlow, 1964).

As a result of cropping, both total increment and vegetative increment were significantly reduced, i. e. the reduction in vegetative increment was greater than the weight of crop in 'Worcester Pearmain'/M7 apple. Defruiting had slightly less effect than deblossoming (Maggs, 1963). Fruit thinning increased girth increment of 'Laxton's Superb' apple (Preston, 1970). Flower thinning resulted in an increase of girth increment in 11 year old 'Golden Delicious'/M9 apple (Palmer, 1984). Fruit crop reduced growth in TCSA in 10 year old 'Jonathan'/M26 apple trees (Taylor and Ferree, 1984).

With other experiment, however, trunk growth was found

unaffected by fruit thinning in 7 year old 'Empire',
'McIntosh'/MM106 apples (Forshey, 1982). Preston (1954) found that
neither degree nor time of thinning had an significant effect upon
trunk growth increment in 14 year old 'Duchess Favourite'/M9
apple.

2. Shoot Growth

Knowing the nature of shoot growth, especially the relationship
between shoot growth and fruiting, is vital to the proper
management of fruit trees.

It is well established that fruiting reduces shoot growth of
apple trees. Nevertheless, the evaluation of this response
sometimes is complicated by the effect of the previous crop
(Forshey, 1982; Mochizuki, 1962; Rogers and Booth, 1964; Wilcox,
1937), as well as the current crop (Avery, 1969, 1970; Barlow,
1964, 1966; Quinlan and Preston, 1968). The relationships were
found as negative between shoot growth and previous crop (Barlow,
1964; Forshey, 1982; Rogers and Booth, 1964; Wilcox, 1937), or as
negative between shoot growth and current crop , in which the
trees in question did not produce differential crops the previous
year (Avery, 1969, 1970; Barlow, 1964, 1966; Quinlan and Preston,
1968), or as consistent and positive between growth and current
crop (Forshey, 1982; Wilcox, 1937). In some cases, the effects
from the previous crop were apparently so pronounced that they
masked the response to current crop. It is also possible that
differences in crop load in some studies were not great enough to

provide a measure of current crop effects since some other studies involved comparisons of fruiting trees with trees that were either deblossomed or defruited (Avery, 1969, 1970; Barlow, 1964, 1966). Rogers and Booth (1964) indicated that the influence of the previous crop declined with increasing vigor.

The effect of cropping on shoot growth have been observed by thinning (deblossoming, deflowering or defruiting) or comparing fruiting and non-fruiting trees. The difference in crop level resulting from the thinning treatments were associated with larger differences in shoot growth (Forshey, 1982). He found the partitioning the treatment sum of squares indicated that 31.6% of the differences in shoot growth in 1979, and 55% in 1980, were due to the fruit-thinning treatments during the same year. Differences in crop load due to the thinning treatments were reflected in differences in shoot growth with the 'on' year trees (heavy flower density) making more total growth/tree than the 'off' year trees (light flower density) in 7 year old 'McIntosh' and 'Empire'/MM106 apple. Curry (1986) also found trees in the 'on' year consistently had more extension growth than trees in the 'off' year in 8 year old 'Goldspur Golden Delicious' apple.

Shoot growth was found to be reduced by fruit (Lenz, 1979) in 'Golden Delicious'/M9 apple. Palmer (1984) found also flower thinning resulted in an increase of shoot growth in 11 year old 'Golden Delicious'/M9 apple. High crop load decreased terminal shoot growth of summer pruned trees of 'Jonathan'/M26 apple (Taylor and Ferree, 1984). Cropping reduced total and individual

shoot growth in 'Worcester Pearmain'/M7 apple (Maggs, 1963). As with trunk growth, Barlow (1964) noted an obvious effect from the lack of cropping is increased extension growth due to the deblossomed trees in 'Worcester Pearmain', 'Cox's Orange Pippin' 'Miller's Seedling', and 'Laxton's Superb' apples.

Mochizuki (1962) found less shoot growth on trees which fruited the previous year. Deblossomed trees of 8 year old 'Goldspur Golden Delicious' exhibited less extension growth than trees that had carried a crop during either the current year or the previous year. Shoots on trees deblossomed at full bloom had significantly less terminal growth than those on trees carrying a moderate to heavy fruit crop.

The total length of all the shoots per tree was greater on fruiting than on deblossomed trees in 'Worcester Pearmain' apple (Avery, 1970). Erf and Procter (1987) found defruited trees had longer shoot extensive than those not defruited. In addition, trees with less fruit tended to have more shoot growth than trees with more fruit in 11 year old 'Golden Delicious'/M26 apple.

Fruiting trees had fewer shoots and less shoot extension especially the late developing shoots (Avery, 1969; Barlow, 1966). While fruiting affected the shoots on the tree as a whole, the proximity of the fruit affected individual shoots (Avery, 1969) in 'Worcester Pearmain' apple trees. The number of extension shoots were found to be affected by cropping. Average extension shoot length was also affected by cropping in 'Worcester Pearmain', 'Cox's Orange Pippin', 'Millers Seedling', 'Laxton Superb' apples

(Barlow, 1966).

In most cases the trees with the greater leaf:fruit ratios had greater shoot diameter in 'Anjou', 'Bartlett', 'Winter Nelis' pears (Aldrich, 1938). Thinning increased weight of the terminals in 'Oldenburg', 'Rome Beauty', 'York Imperial', and 'Delicious' apples (Aldrich, 1931).

The reduction in total extension growth could be due to a reduction in the number of shoots or their average length, or both. Some researchers indicated that effect of fruiting on shoot growth was a reduction in shoot numbers rather than reduced shoot length in 'Worcester Pearmain' (Avery, 1969, 1970), 'Sunset'/M9 (Quinlan and Preston, 1968), 7 year old 'McIntosh' and 'Empire'/MM106 (Forshey, 1982) and 14 year old 'McIntosh' (Forshey and Marmo, 1985) apples. Barlow (1966) suggested that fruiting reduced the number of growing points that develop into long shoots. The close relationship between total shoot growth/tree and the number of shoot/tree would suggest that the reduction in shoot growth associated with heavier fruiting the previous year was due to a reduction in shoot number (Forshey and Marmo, 1985).

However, Barlow (1966) found cropping decreased the number and average length of extension shoots, and that long shoots were a smaller proportion of total. Fruit suppressed the growth of shoots which developed in June on deblossomed trees. The trees had a smaller rate of extension and terminated their growth sooner.

Cropping, as a result of fruit-shoot competition (Barlow, 1966), increases the proportion of short shoots, shifting the

distribution curve in form of short shoots. In spite of differences in total shoot growth between fruiting and non-fruiting trees of 'McIntosh'/M26 apple, there were no differences in the relative proportions at 3 shoot types (terminal shoots, lateral shoots, bourse shoots) (Forshey and Marmo, 1985). They reported that deblossoming alone increased the number of all 3 types of shoots and increased total shoot length. Relative proportions of 3 types of shoots approached a 1:1:1 distribution. Deblossoming had no significant effect on this distribution.

3. Tree Canopy Width and Height

It was also found that the presence of a fruit crop significantly reduced the across-row width in comparison to defruited trees, but no consistent effect on height in 10 year old 'Jonathan'/M26 apple (Taylor and Ferree, 1984). Preston and Quinlan (1968) reported fruit thinning increased the area of branch spread but tree height was unaffected.

4. Leaf Growth

Leaf growth was also reduced by cropping. Some researchers have reported such reductions in leaf size associated with fruiting (Avery, 1969; Chandler and Heinicke, 1926; Harley, 1925; Maggs, 1963). The effect of crop removal on vegetative growth was detected within 10 days in increased number of larger leaves in 'Worcester Pearmain'/M7 apple. Heavy cropping trees produced smaller, and more crowded leaves (Maggs, 1963). The leaf area per

spur on very vigorous 'Oldenburg', 'Rome Beauty', 'York Imperial' and 'Delicious' apples was increased by thinning. Hansen (1980) found that the total leaf area per tree is decreased if crop load is heavy. Similar results were obtained by Hansen (1967), he found a small increase in leaf size on defruited, 5 year old 'Golden Delicious' trees, in agreement with Maggs (1963). Avery (1969), with 'Worcester Pearmain' apple trees, found the leaves were smaller, the rate of leaf production was lower in fruiting than in non-fruiting trees. Maggs (1963) reported that after deblossoming, the 'Worcester Pearmain'/M7 apple made extra growth in terms of more and larger leaves. Aldrich (1931) reported that defruiting or fruitlet thinning increased green weight of the spurs and leaf area per spur, as compared to the checks, in 'Oldenburg', 'Rome Beauty', 'York Imperial Delicious' apples. In some cases early thinning resulted in an increase in the size of the leaves. Palmer (1984) found that flower thinning resulted in an increase of leaf area. Thinning resulted in an increase in the size of the leaves and showed an pronounced effect on the tree vigor (Aldrich, 1931). Lenz (1979) reported that fruit load had strong effects on the total leaf areas of 'Golden Delicious'/M9 apple trees.

Erf and Procter (1987) found that defruited 11 year old 'Golden Delicious'/M26 apple trees had higher specific leaf weights (SLW). Statistical analysis revealed SLW to be negatively correlated with fruit number and yield. Increasing SLW for non-bearing apple trees has been reported also (Monselise and Lenz, 1980). Of further interest, SLW was found to be positively correlated with fruit

size, TCSA increase, and mean shoot length. High SLW indicates an excess of leaf assimilates, which can become available for the promotion of vegetative growth. Lenz (1986) reported SLW was higher for non-fruiting trees than for fruiting trees and most likely represents an accumulation of leaf carbohydrates, especially starch. Bobb and Blake (1938) found that the effect of bloom thinning was to promote immediately increased leaf development upon all spurs in 19 year old 'Wealthy' apple. Mean leaf weights tended to be higher on the fruitful compared to unfruitful branches of 8 year old 'Golden Delicious' apple.

Deblossoming of 14 year old 'McIntosh'/M26 apple trees alone had no effect on the total number of leaves/tree, but it increased the number of terminal, lateral and bourse shoot leaves while reducing the number of spur leaves. There were also increases in dry weight and area of terminal and total shoot leaves, but there was no effect on mean leaf weight or mean leaf area. The reduction in leaf size were limited to spur leaves (Forshey and Marmo, 1985).

However, Preston (1954) found there was no significant difference of leaf area due to thinning in 14 year old 'Duchess Favourite'/M9 apple. Mochizuki (1962) found the thickening of the trunk was less, but no decrease in shoot and leaf growth was detected.

5. Root Growth

There are only few reports dealing with the effect of cropping

on the root growth, but the root was found to be the most
sensitive system to the influence of cropping than others. Hansen
(1980) found cropping affected root growth and this may affect the
total surface of absorbing roots. Avery (1969) found that the dry
weight increment of all parts, especially the rootstocks, was less
in fruiting than in non-fruiting 'Worcester Pearmain' apple trees.
The greatest differences in root growth occurred in the trees on
the very dwarfing M27 rootstock which bore the largest crop
relative to the size of the tree. In this case, the roots were
severely reduced, because the proportion of dry matter distributed
to the fruit was so large that growth of the roots was completely
stopped (Avery, 1970). Maggs (1963) also found that the dry weight
increment of the root differed most between fruiting and non-
fruiting 2 year old 'Worcester Pearmain' apple trees. The root
increment was reduced to a quarter of deblossomed value while leaf
increment was reduced to only two thirds. The soil depth explored
by tree roots were also decreased by fruiting (Maggs, 1963).
Mochizuki (1962) also found that fruiting decreased the growth of
the root system more than the aerial parts of 9 year old
'Jonathan' apple trees compared with deblossomed ones. Head (1969)
reported that trees that were allowed to bear a crop showed a
marked reduction in the amount of white root in the observation
panels from July onwards, when compared with deblossomed trees.
These reduction were evident even though the crops were relatively
light, 0.2-0.5 kg cm^{-2} TCSA. The reduction in white root on the
fruiting trees after July was greater on the tree with the larger

crop, but the effect was clear until the end of the year.

The root system of fruit-bearing apple trees, in comparison with the root of plants not fruiting in the same season, is characterized by high metabolic activity, as expressed in a high rate of synthesis of both protein and amino acid. The seasonal dynamics in the quantitative changes in polysaccharides and soluble carbohydrates in the roots of fruit bearing and non-fruit-bearing trees differ markedly. During the course of the growing season, the roots of fruit-bearing trees show a progressive increase in the content of polysaccharides. In the roots of non-fruit-bearing plants, soluble carbohydrates remain at virtually the same level throughout while polysaccharides increase (Kazaryan and Arutyunyan, 1966).

6. Relative Partitioning of Fruiting and Non-fruiting Branches

Differences between fruiting and non-fruiting branches were reported also. Rom and Ferree (1986) found that fruiting spurs were larger in weight than non-fruiting spurs, and buds on non-fruiting spurs were larger than those of fruiting ones in 'Starkimson Delicious'/MM106 apple. Curry (1986) reported fruitful branches of 'Golden Delicious' and spur-type 'Golden Delicious' generally had more new shoot growth than branches without fruit from the same tree, but they did not differ in the number of foliated growing points and the number of leaves per branch when expressed on a branch cross-sectional area basis.

B. EFFECT OF CROPPING ON THE FLOWERING AND FRUIT DEVELOPMENT

   OF FRUIT TREES

1. Fruit Bud Formation, Fruit Set and Biennial Bearing

It has been demonstrated that the flowering was affected by varying cropping level by thinning, deblossoming or defruiting. The relationship between return bloom of apple and crop load has been investigated since 1920's. Blossom bud formation depends primarily on leaf function, and this may be influenced to a marked degree by fruit thinning (Harley et al., 1933). Thinning to increase the leaf area per fruit resulted in increased fruit bud formation (Aldrich, 1931; Aldrich and Fletcher, 1932; Aldrich and Work, 1934; Harley et al. 1933; Hennerty, 1971; Rom and Ferree, 1986; Taylor and Ferree, 1984) and fruit set (Aldrich, 1931; Aldrich and Fletcher, 1932; Bobb and Blake, 1938; Hennerty, 1971; Westwood and Bjornstad, 1974) were increased by thinning. Rom and Ferree (1986) found the presence of fruit had a great effect on flower bud formation and fruiting reduced (but did not eliminate) flowering the following season in 'Starkrimson Delicious'/MM106 apple (Rom and Ferree, 1986). Hennerty (1971) reported that defruiting resulted in significant differences in flowering and fruit set of 'Golden Delicious' apple in the following year. Fruit set of defruited treatment was significantly greater than that of the other treatment. Bloom thinning was found to have an effect to promote immediately increased the number of fruit set per spur in 19 year old 'Wealthy' apple (Bobb and Blake, 1938).

Harley et al. (1933) found that at 10 leaves per fruit, no flower bud initiation occurred, while at 70 leaves per fruit, all spurs formed flower buds. It was found that fruit thinning to a ratio of 70 leaves per apple in June in 'Yellow Newtown' apple had a pronounced influence on fruit bud formation. In 'Oldenburg', 'Rome Beauty', 'York Imperial' and 'Delicious' apples, it was shown that the formation of fruit buds and per cent of fruit set of bloom were greatly increased by thinning. Aldrich and Fletcher (1932) also concluded that the number of leaves per fruit was related positively to percent bloom and set the following season. There was less fruit bud formation with lower leaf area per apple on branches carrying less than 40 leaves per fruit. Beer et al. (1987) reported that the relationship between bloom density and leaf:fruit ratio was linear in 'Rome Beauty' and 'Yorking'/MM111 apple. The model suggested, however, that return bloom may be saturated at a higher leaf:fruit ratio than fruit size. The most important effect of time of thinning on 'Duchess Favourite'/M9 apple has been to influence the regularity in fruit bud formation; early thinning significantly reduced the intensity of the biennial habit compared with late thinning (Preston, 1954).

Taylor and Ferree (1984) reported that flower cluster density of 'Jonathan'/M26 apple in May and fruit density in late June were not influenced by previous cropping treatments (full crop and defruiting). In addition, flower opening of defruited trees was delayed in comparison to full crop trees. But no influence of fruiting on date of bloom the following season was found in

'Starkrimson Delicious'/MM106 apple (Rom and Ferree, 1986).

On ringed limbs of 'Anjou', 'Bartlett', and 'Bosc' pear trees, fruit thinning to give 100 leaves per fruit and defoliation to leave 10 leaves per fruit increased and decreased, respectively, the amount of fruit bud formation compared with normal limbs. The amount of the increase or decrease of bloom depended on the time of treatment. Fruit thinning of entire 'Bartlett', 'Bosc', and 'Comice' pear tree within 60 days after the beginning of full bloom resulted in increased amount of bloom the following season (Aldrich and Work, 1934). Westwood and Bjornstad (1974) found early fruit thinning to 1 fruit per cluster increased ultimate % fruit set of 'Comice' pear while thinning to 2 fruit per cluster did not increase ultimate set. So Harley et al. (1933) suggested that thinning fruit should be heavy enough to establish the leaf area necessary for fruit bud formation and thinned early enough before differentiation has begun or before the buds have reached the stage at which they can no longer be influenced by the increased leaf area.

Preston (1954) reported that thinning to 20 or 30 leaves per fruit, significantly reduced the intensity of the biennial habit of 'Duchess Favorite' apple. The lowest degree of thinning, 10 leaves per fruit, showed no improvement over the control treatment. Early thinning significantly reduced the biennial intensity. Over a five year period, thinning to 20 leaves per fruit gave the best set of fruit. All degrees of thinning produced more regular cropping trees than the control in 'Duchess

Favourite' apple.

Others reported cropping does not affect annual bearing of of 'Rome Beauty', 'York Imperial', and 'Baldwin' apple trees (Auchter, 1919) or fruit set and development 'Starkrimson Delicious'/MM106 apple the following year (Rom and Ferree, 1986) .

2. Fruit Growth

Generally speaking, the fruit size was improved by thinning. It was found that thinning resulted in an increase of fruit size in 'Laxton's Superb'/M9 apple (Preston, 1969); fruit size in 'James Grieve' apple (Van Der Boon, 1980), in 'Duchess Favourite'/M9 apple (Preston, 1954) and in asian pears (Lombard, 1986).

Increasing leaf:fruit ratio was associated with increased fruit weight of both 'Lambert' and 'Bing' sweet cherries. In general, fruit size increased as leaf:fruit ratio increased. When the crop was heavy, the fruit was small at shipping maturity, but continued to grow and ultimately approached the size of fruit grown with a lighter crop load (Proebsting and Mills, 1981).

The relationship between fruit growth and cropping was well established. It was found there was a close negative relationship between fruit size and crop load in 'Bing' cherries (Proebsting and Mills, 1981) and a positive correlation between average fruit weight and Ln leaf:fruit ratio in 'Bing' and 'Lambert' cherries (Fecteau et al., 1983); a linear relationship between mean fruit weight and number of fruit cm^{-2} of TCSA in 'McIntosh' apple

(Forshey and Elfving, 1979); a curvilinear relationship between mean fruit weight and leaf:fruit ratio in 'Rome Beauty'/MM111 and 'Yorking'/M26 apples (Beers et al., 1987); a positive curvilinear relationship between fruit growth m^{-2} of leaf area and crop load in 'Golden Delicious' apple (Hansen 1977); a correlation between severity of thinning and size of fruit in 'York Imperial' apple (Fletcher, 1932); and a negative correlation between mean fruit weight per tree and the fruit load ratio (number of harvested fruit m^{-2} leaf area) in Japanese pear and persimmon trees (Kishmoto, 1975).

The works of Harley and Magness (1925), Magness (1928), and Magness and Overley (1929) who varied the number of leaves per fruit on ringed branches have shown that with an increased number of leaves per apple increased size of fruit. Bobb and Blake (1938) found the effect of bloom thinning promoted the rate of fruit enlargement in 19 year old 'Wealthy' apple.

Auchter (1919) reported that the size of the individual specimens (fruit) left on the tree after thinning is greatly increased during the same year as a result of the removal of part of crop. More marketable fruit was produced by thinning and increased size of each apple where trees were bearing a good crop of fruit in 'Rome Beauty', 'York Imperial' and 'Baldwin' apples.

Fruit growth is mainly determined by the rate of cell division during the month following full bloom and by the amount of cell enlargement from full bloom to picking (Westwood, 1978). Total cell number was higher in the thinned or light-crop than in the

control fruit in 'Cox's Orange Pippin' apple (Sharples, 1968).
This suggested that the marked increase in fruit size recorded 9
days after thinning was, at that stage, due mainly to a stimulus
in cell division while differences in the rate of fruit growth
after mid-June were due to cell enlargement. Thinning also caused
an increase in cell enlargement rate but the magnitude of the
response varied between different experiments and did not appear
to be related to the developmental stage at which the treatment
was applied (Sharples, 1968). Quinlan and Preston (1968) also
found the increase in fruit size following thinning was entirely
the result of an increase in cell number per fruit. Cell volume
was not affected by any of the thinning treatments in 'Sunset'
apple.

3. Yield

Fruit thinning of entire pear trees which increased the leaf
area per fruit, resulted in increased growth rate of the fruit
(Aldrich, 1938). However, the increase in fruit growth rate was
not in proportion to the increase in leaf area; in other words,
thinning decreased total yield in 'Anjou', 'Bartlett', 'Winter
Nelis' pears and in 'Elberta' peach (Weinberger and Cullinan,
1932).

Preston (1969) found fruit thinning did not affect total crop
with trees on M9 but on M2 it reduced crop by 16% in 'Laxton
Superb'/M9 and M2 apples. Palmer (1986) reported a final yield
reduction of 56 and 30%, and a fruit number reduction of 55 and

31% resulted from flower thinning of 33 and 11%. Van Der Boon (1980) reported a decrease of yield by 27% for 'Cox's' and 17% for 'James Grieve' apples by fruit thinning.

The heaviest thinning resulted in a decreased yield but gave the highest percentage of fruit of the large size in 'Jonathan' and 'York Imperial' apples (Fletcher, 1932)

Thinning on 'Bartlett' pear trees gave fruit of the larger sizes but tended to decrease the proportion of extra fancy fruit (Aldrich, 1938). However, unthinned 'Anjou' trees with the largest total yield, also gave the largest packout yield.

Fruit thinning in 'Empire' apple trees increased the percentage of large fruits, but reductions in yield were such that the actual number of large fruits was either unchanged or reduced (Forshey, 1982).

Thinning, as stated by Tukey (1970), does not change a potentially small fruit into a large fruit, but rather ensures that a potentially large fruit will size properly.

The yield of an apple tree is the product of the number of fruit on the tree and the size of those fruit (Forshey, 1977). It has been generally assumed that both factors contribute more or less equally to yield. However, data from 'McIntosh' apple crop prediction studies indicated a strong positive correlation between yield and fruit numbers, but a weak negative correlation between yield and fruit size. Increases in fruit size from thinning were proportionately less than decreases in fruit number. Thus, yield was more closely related to fruit number than to fruit size

(Forshey, 1982; Forshey and Elfving, 1977)

C. EFFECT OF CROPPING ON THE PHYSIOLOGICAL PARAMETERS AND DRY MATTER PRODUCTION AND PARTITIONING OF FRUIT TREES

1. Photosynthesis

There have been several reports that crop load or fruiting of fruit crops has an effect on the photosynthetic rate (Pn), the photosynthetic efficiency, and the production and partitioning of dry matter. Reports on the effect of fruiting trees on a higher photosynthetic rate are DeJong (1986); Ghosh (1973); Hansen (1967, 1970); Lenz (1986); Mouselise and Lenz (1980); and Palmer (1986). Leaf photosynthesis was significantly reduced in non-cropping trees only in July and August in 'Crispin'/M27 apple (Palmer, 1986). The presence of fruit can significantly affect the rate of CO_2 assimilation in vigorously growing 'O'Henry' peach trees under field condition (DeJong, 1986).

Palmer (1984), with 11 year old 'Golden Delicious'/M9 apple, found thinning had little consistent effect on leaf photosynthesis except at the beginning of July when the trees carrying the lightest crop had only 80% of the Pn of the controls. He found that the thinning effect on the stomatal conductance was more pronounced than on Pn, although the two variebles are closely linked. At the end of June and mid-October the intermediate crop load treatment had the highest stomatal conductance whereas in July and September larger crop loads resulted in higher stomatal

conductance. Many of the changes in Pn over the season appear to be closely linked to changes in stomatal conductance, although the latter is only one of several involved in the movement of carbon dioxide.

Similar results were reported by other researchers. Monselise and Lenz (1980a) found defruited trees had lower leaf stomatal conductance than fruiting trees, but the relationship between fruit number/tree and stomatal conductance was not quantitative (Erf and Procter, 1987). DeJong (1986), with 11 year old 'O'Henry' peach, found there were no significant differences in leaf gas exchange characteristics between fruiting and defruited trees. During the early part of the last stage of fruit growth, CO_2 assimilation rates were 11-15% higher in fruiting trees than defruited trees during early stages of fruit growth. These increased assimilation rates corresponded with approximately 30% increase in leaf conductance and only minor changes in mesophyll conductance. He concluded that under field conditions the fruit affected photosynthesis primarily through stomatal behavior. So it can be concluded that the CO_2 assimilation response to the presence of fruit was primarily related to changes in leaf conductance and not to any major changes in mesophyll conductance.

Hansen (1967) hypothesized that apple fruits absorbed photosynthates from surrounding foliage leading to increase photosynthesis as its products was removed. The uptake of nearly 90% of the ^{14}C taken up by the leaves can be transferred to a fruit close by, the majority during the first 4 to 5 days

following the addition of the ^{14}C. The content of ^{14}C in the leaves was reduced more rapidly in shoots with fruit than those without in 'Graasten' apple (Hansen, 1967). He postulated that vegetative growth and fruit development may be limited by the supply of assimilates. However, the fruit may increase the demand for assimilates and thereby stimulate the production of photosynthate. This implies that fruit act as 'sink' for metablites. Thus, fruit impose assimilates demand on leaves through feedback mechanisms (Avery, 1975) affecting source potential.

Flore (1986) indicated that under most conditions fruit trees are not source limited, and that Pn potential is seldom reached. Assimilate accumulation within the whole plant seems to be controlled in one of two ways, either (1) the rate of assimilate production is less than the potential maximum consumption, or (2) the potential rate of production is greater than the actual rate of consumption. Thus the overall rate of assimilate accumulation is determined by the rate of production (source limited) or by the rate of consumption.

However, several other reports have shown no difference between Pn of fruiting and non-fruiting spur leaves of apple (Ferree and Palmer, 1982; Rom and Ferree, 1986a, b). Evidence for spurs acting as an individual entity is supported by the fact that most of the carbon assimilated by spur leaves is retained within the spur (Hansen, 1970). All trees were in a fruiting condition. Therefore the fruiting spur may have imposed a sink demand away from the

fruiting spur on the non-fruiting spur. An alternative situation may have existed if carbohydrates were not limited within the small trees and thus did not require increased photosynthetic activity of spur leaves on fruiting spur to maintain fruit growth. In either case, both non-fruiting and fruiting spurs would have similar sink demand and supposedly similar Pn. This conclusion suggests that the spur may act as a unit and is more responsive to other factors than just that in the immediate vicinity. Also, Marquard (1987) could not find a difference in Pn among the various leaf:nut ratios in pecans. Therefore, the difference among the reports maybe due to the plant materials used and the time of measurement.

2. Respiration

The respiration of leaves were found to be increased in bearing shoots compared to non-bearing ones in the apple tree (Lewak et al., 1970). Grochooska and Lubinska (1973) reported the respiration rate of leaves of bearing spurs was 10 to 25% higher than that of the non-bearing spur leaves.

3. Transpiration and Water Consumption

Comparing fruiting with non-fruiting apple trees show that, in the presence of a crop, transpiration rates and total water consumption are increased. On a per-unit leaf area basis, transpiration rates for cropping trees can be as much as twice those for non-cropping trees (Hansen, 1971b; Lenz, 1986). Hansen

(1971b) reported the uptake of water by 3 year old 'Golden Delicious' apple trees was found to be much greater than in comparable specimens without fruit. The main reason seemed to be differences in the transpiration rates of the leaves. This was corraborated by microscopic investigations which showed a higher degree of stomatal opening in the fruiting trees. Fruiting trees have leaves with greater stomatal apertures (Hansen, 1971b) and higher stomatal conductance (Erf and Procter, 1987; Jones and Cumming, 1984; Monselise and Lenz, 1980; Tromp and Penders, 1986) than defruited trees, two characteristics that appear to explain the observed increase in transpiration and water usage for these trees. Chalmers and Wilson (1978) observed that peach trees bearing a heavy crop wilt much sooner prior to irrigation than non-bearing trees, indicating increased water use in fruiting trees and consequently a reduction in leaf turgor when fruit are present. In addition, they reported an increase in plant water stress during periods when developing fruit were undergoing rapid dry weight accumulation. Evidence for increased water stress in cropping apple trees also exists. Measurements of apple leaf water potentials have averaged 0.07 MPa lower for leaves on fruit-bearing branches (Erf and Procter, 1987). The result from their experiment suggested midday leaf potential decreased with increasing fruit load. Correlations between water potential values and fruit number per tree indicated a negative relationship between these two variables. Lower leaf water potential observed for fruiting trees may be associated with increased transpiration

(Hansen, 1971b; Lenz, 1986) resulting from higher stomatal conductance (DeJong, 1986; Palmer, 1984). However, this explanation for the lowering of leaf water potential may not be entirely satisfactory. Possibly, the presence of fruit may be affecting the turgor or osmotic components of leaf water potential (Erf and Procter, 1987).

Rom and Ferree (1986) reported the transpiration rate of spur leaves was independent of the spur's fruiting condition since it was not correlated to the number of flowers or fruit per spur.

4. Carbohydrates

Carbohydrates have been increased by fruit removal (Weinberger and Cullinan, 1923). Ferree and Cahoon (1987) found the only effect of adjustment in leaf:fruit ratio on carbohydrates was an increase in leaf nonstructural carbohydrate in 'Golden Delicious'/M9 apple. Priestley (1969) found cropping brought about a consistent reduction of starch plus sugar content in the bark and underlying wood. Starch plus sugar levels were generally lower in cropping trees than in deblossomed trees of 'Worcester Pearmain', 'Cox's Orange Pippin', and 'Miller's Seedling' apples. Hansen (1967) found the ^{14}C-sorbital content was higher in leaves from shoots without fruit than in those from fruit-bearing trees, which applied also to the total content of sorbital and of glucose. The production of a heavy crop presumably depletes carbohydrate reserves (Shoemaker and Teskey, 1959). Marquard (1987) reported shoot carbohydrates (starch) in 'Mohawk' pecan was

most closely related to the leaf:nut ratio, presumably because of the greater assimilate demand imposed by large nuts. Fruit thinning of entire pear trees did not result in material increase in percent of carbohydrates, but the absolute amounts per shoot or spur was greatly increased compared with the checks (Aldrich, 1931, 1938).

Taylor and Ferree (1986) found fruit cropping of 'Jonathan'/M26 apple trees did not affect the concentration of water-soluble reducing sugar (SRS) or insoluble hydrolyzable carbohydrates (IHC) of dormant spurs in late March, or of stems of growing spurs in late June. However, fruit cropping reduced the IHC level in leaves of the growing spurs. Marquard (1987) also found leaf:fruit ratio had no apparent effect on sugar or starch content in 'Sioux' shoots and may related to small nut size, and, therefore, relatively small sink demand.

5. Dry Matter Production and Partitioning

The tree made extra growth in terms of dry weight after blossoming. This extra vegetative growth, including more trunk thickening and root growth as well as leaves and new shoots, weighs more than the crop on the fruiting trees (Avery, 1969). Defruiting had slightly less effect than deblossoming. He reported that the dry weight increment of all parts, especially the rootstocks, was less in fruiting than non-fruiting 'Worcester Pearmain' apple trees. He also found that trees with low levels of fruitfulness produced less dry matter, including fruit, than

deblossomed trees because of less shoot growth. Trees of high fruitfulness produced as much, or even more dry matter than deblossomed trees because of increased photosynthetic efficiency. Maggs (1963) reported that fruiting 2 year old 'Worcester Pearmain' apple trees had a smaller dry weight increment, including the fruit, than others which were deblossomed or defruited trees. Fruiting decreased total dry weight increment and particularly increment of rootstock, reflecting the large effect on root increment.

Crop load influenced the dry matter partitioning markedly (Hansen, 1980; Lenz, 1986; Palmer, 1986). Hansen (1980) reported that in heavy cropping trees the major part of the total dry matter was translocated into the fruit. Apple trees under heavy cropping had about 70% of their annual production as fruit in 'Crispin'/M27 apple trees (Palmer, 1986), indicating that these organs compete successfully with vegetative parts of the plant for photosynthetic products (Lenz, 1986). However, he found little indication of anything other than a positive linear response to crop load, with heavily cropping trees producing over twice the dry matter per unit intercepted light compared to non-fruiting trees.

D. EFFECT OF CROPPING ON THE MINERAL STATUS OF FRUIT TREES

Understanding of the specific role of the fruit in the uptake and partitioning of mineral elements is of major significance for

the nutritional requirement of the tree. The total uptake of
nutrients by the plant depends on the size of the plant, the
nutrients' availability in the soil and the distribution of growth
of the different organs. For elements that have wide differences
in mineral concentrations as leaves and fruit, total nutrient
uptake is affected more by cropping than soil nutrient
availability (Hansen, 1971).

1. Nitrogen

Since crop load alters total mineral uptake and partitioning,
the concentration of nutrients in individual organs may also be
affected. There was a highly significant difference in leaf
nitrogen concentration between the bearing and non-bearing trees
of 'Miller's Seedling' apple for the whole or part of the season
with the leaves of the bearing trees containing the greater
nitrogen concentration (Mason, 1955). With different leaf:fruit
ratios in 'Golden Delicious'/M9 apple trees, Ferree and Cahoon
(1987) reported that mean leaf nitrogen level over 5 years was
slightly reduced when crop was adjusted to high number of
leaves:fruit. The leaf nitrogen level followed the same pattern as
the average number of fruit per tree, showing clearly that leaf
nitrogen increased as the density of the crop increased. In a
summary of the effects of crop load on foliar nutrient levels,
Lord and Bramlage (1983) indicated that trees with a large apple
crop may contain 0.2-0.3% more nitrogen than a similar tree with a
light crop. Forshey (1982) found that there were some differences

between fruit-thinning treatments that were apparently related to previous crop; trees that produced a heavy crop had lower leaf nitrogen the following year than trees with lighter crop. But nitrogen concentration did not differ consistently in 'Cox's Orange Pippin' apple with various crop load (Sharples, 1968). In fruiting trees of 5 year old 'Golden Delicious'/M4 apple trees, total uptake of nitrogen was reduced to about half of that in non-fruiting trees (Hansen, 1980). This relationship could relate to the fact the fruit, which constitute the great part of the total dry matter in fruiting trees, have a much lower concentration of nitrogen in their dry matter than is found in the new growth in form of leaves on non-fruiting trees.

For the 'Elberta' and 'Halehaven' peach trees, the removal of the crop from the trees resulted in a decrease in the level of leaf nitrogen. The difference in nitrogen level in the leaves between the thinned and unthinned crop treatments were small and usually in the same direction as the effect of total removal. The lower level of nitrogen found in the leaves of the uncropped trees may be associated with increase in terminal growth, which averaged 5 or 6 inches more than the terminal growth on the crop-bearing trees, and also with the fact that the nitrogen level in the twigs which made up this terminal growth was relatively high (Popenoe and Scott, 1956).

2. Phosphorus

Phosphorus concentration generally follow the same pattern as

nitrogen (Messaoud,1986), but the results are not equivocal.

Similar reduction of total uptake of phosphorus as nitrogen was

found in non-fruiting 'Golden Delicious' apple trees (Hansen,

1980). In non-fruiting trees root growth requires large amounts of

nitrogen and, especially, of phosphorus as is shown by P/N ratio

in roots of non-fruiting trees. Hansen (1976) has shown that the

uptake ratio of P/N is higher at the time of rapid root growth.

Phosphorus contents, expressed on a fresh weight basis, were found

to be higher in the cortical tissue of the thinned 'Cox's Orange

Pippin' apple fruit (Sharples, 1964). Taylor and Ferree (1986)

found the previous season's cropping treatments had no effect on

phosphorus concentration in spur leaves of 'Top Red Delicious'/M9

and 'Jonathan'/M26 apples, while the spur leaves of fruiting trees

had higher magnessium levels than did those on defruited trees.

Marked decrease in leaf phosphorus was found with a heavy crop of

fruit in 'McIntosh' apple (Cain and Boynton, 1948). Also, there

was a significantly higher leaf phosphorus concentration for the

bearing versus the non-bearing trees for the whole or part of the

season in 'Miller's Seedling' apple (Mason, 1955). But no

difference in phosphorus concentration was found between lightly

cropping and heavily cropping trees in 'Cox's Orange Pippin'

apple. In 'Elberta' and 'Halehaven' peach trees, phosphorus level

were higher in the leaves of non-cropping trees than it was in the

leaves of cropping trees, while the removal of the crop from the

trees resulted in a decrease in the level of nitrogen.

3. Potassium

Similar to nitrogen, phosphorus and magnessium, the major part of potassium (which is present in large amounts) in apples is translocated into the fruit nearly linearly with dry weight (Tromp, 1975). Fruiting seems to affect dry matter and potassium in very similar ways for fruit are strong sinks of both. Total dry matter production and total uptake of potassium per tree in 5 year old 'Golden Delicious'/M4 apple were both similar in fruiting and defruited trees. Equalization of potassium and starch with the tree was interpreted as a contemporary translocation of assimilates and potassium from defruited to fruiting limbs (Hansen, 1980). The greater stress for potassium in cropping trees, due to the high demand by fruit compared to growth in woody parts, also manifests itself as a generally lower accumulation of potassium in dry matter of other organs of the fruiting trees compared to non-fruiting trees (Hansen, 1971c). The drop in potassium concentration with fruiting seems to occur in particular range of fruit/leaf ratios (Hansen, 1980). Fruit on heavily thinned trees, or the large fruit from the other parts of the tree, have the higher concentration of potassium (Sharples, 1964). Positive correlation between potassium and the soluble dry matter or acid contents of fruit have been demonstrated (Wilkinson, 1958; Perring and Preston, 1974). With 'Golden Delicious'/M9 apple trees, Ferree and Cahoon (1987) found that the only significant interaction between crop load and the foliar nutrition treatment occurred with potassium. When no foliar

nitrogen was applied, the medium level of leaves:fruit ratio

resulted in the highest leaf potassium. However, when foliar

nitrogen was applied, there was no difference in leaf potassium.

Sharples (1964) reported a higher potassium content, expressed on

a fresh weight basis, in the cortical tissue of the thinned 'Cox's

Orange Pippin' apple. Cain and Boynton (1948) found no difference

in leaf potassium content up to July but a marked difference

developed later in the year, with leaves from the bearing trees

having the lower concentration. Ljones and Braadlie (1954) found

that there was less potassium in the leaves of apple trees bearing

a heavy crop than in those from trees bearing a light crop. Higher

potassium level was found in the leaves of the non-cropping trees

than in the leaves of cropping trees in 'Elberta' and 'Halehaven'

peaches. But no significant difference in leaf potassium content

was found between bearing and non-bearing 'Miller's Seedling'

apple trees (Mason, 1955).

4. Calcium

Calcium shows quite a different picture from nitrogen,

phosphorus and potassium. Generally, fruiting reduced the

concentration of potassium but increased that of calcium within

different parts of the tree (Hansen, 1980). In the roots and fruit

a steady increase in calcium concentration is demonstrated with

increasing fruit/leaf ratios. The calcium content of fruit is very

low, but the change with crop load is relatively large. Deake et

al. (1974) found a substantial increase in the calcium

concentration of the peel with higher mean yield. Perring (1968)

and Perring and Preston (1974) demonstrated a negative correlation

between fruit size and calcium concentration. Cain and Boynton

(1948) reported a marked increase in calcium and a total base of

Ca+Mg+K with a heavy crop of fruit in 'McIntosh' apple. Mason

(1955) reported also the higher calcium concentration in leaves of

the bearing than non-bearing 'Miller's Seedling' apple trees. The

removal of the crop from 'Elberta' and 'Halehaven' peaches

resulted in a decrease of calcium level in leaves (Popenoe and

Scott, 1956). But others (Ferree and Cahoon, 1987; Sharples, 1964,

1968) found leaf or fruit calcium was unaffected by cropping or

thinning.

5. Magnessium

Magnessium is another mineral element which was found to be

affected by cropping and it is more complex than nitrogen,

phosphorus, potassium and calcium. Some similarity to calcium was

found with respect to total uptake in 5 year old 'Golden

Delicious' apple (Hansen, 1980). Higher content was found in the

cortical tissue of the thinned 'Cox's Orange Pippin' apple fruit

(Sharples, 1964). The spur leaves of fruiting trees had higher

magnessium level than did those on defruited 'Top Red

Delicious'/M9 and 'Jonathan'/M26 apple trees (Taylor and Ferree,

1986). Magnessium was found to be significantly higher in the

leaves of the bearing 'Miller's Seedling' apple trees for the

whole or part of the season (Mason, 1955). But Sharples (1968)

found the concentration of magnessium did not differ consistently between lightly cropping and heavily cropping 'Cox's Orange Pippin' apple trees. The removal of the crop from the 'Elberta' and 'Halehaven' peach trees resulted in a decrease in the magnessium level in the leaves (Popenoe and Scott, 1956).

6. Other Elements

For the other elements, mangnese was found to be higher in the leaves of bearing 'Miller's Seedling' apple trees and iron was unaffected by fruiting (Mason, 1955).

7. Residual Effect

Residual effect of the fruiting conditions on following year's mineral composition were also observed. The supplies of nitrogen, phosphorus and potassium used in the formation of new tissue at the beginning of the season are derived mainly from tree reserves, principally the bark of branches and stems (Mochizuki and Kamakura, 1968), thus the effect that crop load has on the establishment of these reserves is manifest in the following season.

Crop load induced differences in nitrogen content are frequently obliterated quite rapidly in the following spring (Mochizuki, 1962; Hansen, 1965), whereas in spur leaves the differences for potassium and calcium may be maintained throughout the following summer. The residual effect in leaves is evidence of transportation from older to young tissues, even in the case of

calcium which is often considered rather immobile. The residual effect for calcium is clearly preserved in the perennial parts of the tree which suggests its mobility to be lower than that of potassium. Iron, boron and sodium concentrations in spur leaves of 'Top Red Delicious'/M9 and 'Jonathan'/M26 apple trees were found to be unaffected by previous season's cropping treatments (Taylor and Ferree, 1986).
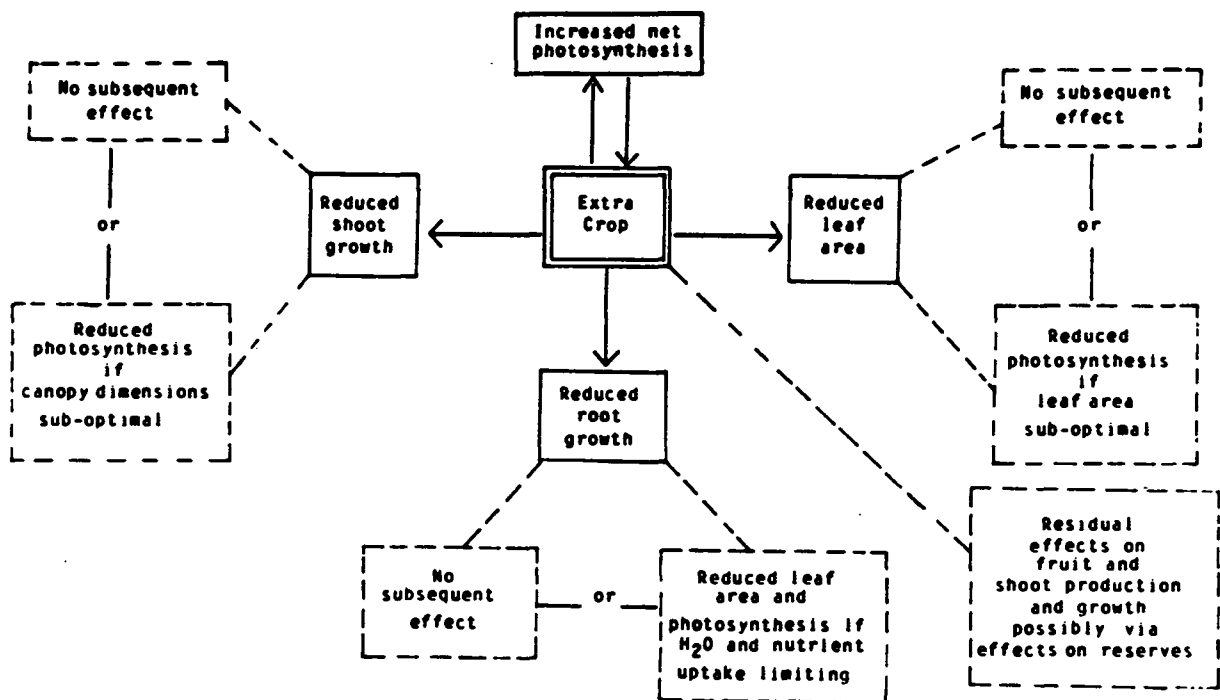
Fig. 2-1. effect of increased cropping on carbon balance
and photosynthetic productivity and growth.
solid lines and boxes represent possible effect
in the year of heavy cropping;
dotted lines and boxes possible effect in the
following year (Jackson, 1984).

Chapter 3. EFFECT OF CROP DENSITY ON VEGETATIVE GROWTH, FLOWERING, FRUIT GROWTH, YIELD AND YIELD EFFICIENCY IN NIJISEIKI PEAR TREES

Abstract

Fruitlets of Nijiseiki (Pyrus pyrifolia) on P. betulaefolia pear trees were thinned to various crop density (CD) levels of 3-16 fruit cm^{-2} trunk cross-sectional area (TCSA) in 1986 and 4 levels of CD (1, 3, 5, and 7 fruit cm^{-2} TCSA) in 1987. Completely randomized experimental design was used. Increase in CD reduced trunk growth, leaf area and weight of non-fruiting spur, mean and total length and number of terminal shoots. Decreasing levels of CD increased fruit size with decreasing yield. A decrease of CD levels from 3 to 1 fruit cm^{-2} TCSA reduced yield by about 66% while the reduction amounted 33% between 5 and 3 fruit $^{-2}$ TCSA in 1987.

There was a positive linear correlation between CD and biomass in fruit and total of leaves and fruit, but negative in leaves alone. CD affected the partitioning of biomass (fresh weight and dry matter) between leaves and fruit also. There was no effect of CD on return bloom and flower size.

Introduction

It is well accepted that fruit load influences fruit and tree growth of fruit trees (Avery, 1969; Barlow, 1964; Jackson, 1984; Singh, 1948). A significant relationship has been established between cropping level and the reduction in trunk growth (Barlow, 1964; Mochizuki, 1962; Palmer, 1984; Preston, 1969; Quinlan and Preston, 1968; Taylor and Ferree, 1984). Shoot growth was reduced by previous crop (Forshey, 1982; Mochizuki, 1962; Rogers and Booth, 1964; Wilcox, 1937) as well as the current crop (Avery, 1969, 1970; Barlow, 1964, 1966; Quinlan and Preston 1968). However, a few have reported there is no effect of cropping on either trunk growth (Forshey, 1982; Preston, 1954) or shoot and leaf growth (Mochizuki, 1962; Preston, 1954).

The productivity of fruit trees has been found to be markedly affected by cropping. Cropping has reduced fruit bud formation (Aldrich, 1931; Aldrich and Fletcher, 1932; Aldrich and Work, 1934; Harley et al., 1933; Hennerty, 1971; Rom and Ferree, 1986; Taylor and Ferree, 1984) and fruit set (Aldrich, 1931; Aldrich and Fletcher, 1932; Bobb and Blake, 1978; Hennerty, 1971; Westwood and Bjornstad, 1974). Reduced cropping resulted in an increase of fruit size (Lombard, 1986; Palmer, 1986; Preston, 1954, 1969; Van Der Boon, 1980). Increasing leaf:fruit ratio was associated with increased fruit weight (Beers et al., 1987; Proebsting and Mills, 1981). The increase in fruit growth rate was not in proportion to the increase in leaf area and therefore, crop load decreased the

total yield per tree (Aldrich, 1938; Palmer, 1986; Preston, 1969; Weinberger and Cullinan, 1932; Van Der Boon 1980).

The dry matter production was reported to be reduced by heavy crop (Avery, 1969, 1970; Maggs, 1963) and crop load influenced the dry matter partitioning markedly (Hansen, 1980; Lenz, 1986; Palmer, 1986).

Growing Asian pears in the U. S. A. requires heavy fruit thinning to increase the rate of fruit growth and improve 'pack-out' size at harvest. Nijiseiki is the leading cultivar but it is small fruited. Since marketing Asian pears depends on large fruit, the level of thinning necessary to produce marketable fruit must be known. Crop density (CD) which is a principle component of yield (Lombard, 1987), can be adjusted at various thinning levels to evaluate its relative effect on yield and fruit size. Since continued production is important, the study should include the effect of CD on vegetative growth, return flowering, fruit development and dry matter production and partitioning.

Materials and Methods

The study was conducted in a drip irrigated Asian pear orchard near Dayton, Oregon. Nijiseiki pear trees on <u>P. betulaefolia</u> were transplanted in the orchard in 1985 at a spacing 2.4*4.8 m. Twenty-four trees were adjusted to 6 levels (3, 5, 7, 9, 11 and 13 fruit cm^{-2} TCSA) of CD by fruitlet thinning on May 29, 1986 (8 weeks after full bloom). The fruit were uniformly thinned over the canopy of the trees. Fruitlets were thinned to none, 1, 2 or 3 on each cluster according to CD designed. At harvest, the fruit number per tree was counted and CD was found not in 6 levels, but ranging from 3 to 16 fruit cm^{-2} TCSA (measured in April, 1986). In 1987, CD was carefully adjusted to 4 different level (1, 3, 5, 7 fruit cm^{-2} TCSA) on June 9 after cluster thinning at full bloom, March 30.

Trunk circumference was measured at the beginning and the end of the season after harvest. Diameter and TCSA were calculated from the circumference. The increase of trunk size was determined in terms of actual increase and per cent increase. All terminal shoots were measured with a tape at the end of the growing seasons to obtain shoot numbers, mean shoot length and total shoot length per tree. Spur number was counted at the end of the growing season in 1987. Leaf number, area, dry weight were estimated for shoots and spurs (Appendix A). Fully expanded leaves were taken from 30 terminal shoots, fruiting and non-fruiting spurs on August 4, 1986; and from 10 terminal shoots, 15 fruiting and non-fruiting

spurs on August 4, 1987. Leaf area, fresh weight and dry weight were measured for the samples. Total leaf number, area, fresh and dry weight were estimated from total shoot length, spur number and the samples of 100 leaves for each tree.

Five fruit on August 4, 1986 and 25 fruit per tree at harvest were taken for the size measurement (diameter, length, fresh and dry weight) in 1986 and 1987. Fruit shape was determined as the ratio of length to the diameter. In 1987, 10 fruit per tree were measured in terms of diameter and length with a caliper after thinning at one month intervals till harvest. Fruit shape was calculated and fruit fresh weight was estimated from diameter and length (Appendix B). At harvest, firmness, total soluble solids measurement and seed content were taken on 5 fruit per tree.

Yield were calculated by multiplying the fruit number and the mean fresh weight of 25 fruit from each tree. Yield efficiency was defined as the fruit weight cm^{-2} TCSA at the beginning of the season. Total dry weight in fruit was calculated from the yield and fruit water content for each tree.

Partitioning of fresh biomass and dry matter was considered as the ratio of those in leaves or fruit to the total in leaves and fruit.

Clusters were counted for each tree at the beginning of the second growing season. Fifty flowers were taken from each tree and weighed for fresh and dry weight to determine if the CD affected return flowering in Nijiseiki pear.

A completely randomized design was used with 4 (in 1986) or 6

(in 1987) single-plant replications per treatment. Data were
analyzed with regression procedure for 1986 and ANOVA procedure
for 1987.

Results and Discussion

1. Fruit Growth

Negative correlation was found between CD and fruit size, in terms of diameter, length, fresh and dry weight in 1986. Fruit measurements bore a negative linear correlation, except dry weight bore a curvilinear relationship with CD (Fig. 3-1).

In 1987, a significant difference of fruit size and fruit growth rate was found between the 2 lower levels and the 2 higher levels of CD (Table 3-1). No significant correlation was found between CD and fruit firmness or total soluble solids in 1986 (data not shown), but there was significant increase in fruit firmness and total soluble solids with decreasing CD in 1987 (Table 3-2). No difference of seed content was found among the treatments.

Predictably, CD had a great effect on the fruit size, as previous studies found (Beers et al., 1987; Fletcher, 1932; Kishmoto, 1975; Palmer, 1986; Preston, 1969; Van Der Boon, 1980). The steeper regression slope at harvest than one month earlier indicated the effect of crop density on fruit growth was cumulative during the growing season. Since CD had greater effect on fruit length than on fruit diameter, evidently CD affected the faster growing parameter than slower growing parameter of fruit.

2. Yield and Yield Efficiency

The relationship between CD and yield expressed as kg tree^{-1},

tons ha.$^{-1}$ and yield efficiency (YE) were linear and positive
(Fig. 3-2) in 1986. In 1987, the yield and yield efficiency were
significantly different between each level of CD (Table 3-3).
Difference of yield and YE between successive CD levels became
larger as CD decreased. The largest interval in yield occurred
between 1 and 3 fruit cm^{-2} TCSA while the yield deference were
similar between 3 and 5, and 5 and 7 fruit cm^{-2} TCSA.

Yield varied considerably among the various CD levels. The
lowest CD (1 fruit cm^{-2} TCSA) resulted in a very small yield with
no increase in larger fruit compared with CD of 3 fruit cm^{-2} TCSA.
But lower CD showed a big advantage in fruit size compared with
higher CD (Table 3-4), agreed well with previous studies in apples
(Aldrich and Fletcher, 1932; Forshey, 1982), pears (Aldrich, 1938)
and peaches (Weinberger and Cullinan, 1932). The yield was more
closely correlated with fruit number (r=0.95[**]) than fruit size
(Fig. 3-2, Table 3-3). Forshey (1977, 1982) and Forshey and
Elfving (1977) also found that yield bore a strong positive
correlation with fruit numbers, but a weak negative correlation to
fruit size.

3. Vegetative Growth and Leaf Canopy

Level of CD influenced trunk growth, rate of TCSA increase,
markedly in 1986 (Fig 3-3). Significant and negative correlation
was found between CD and trunk growth. However, no significant
effect of CD on TCSA increase occurred in 1987 (data not shown).

High levels of crop load was shown to reduce trunk growth

(Avery, 1975; Barlow, 1964; Lenz, 1979; Palmer, 1984; Quinlan and Preston, 1968; Taylor and Ferree, 1984). But others (Forshey, 1982; Preston, 1954) found trunk growth was unaffected by either degree or the time of fruit thinning. The lack of any significant differences among the treatments in 1987 was due to the narrow and low levels of CD in the study, 1 to 7 fruit cm^{-2} TCSA.

Also in 1987, there was no significant differences among CD levels in total vegetative points although they increase with larger CD, but a heavier CD level resulted in less shoots and more spurs (Table 3-5). Consequently, there was no effect of CD on total leaf number, area and dry weight per tree, but CD had a significant effect on the distribution of shoot and spur leaf area and leaf dry weight (Table 3-6). Heavier cropping trees had less shoot leaves and more spur leaves compared with lighter cropping trees.

In 1986, CD was negatively correlated with the dry weight (r=-0.5146**) and area (r=-0.76**) of fully expanded leaf in non-fruiting spurs only (Fig. 3-4). No significant effect of CD was found on leaf size of terminal shoot and fruiting spurs, specific leaf weight of terminal shoot, fruiting and non-fruiting spur leaves, tree width, leaf canopy area and leaf area index.

The trees with 1 fruit cm^{-2} TCSA had about twice the shoots as trees with 5 or 7 fruit cm^{-2} TCSA (Table 3-5) since CD affected number of terminal shoots. This agrees with Barlow (1966), who suggested that fruiting reduced the number of growing points that develop into long shoots.

Also, CD influenced mean and total length but not the number of terminal shoots per tree in 1986. There was negative correlation between crop density and mean or total shoot length per tree (Fig. 3-5). In 1987, significant differences were found with shoot number and total shoot length but not with mean shoot length (Table 3-6).

It is well established that terminal shoot growth of apple trees was reduced by either previous crop (Forshey, 1982; Mochizuki, 1962; Rogers and Booth, 1964; Wilcox, 1937) or current crop (Avery, 1969, 1970; Barlow, 1964, 1966; Quinlan and Preston, 1968). However, some have found that the effect of fruiting on shoot growth was from a reduction in shoot numbers rather than reduced shoot length (Avery, 1969, 1970;, Forshey, 1982; Forshey and Marmo, 1985; Quinlan and Preston, 1968). Similar results were obtained in this study, but the correlation coefficients were similar between CD and both numbers and mean length of shoots in 1986.

4. Dry Matter Production and Partitioning

CD affected the dry matter partitioning between leaves and fruit significantly. Total fresh biomass or dry matter in leaves bore negative linear correlation to CD while total fresh biomass or dry matter in fruit bore a positive correlation to CD (Fig. 3-6). The slope of the regression lines for fruit were much greater than that for leaves. So the relationship between CD and partitioning of fresh biomass or dry matter between leaves and

fruit, expressed as % of total, was curvilinear instead of linear
(Fig. 3-6). In 1987, significant differences were found with dry
matter in fruit but not that in leaves (Table 3-7), indicating
that CD mainly influenced the dry matter transferred into fruit
but not in leaves.

The influence of CD on dry matter production and partitioning
was also found by others (Hansen, 1980; Lenz, 1986; Palmer, 1986).
For either fresh biomass or dry matter, the distribution in leaves
was much less sensitive to CD than fruit because total leaf dry
weight was hardly affected by CD. The partitioning of dry matter
in leaves decreased from 58 to 22% while the fresh biomass
decreased from 22 to 8% as CD increased from 3 to 16 fruit cm^{-2}
TCSA in 1986 (Fig. 3-6).

5. Return Bloom and Flower Size

There was no significant correlation between CD and flower
cluster number per tree or flower cluster density expressed as
cluster number cm^{-2} TCSA. No effect of CD was found on flower size
in spring 1987 (data not shown). This did not agree with previous
studies (Aldrich, 1931; Aldrich and Fletcher, 1932; Aldrich and
Work, 1934; Harley et al., 1933; Hennerty, 1971; Rom and Ferree,
1986; Taylor and Ferree, 1986) possibly because the young age of
the trees.

CD affected fruit growth, yield, yield efficiency, vegetative
growth, dry matter production and partitioning, but not return

flowering in young Nijiseiki pear trees. The trees with high CD were smaller because of high productivity, while the trees with low CD were becoming larger and more vigorus and would have a greater potential to have high productivity afterwards.
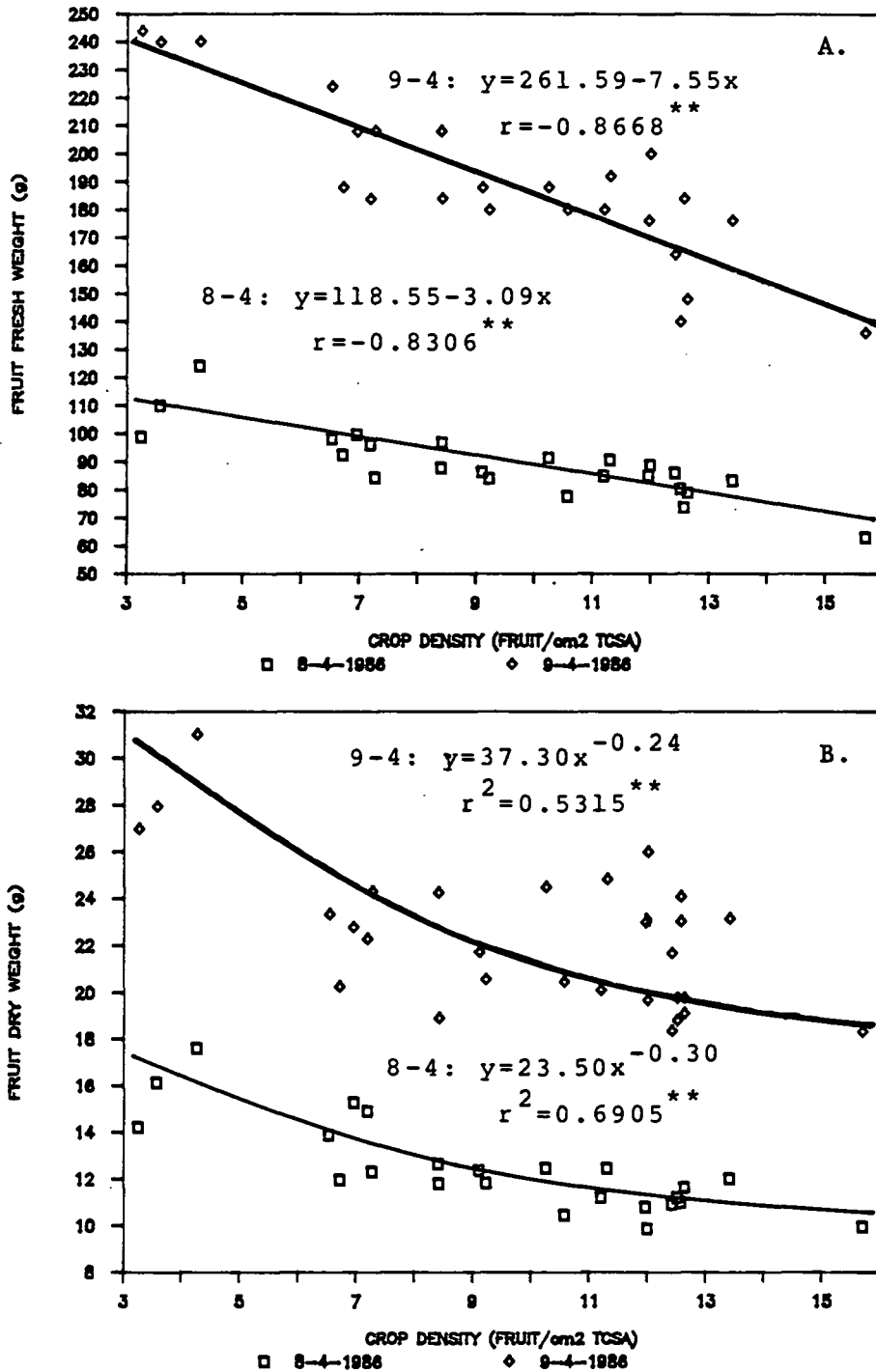
Fig. 3-1. The relationship between crop density
and fruit growth in Nijiseiki pear (1986):
A: fruit fresh weight, B: fruit dry weight.

** significant at 1% level.
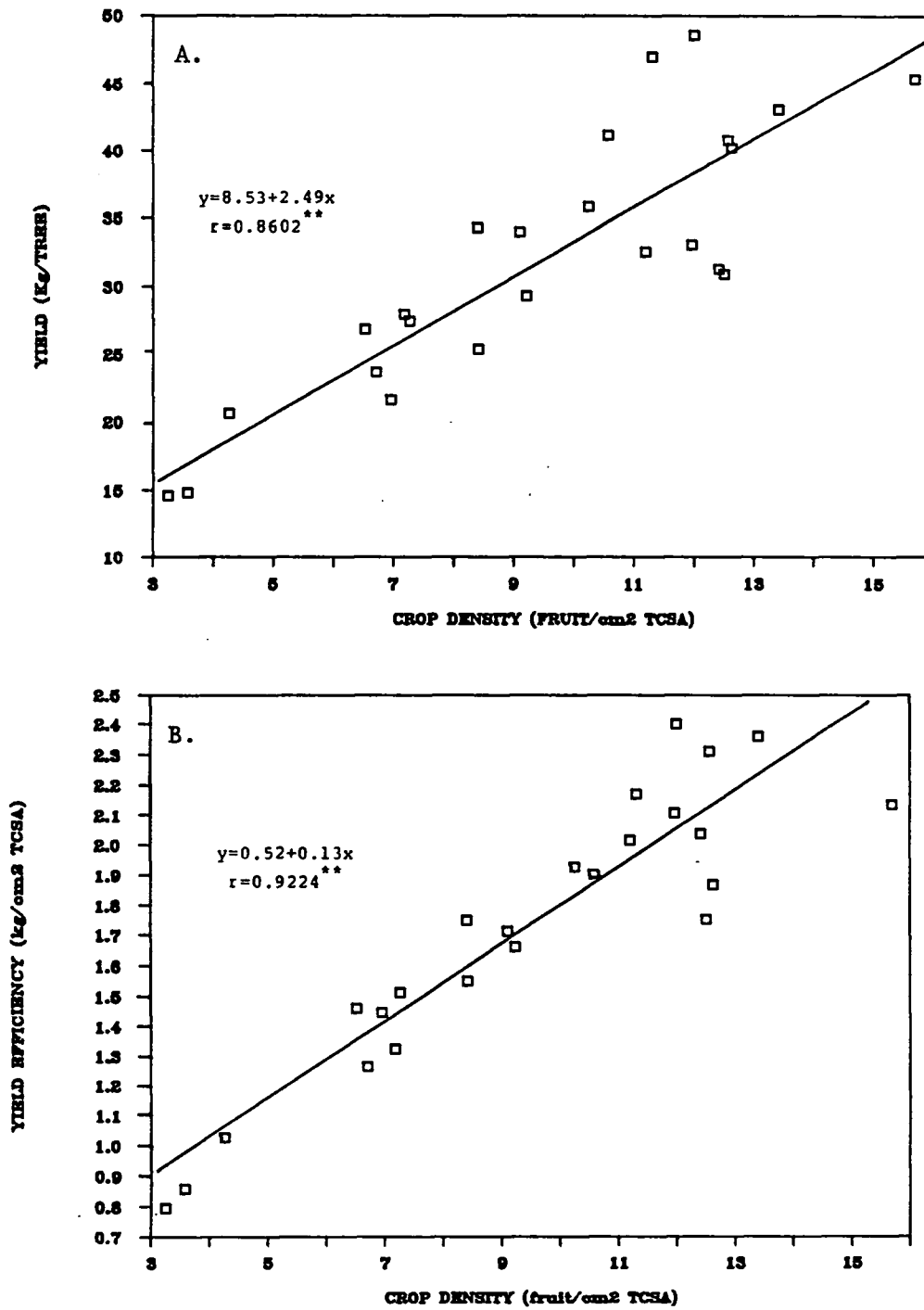
Fig. 3-2. The relationship between crop density
and yield (A) or yield efficiency (B)
in Nijiseiki pear (1986).

** significant at 1% level.

The chart shows a scatter plot with:
- Y-axis: TRUNK TCSA INCREASE (cm2), ranging from 5 to 15
- X-axis: CROP DENSITY (FRUIT/cm2 TCSA), ranging from 3 to 15
- Equation: $y = 13.67 - 0.37x$
- $r = -0.6703^{**}$
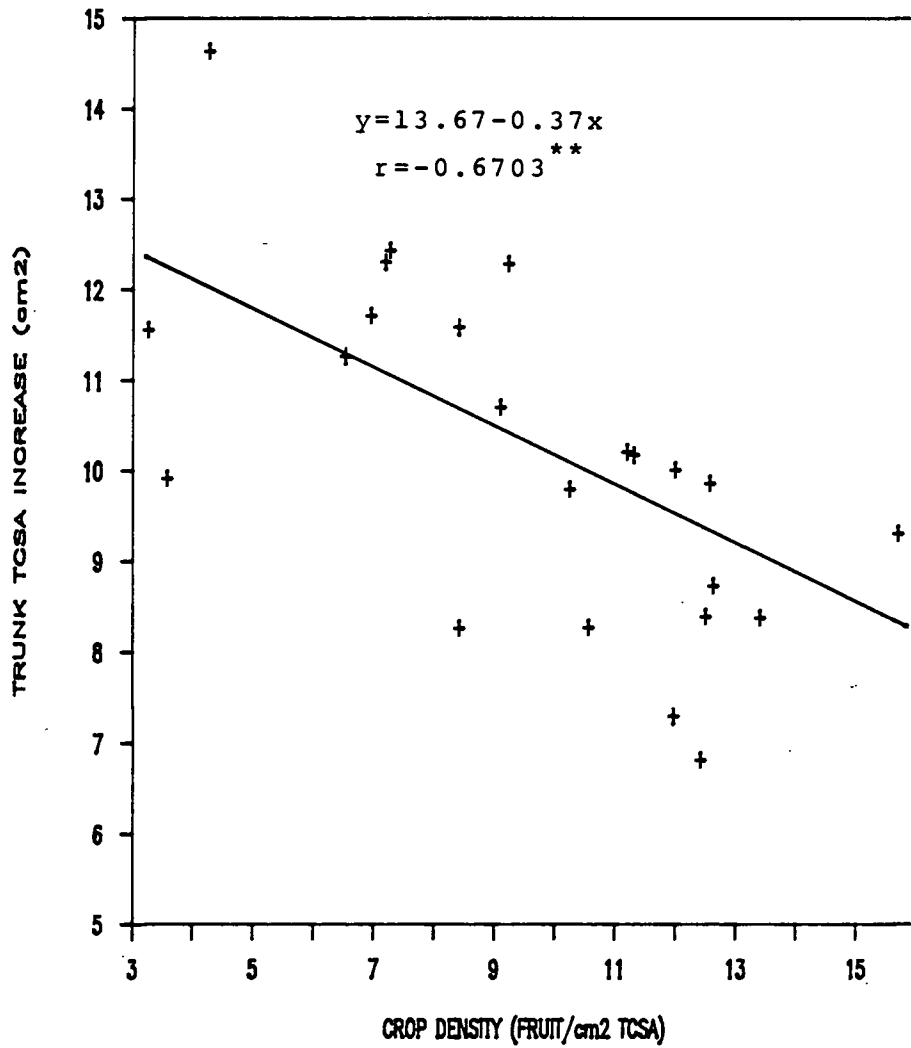
Fig. 3-3. The relationship between crop density
and trunk cross-sectional area increase
in Nijiseiki pear (1986).

** significant at 1% level.

$$y = 51.23 - 0.67x$$
$$r = -0.7578^{**}$$

LEAF AREA (cm2/LEAF)

CROP DENSITY (FRUIT/cm2 TCSA)
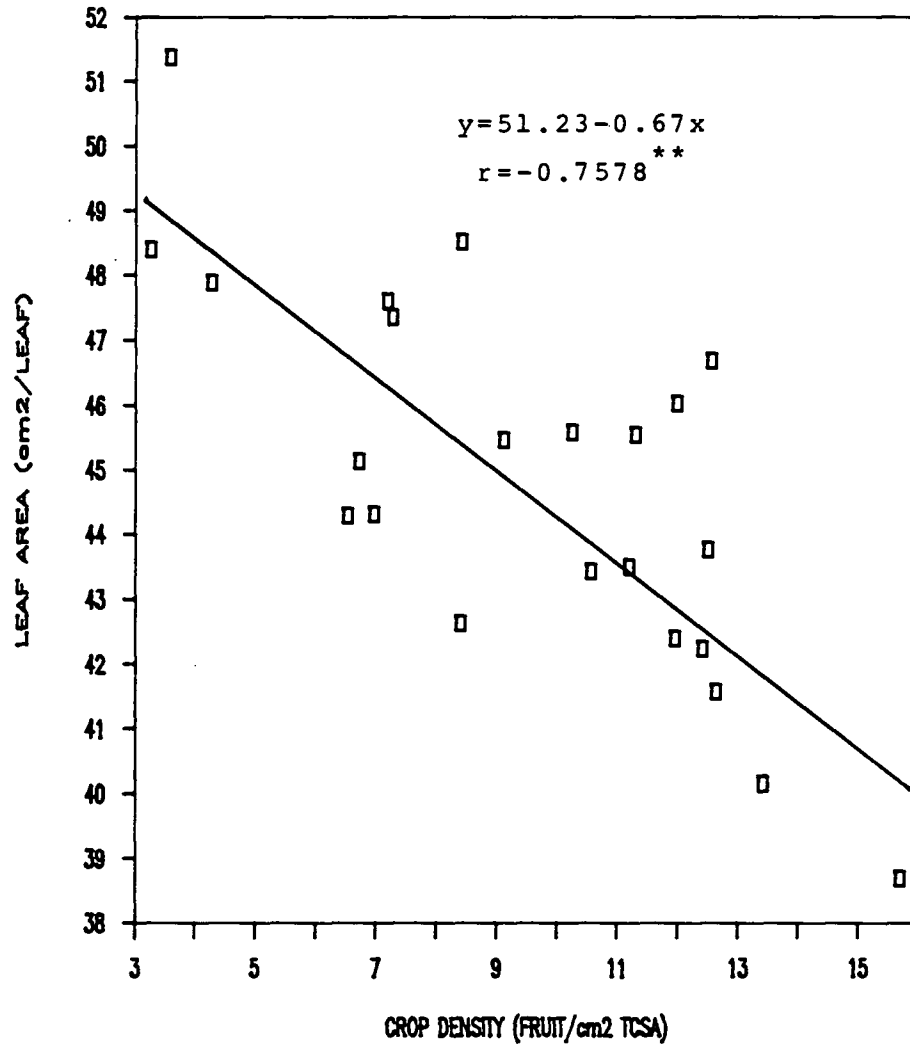
Fig. 3-4. The relationship between crop density
and leaf area of non-fruiting spurs
in Nijiseiki pear (1986).

** significant at 1% level.
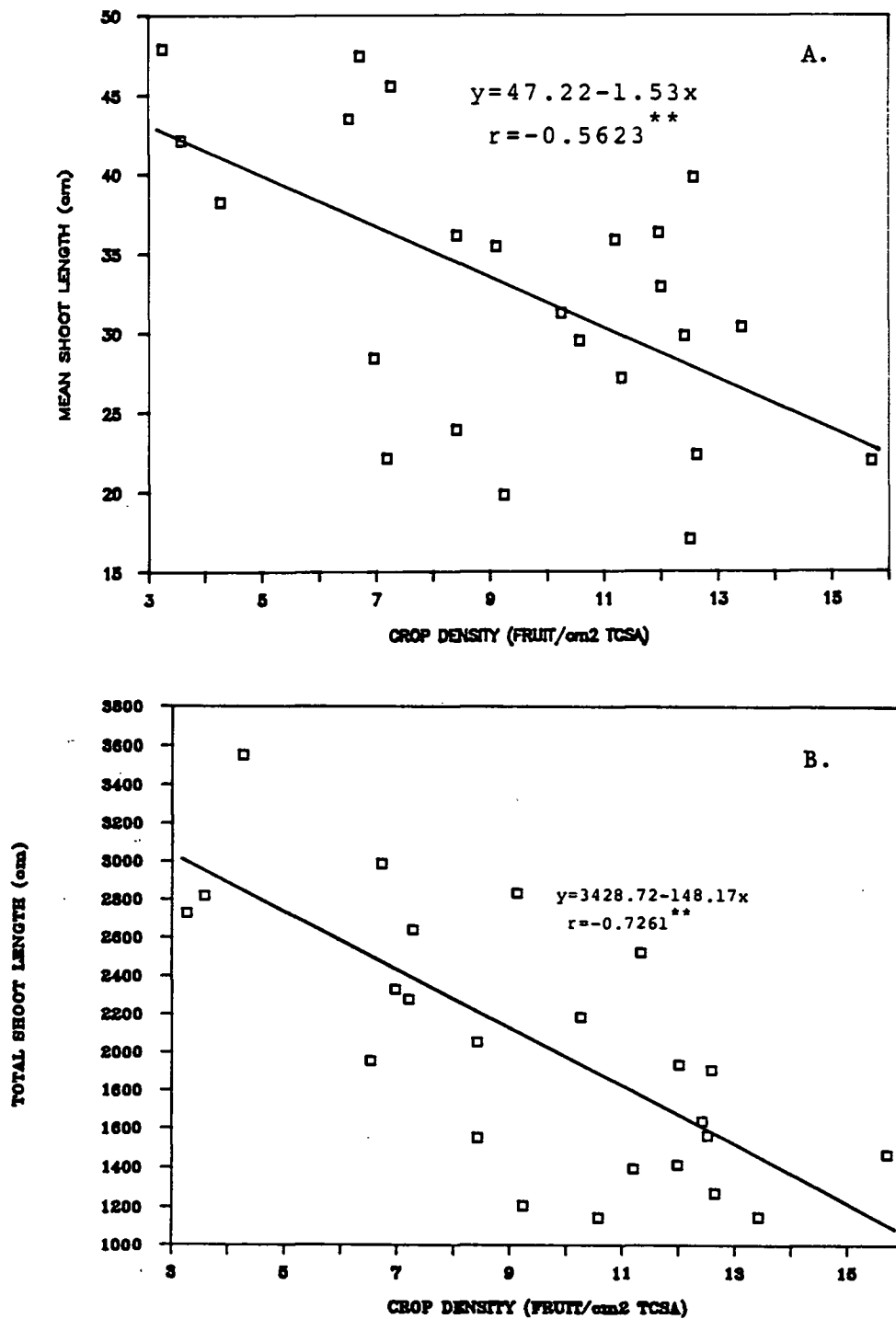
Fig. 3-5. The relationship between crop density and
mean (A) or total (B) terminal shoot length
in Nijiseiki pear (1986).

** significant at 1% level.
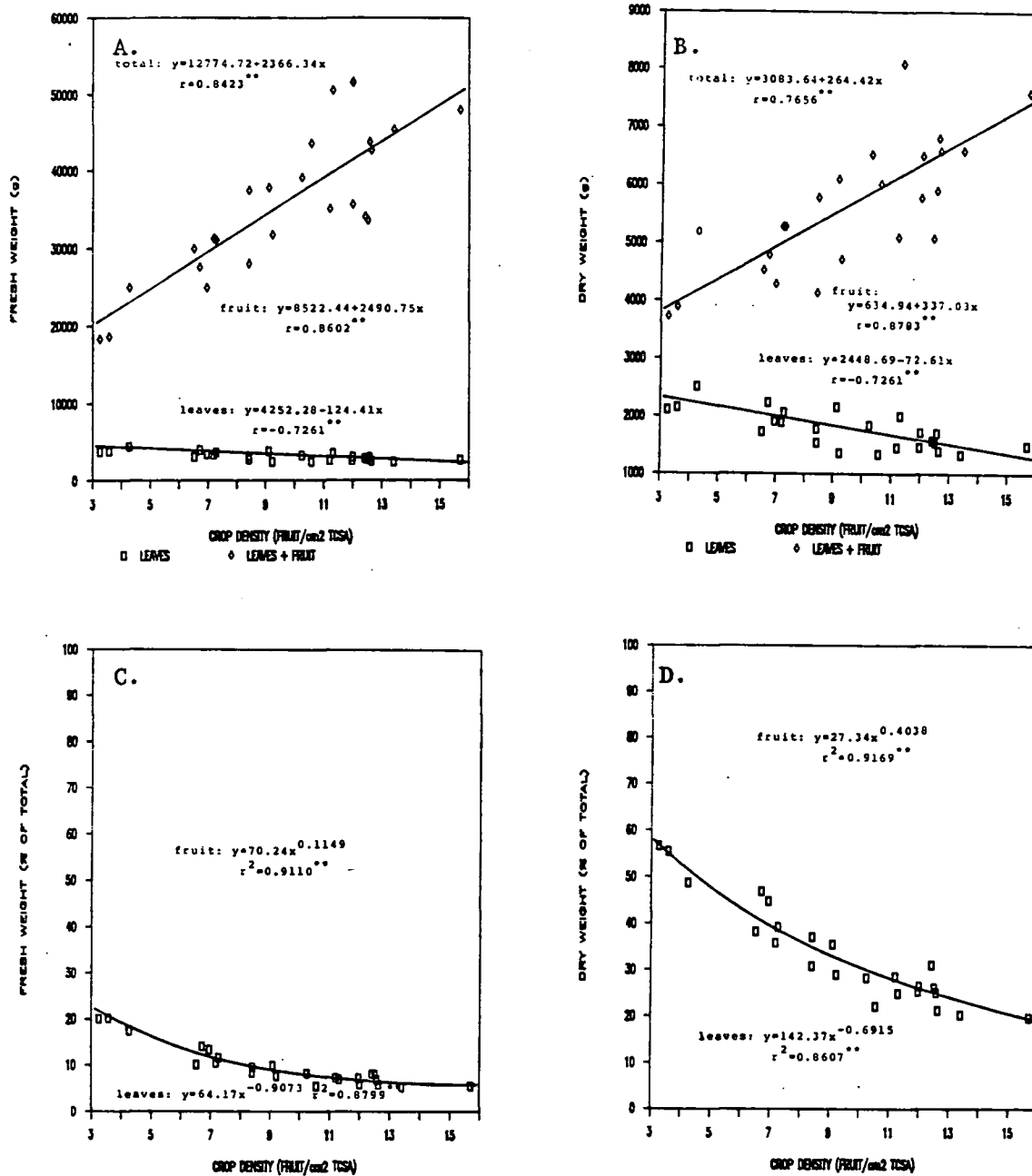
Fig. 3-6. The relationship between crop density
and fresh or dry biomass production and
partitioning in Nijiseiki pear (1986):
A: fresh biomass,   B: dry matter,
C: fresh biomass partitioning, D: dry matter partitioning.

** significant at 1% level.

Table 3-1. The effect of crop density on fruit size
and growth rate in Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	diameter (cm)	length (cm)	shape (L/D)	fresh weight (g)	growth rate (g day^{-1})
July 9					
1	4.09 a	3.84 a	0.9401	37.38 a	0.81 a
3	4.07 a	3.80 a	0.9531	36.62 ab	0.83 a
5	3.90 b	3.64 b	0.9331	32.02 c	0.71 b
7	3.94 b	3.64 b	0.9228	32.74 c	0.75 b
August 5					
1	6.22 a	5.58 a	0.8972	128.38 a	3.50 a
3	6.20 a	5.62 a	0.9066	128.98 a	3.55 a
5	5.90 b	5.35 b	0.9073	110.61 b	3.02 b
7	5.86 b	5.26 b	0.8975	107.36 b	2.87 b
September 5					
1	7.49 a	6.65 a	0.8878	224.18 a	3.09 a
3	7.46 a	6.74 a	0.9032	224.91 a	3.09 a
5	6.97 b	6.26 b	0.8975	182.26 b	2.31 b
7	6.86 b	6.11 b	0.8917	171.87 b	2.08 b

* Mean separation in columns within each date by Duncan's
multiple range test, p = 5%.

Table 3-2. The effect of crop density on fruit firmness,
total soluble solids and seed content in Nijiseiki pear (1987)

crop density (frui cm^{-2} TCSA)	firmness (newton)	total soluble solids (Brix %)	seed content (seeds/fruit)
1	12.82 b	13.23 a	6.33
3	13.13 a	12.59 ab	5.83
5	11.98 c	12.48 ab	5.77
7	12.24 c	11.87 b	5.56

* Mean separation in columns by Duncan's multiple range test,
  p = 5%.

Table 3-3 The effect of crop density on leaf:fruit ratio,
yield and yield efficiency in Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	leaf: fruit ratio	no. fruit /tree	yield (kg/tree)	yield (tons/ha.)	yield efficiency (kg/cm^2 TCSA)
1	143 a	29 d	6.38 d	5.54 d	0.1386 d
3	49 b	85 c	18.84 c	18.03 c	0.4150 c
5	26 c	145 b	26.45 b	25.32 b	0.6475 b
7	20 c	195 a	33.41 a	31.96 a	0.8014 a

* Mean separation in columns by Duncan's multiple range test,
  p = 5%.

Table 3-4. The effect of crop density on fruit size
distribution (%) in Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	fruit diameter (cm)						
	5.6-6.0	6.1-6.5	6.6-7.0	7.1-7.5	7.5-8.0	8.1-8.5	8.6-9.0
1		7	13	27	33	16	3
3	1	3	3	35	44	11	4
5	3	17	36	29	17	1	
7	5	23	34	28	10		

Table 3-5. The effect of crop density on vegetative points
and shoot length in Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	vegetative points	no. shoots /tree	no. spurs /tree	shoot length	
				mean (cm)	total (m)
1	569	142 a	427 b	65.47	91.20 a
3	611	107 ab	504 ab	71.98	75.35 a
5	628	73 b	555 ab	73.66	53.16 b
7	673	74 b	599 a	69.17	50.10 b

* Mean separation in columns by Duncan's multiple range test,
  p = 5%.

Table 3-6 The effect of crop density on leaf canopy
of Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	total	shoot	spur
no. leaf per tree			
1	4034	2036 a	1998 b
3	4042	1683 a	2359 b
5	3785	1189 b	2596 a
7	3925	1121 b	2084 a
leaf dry weight (g/tree)			
1	1757	1018 a	739 a
3	1714	841 a	873 ab
5	1555	594 b	961 ab
7	1598	560 b	1038 b
leaf area (m^2/tree)			
1	17.48	9.39 a	8.08 b
3	17.32	7.76 a	9.56 b
5	16.00	5.48 b	10.52 a
7	16.53	5.17 b	11.36 a

* Mean separation in columns within each parameter
by Duncan's multiple range test, p = 5%.

Table 3-7. The effect of crop density on
dry matter partitioning of Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	dry weight (g)			ratio (%)	
	total	leaf	fruit	leaf	fruit
1	2487 d	1757	720 d	71.03 a	28.97 d
3	3917 c	1714	2203 c	43.79 b	56.21 c
5	4714 b	1555	3159 b	33.24 c	66.76 b
7	5765 a	1598	4167 a	27.86 d	72.14 a

* Mean separation in columns by Duncan's multiple range test,
  p = 5%.

Literature Cited

1. Aldrich, W. W. 1931. Effect of fruit thinning upon carbohydrate accumulation, formation of fruit buds and set of bloom in apple trees. Proc. Amer. Soc. Hort. Sci. 28:599-604.

2. Aldrich, W. W. 1938. Pear fruit thinning, in relation to yield and size of fruit for the same season. Proc. Amer. Soc. Hort. Sci. 36:332-339.

3. Aldrich, W. W. and L. A. Fletcher. 1932. Relation of foliage system and fruit thinning to biennial bearing in apples. Proc. Amer. Soc. Hort. Sci. 29:56-61.

4. Aldrich, W. W. and R. A. Work. 1934. Effect of leaf-fruit ratio and available soil moisture in heavy clay soil upon amount of bloom of pear trees. Proc. Amer. Soc. Hort. Sci. 31:57-74.

5. Avery. D. J. 1969. Comparisons of fruiting and deblossomed maiden apple trees and of non-fruiting trees on a dwarfing and in invigorating rootstock. New Phytol. 68:323-336.

6. Avery. D. J. 1970. Effects of fruiting on the growth of apple trees on four rootstock varieties. New Phytol. 69:19-30.

7. 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. Sta. 1963:84-93.

8. Barlow, H. W. B. 1966. The effect of cropping on the number and kind of shoots on four apple varieties. Rep. E. Malling Res. Sta. 1965:120-124.

9. Beers, E. H., L. A. Hull, and J. W. Grimm. 1987. Relationships between leaf:fruit ratio and varying levels of European red mite stress on fruit size and return bloom of apple. J. Amer. Soc. Hort. Sci. 112:608-612.

10. Bobb, A. C. and M. A. Blake. 1938. Annual bearing of the 'Wealthy' apple as induced by blossom thinning. Pro. Amer. Soc. Hort. Sci. 36:321-327.

11. Forshey, C. G. 1977. 'McIntosh' apple crop prediction. Grower sampling instructions. N. Y. Food and Life Sci. Bul. 65:1-3.

12. Forshey, C. G. 1982. Effects of fruiting, prunning, and nitrogen fertilization on shoot growth of 'Empire' apple trees. J. Amer. Soc. Hort. Sci. 107:1092-1097.

13. Forshey, C. G. and D. C. Elfving. 1977. Fruit numbers, fruit

size, and yield relationships in 'McIntosh' apples. J. Amer. Soc. Hort. Sci. 102:399-402.

14. Forshey, C. G. and C. A. Marmo. 1985. Prunning and deblossoming effects on shoot growth and leaf area of 'McIntosh' apple trees. J. Amer. Soc. Hort. Sci. 110:128-132.

15. Hansen, P. 1980. Crop load and nutrient translation. In: Mineral Nutrition of Fruit Trees. Eds D. Atkinson, J. E. Jackson, R. O. Sharples, and W. M. Waller, Butterworths, London, 201-212.

16. Harley, C. P., M. P. Masure, and J. R. Magness. 1933. Fruit thinning and biennial bearing in 'Yellow Newtown' apples. Proc. Amer. Soc. Hort. Sci. 30:330-331.

17. Hennerty, M. J. 1971. Effects of defruiting, scoring, defoliation and shading on the carbohydrate content of 'Golden Delicious' apple trees. J. Hort. Sci. 46:153-161.

18. Jackson, J. E. 1984. Effects of cropping on tree vigor. Acta Horticulturae 146:83-88.

19. Kishimoto, O. 1975. Estimation of optimum range of degree of fruit thinning and desirable fruit weight in Japanese pear and Persimmon Tree. J. Japan Soc. Hort. Sci. 43:368-376.

20. Lenz, F. 1979. Fruit effects on photosynthesis, light- and dark- respiration. In: Photosynthesis and Plant Development (R. Marcell, H. Clijsters and M. Van Pouche, eds). PP. 271-281. Dr. W. Junk, The Hague, ISBN 9-06-193594-6.

21. Lenz, F. 1986. Fruit effects on transpiration and dry matter production in apple. pp. 101-104. In: A. Lakso, and F. Lenz (eds.) The regulation of photosynthesis in fruit trees. Symp. Proc. Publ. N. Y. State Agr. Exper. Sta. Geneva, N. Y.

22. Lombard, P. B. 1986. Fruit thinning of pears. pp. 215-119. In: M. Willett and R. L. Stebbins (eds). Pear Production in the Pacific Northwest.

23. Lombard, P. B. 1988. Terminology, procedures and parameter ranges for measuring temperate zone tree fruit and nut species performance. HortScience (Accepted).

24. Maggs, D. H. 1963. The reduction in growth of apple trees brought about by fruiting. J. Hort. Sci. 38:119-128.

25. Mochizuki, T. 1962. Studies on the elucidation of factors affecting the decline in tree vigor in apples as induced by fruit load. Bull. Fac. Agric. Hirosaki Univ. No. 8:40-124.

26. Palmer, J. W. 1984. Seasonal variation of light saturated photosynthetic rate of 'Golden Delicious' apple leaves as influenced by leaf type and crop load. In: A. N. Lokso and F. Lenz (eds.). Regulation of Photosynthesis in Fruit Trees. Spec. Pub. New York State Agr. Expt. St., Geneva.

27. Palmer, J. W. 1986. Effects of varying crop load on photosynthesis and dry matter production of 'Crispin'/M.27 apple trees. In: Regulation of Photosynthesis in Fruit Crops. Univ. Cal. at Davis, 33-34.

28. Preston, A. P. 1954. Effects of fruit thinning by the leaf count method on yield, size and biennial bearing of apple 'Duchess Favourite'. J. Hort. Sci. 29:269-277.

29. Preston, A. P. 1969. Prunning and fruit thinning trials with 'Laxton's Superb' apple on two rootstocks. Rep. E. Malling Res. Sta. for 1968.

30. Proebsting, E. L. and H. H. Mills. 1981. Effects of season and crop load on Maturity characteristics of 'Bing' cherry. J. Amer. Soc. Hort. Sci. 106:144-146.

31. Quinlan, J. D. and A. P. Preston. 1968. Effects of thinning blossom and fruitlets on growth and cropping of 'Sunset' apple. J. Hort. Sci. 43:373-381.

32. Rogers, W. S. and G. A. Booth. 1964. Relationship of crop and shoot growth in apple. J. Hort. Sci. 39:61-65.

33. Rom, C. R. and D. C. Ferree, 1986. The influence of fruiting and shading of spurs and shoots on spur performance. J. Amer. Soc. Hort. Sci. 111:352-356.

34. Singh, L. B. 1948. Studies in biennial bearing, III. Growth studies in 'on' year trees. J. Hort. Sci. 33:29-38.

35. Taylor, B. H. and D. C. Ferree. 1984. The influence of summer prunning and cropping on growth and fruiting of apple. J. Amer. Soc. Hort. Sci. 109:19-24.

36. Van Der Boon, J. 1980. Prediction and control of bitter pit in apples: II. Control by summer prunning, fruit thinning, delayed harvesting and soil calcium dressings. J. Hort. Sci. 55:313-321.

37. Weinberger, J. H. and F. P. Cullinan. 1932. Further studies on the relation between leaf area and size of fruit, chemical composition and fruit bud formation in 'Elberta' peaches. Proc. Amer. Soc. Hort. Sci. 29:23-27.

38. Westwood, M. N. and H. O. Bjornstad. 1974. Fruit set as related

to girdling, early cluster thinning and prunning of 'Anjou' and 'Comice' pear. HortScience 9:342-344.

39 Wilcox, J. C. 1937. Field studies of apple tree growth and fruiting: II. Correlations between growth and fruiting. Sci. Agr. 17:573-586.

Chapter 4. EFFECT OF CROP DENSITY ON MINERAL STATUS

IN NIJISEIKI PEAR TREES

Abstract

Fruitlets of Nijiseiki (P. pyrifolia) pear trees were thinned to different crop density (CD) levels of 3-16 fruit cm^{-2} trunk cross-sectional area (TCSA) in 1986 and 4 levels of CD (1, 3, 5 and 7 fruit cm^{-2} TCSA) in 1987.

CD affected B concentration of non-fruiting spur leaves, Mg concentration of terminal shoot leaves in 1986, and K concentration of all three leaf types (fruiting spur, non-fruiting spur and terminal shoot) in 1986 and 1987. The correlation between CD and Mg concentration of terminal shoot leaves was positive, others were negative. CD influenced fruit K concentration at harvest and P, S, K, and Mg concentration one month before. All the correlations were negative. K is the element which was affected most by CD in leaves and fruit. Leaf P, K, and Ca were high and Leaf N, Mg and Cu were low compared to pear standard.

CD had significant effect on the nutritional content of all elements analyzed for leaves except Zn and fruit except Fe. Negative correlations were found between CD and total N, K, S, Ca, and Mn contents in 1986. CD had significant effect on total N, P, K, Mg, Cu and B contents in 1987. Linear correlations were found between CD and the partitioning of nutrients (% of total) except Fe between leaves and fruit in 1986. CD influenced nutritional

portitioning of all elements in 1987. The partitioning was mainly due to the biomass of the fruit.

Introduction

Understanding the specific role of fruit in the uptake and partitioning of mineral elements is principle to nutritional requirement of fruit trees. Total nutrient uptake is affected more by cropping than soil nutrient availability (Hansen, 1971), for elements that are strikingly different in mineral concentration whether in leaves or fruit. Leaf N concentration was significantly increased by cropping or on trees with greater crop load in apples (Ferree and Cahoon, 1987; Lord and Bramlage, 1983; Mason, 1955), but decreased in higher cropping peach trees (Popenoe and Scott, 1956). Hansen (1980) found the total uptake of N was reduced to about half of that in non-fruiting trees of 5 year old 'Golden Delicious' apple. Phosphorus concentration generally follows the same pattern as N (Messaoud, 1986). It was found to be reduced (Hansen, 1980; Cain and Boynton, 1948), or increased (Mason, 1955; Sharples, 1964) or unaffected (Taylor and Ferree, 1986) in apples. The major part of potassium in apples is transferred into the fruit nearly linear with dry weight (Tromp, 1975). Fruiting seems to affect dry matter and potassium in very similar ways for fruit are strong sinks of both (Hansen, 1980). In general, fruiting increased (Cain and Boynton, 1948; Hansen, 1980; Mason, 1955; Popenoe and Scott, 1956) or did not affect (Ferree and Cahoon, 1987; Sharples, 1964, 1968) leaf calcium and magnessium concentration. Magnessium was found to be higher in the leaves of bearing apple trees while iron was unaffected by fruiting (Mason, 1955).

Unfortunately, there is little information about the effect of cropping on mineral status in pears, especially Asian pears. The purpose of this study is to determine the effect of CD on (1) leaf and fruit mineral concentration, (2) content of mineral nutrients in leaves and fruit, and (3) the partitioning of mineral nutrients between leaves and fruit.

Materials and Methods

The experiment was conducted in an asian pear orchard near
Dayton, Oregon. A completely randomized design was used with 4 (in
1986) or 6 (in 1987) single-plant replications per treatment.
The trees of Nijiseiki on P. betulaefolia were transplanted into
the orchard in 1985 at a spacing 2.4 * 4.8 m. Twenty-four trees
were adjusted to 6 levels (3, 5, 7, 9, 11 and 13 fruit cm^{-2} trunk
cross-sectional area, TCSA) of CD by fruitlet thinning on May 29,
1986. The fruit were spaced uniformly over around the canopy of
the trees with none, 1, 2, or 3 fruitlets left on each cluster
according to the CD designed. At harvest, the fruit number per
tree was counted but the CD was not found not in 6 levels, but in
a range of 3-16 fruit cm^{-2} TCSA (measured in April, 1986). In
1987, the CD was carefully adjusted to 4 different level (1, 3, 5,
7 fruit cm^{-2} TCSA) on June 9.

The fully expended leaves were taken from 30 terminal shoots,
fruiting and non-fruiting spurs per tree on August 4, 1986, and
from 10 terminal shoots, 15 fruiting and non-fruiting spurs per
tree on August 4, 1987. 5 fruit per tree were taken on August 4,
1986 and at harvest in 1986 and 1987.

Leaf samples were brought to laboratory in plastic bags, washed
in a detergent solution to remove surface dust, and then dried at
75°C temperature for 2 days. Fruit samples were washed in the same
way as leaf samples. Then the fruit was sliced and dried in 75°C
temperature for 30 days.

Dried samples were ground. Nitrogen was analyzed with an

autoanalyzer after microkjeldhal digestion. All other mineral analyses (P, K, Ca, Mg, S, Mn, Cu, Zn, B, Fe, and Al) were done by inductively coupled Argon spectrometer after dry ashing at 550°C and dissolving in 10% HNO_3 (leaves) or HCL (fruit).

Mineral content of samples was expressed as the concentration in a basis of dry weight, and total content of elements in leaves and/or fruit. Partitioning of nutrients was determined in content between leaves and fruit.

Data was analyzed with regression procedure for 1986 and ANOVA procedure for 1987.

Results and Discussion

1. Leaf Mineral Concentration

CD affected leaf K, Mg and B concentration in 1986. B concentration of non-fruiting spur leaves ($r=-0.54^{**}$) decreased while leaf Mg of terminal shoots ($r=0.47^{*}$) increased as CD increased. K concentration was influenced by CD in leaves of all 3 types of growth. The relationships were linear and negative, shoot leaves showed the highest while non-fruiting spur leaves showed lowest K concentration (Fig. 4-1). In 1987, the effect of CD was found only on K concentration in terminal shoot (2.37 to 1.95%), fruiting spur (2.22 to 1.73%) and non-fruiting spur (2.04 to 1.67%) leaves (Table 4-1). K concentration in leaves generally high when considered against nutrient level standards for pear, but they decreased when CD increased. The negative relationship of leaf K with crop density, agrees with previous studies (Sharples 1964, Cain and Boynton 1948, Ljones and Braadlie 1954).

Leaf B followed the same pattern as K, but Mn had an opposite effect as Mason (1955) found. CD had no significant effect on other element concentrations, contrasting with previous studies with N (Ferree and Cahoon, 1987; Lord and Bramlage, 1983; Mason, 1955; Popenoe and Scott, 1956), with P (Cain and Boynton, 1948; Hansen, 1980; Mason, 1955; Sharples, 1964), with Ca and Mg (Cain and Boynton, 1948; Hansen, 1980; Mason, 1955; Popenoe and Scott, 1956). However, CD affected nutritional concentration in various types of leaves differently, indicating the importance of using

the most susceptible leaf tissue in mineral composition when sampling trees of various CD.

Compared with the leaf composition standards for 'Bartlett° pear trees made by Van Ven Ende and Leece (1975), Mn, Fe, B and Zn were in the optimum range, others were in either high (P, K and Ca) or low (N, Mg and Cu) range. Since no deficiency symptoms appeared during the trial, it can be concluded that Nijiseiki pear trees may have different requirement for mineral nutrition of N, P, K, Ca, Mg and Cu compared to 'Bartlett° pear trees and therefore, leaf composition standards may be needed for various Asian cultivars.

2. Fruit Mineral Concentration

CD and fruit P ($r=-0.59^{**}$), S ($r=-0.44^{**}$), Mg ($r=-0.49^{*}$), and K ($r=-0.52^{**}$) concentration in August bore linear correlations one month before harvest but only fruit K correlated significantly at harvest (Fig. 4-2). Concentration for these elements decreased as CD increased. In 1987, heavier crop density reduced K significantly but slightly increased fruit Mn at harvest (Table 4-2). CD had a negative effect on fruit K concentration at harvest but it affected P, S, Mg and K one month before harvest indicating that these elements are under greater crop demand earlier in the season.

Potassium was the element most affected by CD in leaves and fruit, indicating that the demand of K was affected markedly by CD and the fruit was a stronger sink of K than that of other

elements.

3. Mineral Contents and Partitioning in Leaves and Fruit

CD and all nutritional contents in leaves except Zn or in fruit except Fe were highly correlated (Table 4-3). Only the total content of N, K, S, Ca and Mn in leaves and fruit correlated with CD. Leaf contents except Zn bore negative correlation to CD while fruit mineral contents except Fe were positively correlated. The total content of N, K, Ca, and Mn in leaves and fruit increased as CD increased. Others were less affected by CD. In 1987, there was a significant difference between various CD levels in total N, P, K, Mg, Cu and B of leaves and fruit, only K of leaves, and in all nutrient contents of fruit because of the effect of the biomass of fruit (Table 4-4 and 4-5).

Linear correlations were found between CD and partitioning of nutrients (% of total in leaves and fruit) except Fe (Fig. 4-3) in 1986. CD had significant effect on the partitioning of all nutrients, expressed as % of total, between leaves and fruit in 1987 because of the biomass of fruit.

Although the CD only had minimum effect on leaf and fruit concentrations of few elements, the total content of most nutrients in leaves or fruit was affected by CD, except Zn in leaves and Fe in fruit. The difference was mainly due to the difference of biomass but not the concentration of the nutrients. CD had significant effect on total N, K, Ca and Mn contents in leaves and fruit. No effect of CD was found on other nutrient

contents indicating that the CD did not influence the transfer of these nutrients into leaves and fruit although it had significant effect on the partitioning of nutrients between leaves and fruit.
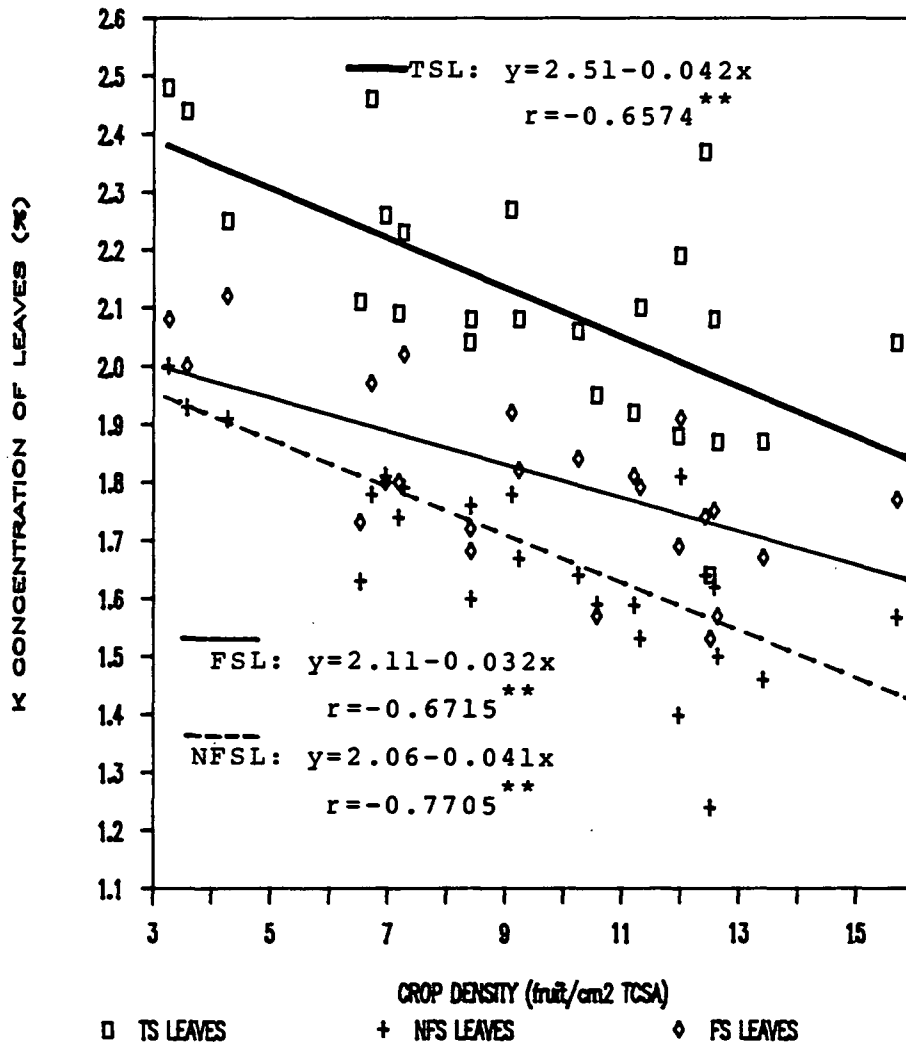
Fig. 4-1. The relationship between crop density and
leaf K concentration of terminal shoots (TS),
non-fruiting spurs (NFS) and fruiting spurs (FS)
in Nijiseiki pear (1986).

** significante at 1% level.
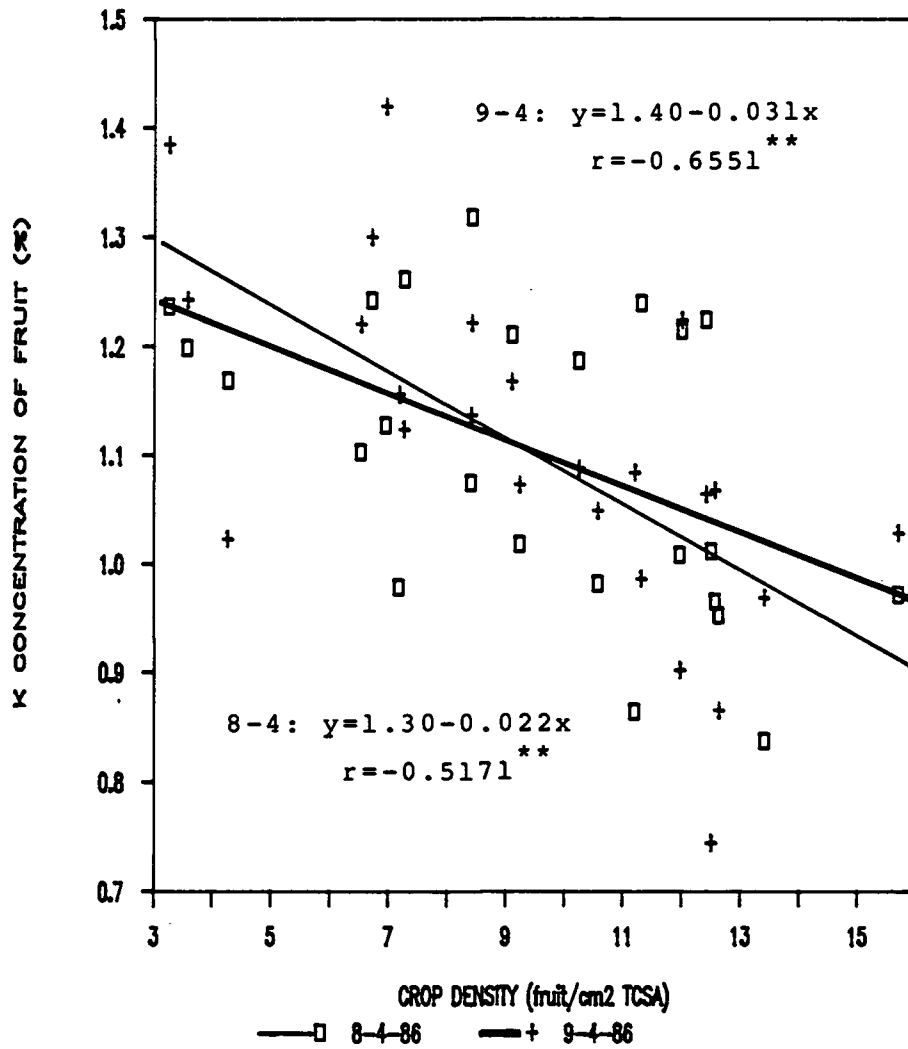
Fig. 4-2. The relationship between crop density and
fruit K concentrations in Nijiseiki pear (1986).

** significante at 1% level.
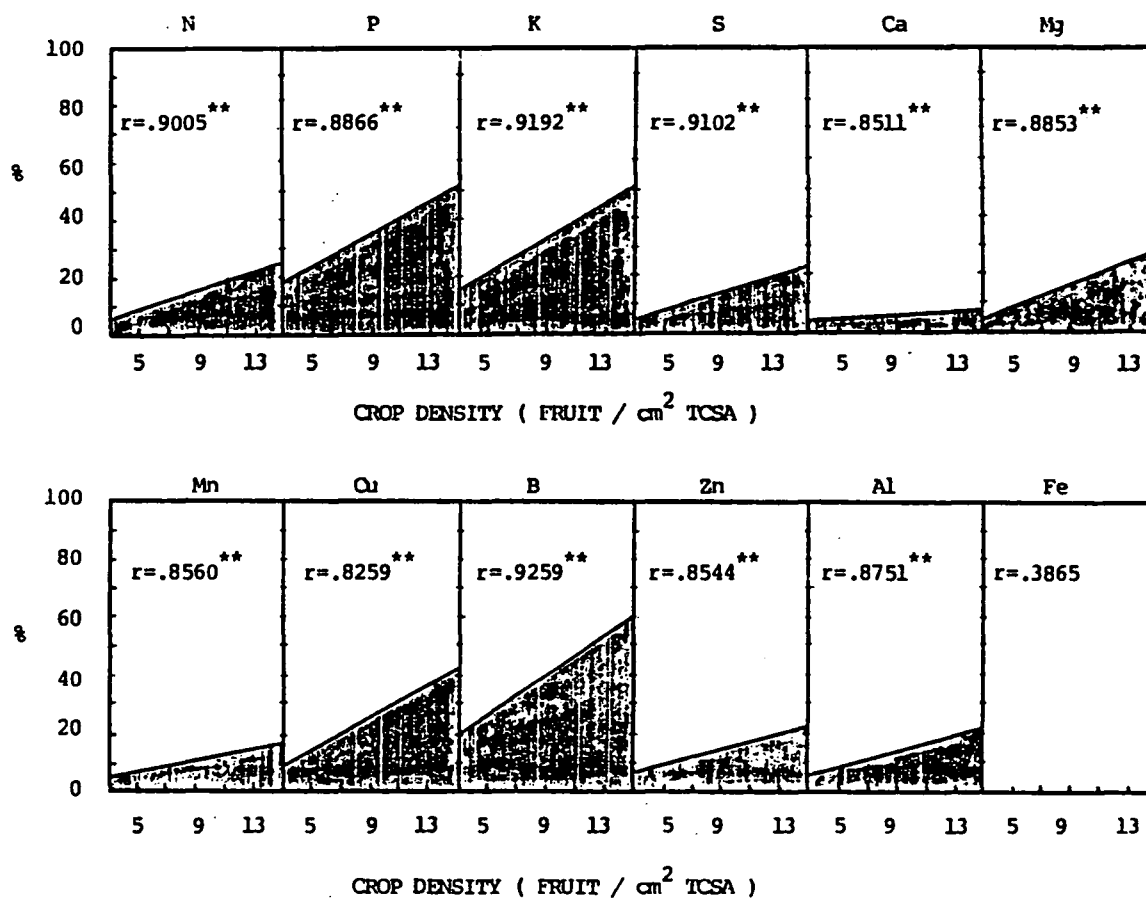
Fig. 4-3. The relationship of crop density and
nutritional partitioning (% of total
in leaves + fruit) between leaves
and fruit in Nijiseiki pear (1986).

** significante at 1% level.

Table 4-1. The effect of crop density on leaf mineral concentrations in Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	N (%)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Al (ppm)
					shoot leaves							
1	1.96 b	0.20	2.37 a	0.16	2.75	0.23	76	129	7	21	31	62
3	2.11 a	0.21	2.05 b	0.15	3.05	0.25	77	114	7	22	41	73
5	2.06 ab	0.21	2.05 b	0.15	3.05	0.23	70	110	7	19	35	70
7	2.13 ab	0.21	1.92 b	0.16	2.66	0.23	68	105	8	21	32	69
					fruiting spur leaves							
1	2.18	0.22	2.22 a	0.13	3.44	0.36	100	142	8	25	37	92
3	2.34	0.23	1.91 b	0.13	3.67	0.36	95	132	8	25	43	88
5	2.25	0.24	1.79 b	0.13	3.39	0.32	92	127	8	23	37	90
7	2.33	0.23	1.73 b	0.14	3.57	0.34	92	115	9	23	40	82
					non-fruiting spur leaves							
1	2.11	0.20	2.04 a	0.14	3.57	0.34	101	123	8	23	46	74
3	2.14	0.20	1.88 ab	0.13	3.56	0.34	93	115	8	23	48	74
5	2.13	0.22	1.76 bc	0.14	3.70	0.31	88	111	8	22	51	66
7	2.30	0.20	1.67 c	0.15	3.60	0.34	94	110	9	22	47	73

+ concentrations on dry weight basis.
* Mean separation in columns within each element by Duncan's multiple range test, p = 5%.

Table 4-2 The effect of crop density on fruit mineral concentrations in Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	N (%)	P (ppm)	K (ppm)		S (ppm)	CA (ppm)	MG (ppm)	MN (ppm)		Cu (ppm)	FE (ppm)	B (pm)	ZN (ppm)	AL (ppm)
1	0.34	1074	10953	a	195	392	469	3.7	b	5.6	12.4	12.2	4.7	9.0
3	0.34	1140	10773	ab	189	425	509	4.4	ab	6.1	13.1	13.4	5.5	9.0
5	0.31	1017	9892	ab	178	366	492	4.2	b	5.7	13.1	11.8	4.8	12.9
7	0.34	1028	9741	b	188	464	536	5.1	a	6.0	12.9	12.3	5.2	11.9

+ concentrations on dry weight basis.
* Mean separation in columns by Duncan's multiple range test, p = 5%.

Table 4-3. The correlation coefficients between crop density
and nutritional contents of leaves and/or fruit
in Nijiseiki pear (1986)

	leaves	fruit	leaves + fruit
N	-0.67^{**}	0.78^{**}	-0.55^{**}
P	-0.70^{**}	0.79^{**}	-0.20
K	-0.77^{**}	0.77^{**}	-0.41^{*}
S	-0.67^{**}	0.82^{**}	-0.51^{**}
Ca	-0.57^{**}	0.83^{**}	-0.55^{**}
Mg	-0.58^{**}	0.86^{**}	-0.27
Mn	-0.51^{**}	0.80^{**}	-0.44^{*}
Cu	-0.53^{**}	0.70^{**}	-0.07
Fe	-0.57^{**}	0.19	-0.36
B	-0.52^{**}	0.74^{**}	0.05
Zn	-0.31	0.69^{**}	-0.20
Al	-0.52^{**}	0.65^{**}	-0.29

*, ** significant at 5% and 1% level, respectively.

Table 4-4. The effect of crop density on total content
of macro-nutrients in leaves and/or fruit and the partitioning
between leaves and fruit in Nijiseiki pear (1987)

crop density (fruit cm^{-2} TCSA)	total content (g/tree)			partitioning (%)	
	leaves	fruit	leaf + fruit	leaves	fruit
N 1	35.80	2.53 d	38.66 b	93.36 a	6.64 d
3	37.08	7.39 c	44.46 ab	83.25 b	16.75 c
5	33.35	9.83 b	43.19 ab	87.44 c	22.56 b
7	35.92	14.09 a	50.00 a	71.82 d	28.18 a
P 1	3.57	0.78 d	4.29 c	82.76 a	17.24 d
3	3.63	2.52 c	6.15 b	58.91 b	41.09 c
5	3.46	3.22 b	6.68 ab	52.17 c	47.83 b
7	3.44	4.25 a	7.69 a	44.62 d	55.38 a
K 1	38.96 a	7.99 d	46.28 c	83.61 a	16.39 d
3	34.04 ab	23.68 c	57.52 b	58.50 b	41.50 c
5	28.46 b	31.11 b	59.57 ab	48.00 c	52.00 b
7	28.45 b	40.38 a	68.84 a	41.29 d	58.71 a
S 1	2.55	0.15 d	2.67	94.95 a	5.05 d
3	2.45	0.42 c	2.86	85.29 b	14.71 c
5	2.14	0.56 b	2.70	79.29 c	20.71 b
7	2.36	0.78 a	3.14	75.15 d	24.85 a
Ca 1	54.06	0.27 c	52.79	99.48 a	0.52 d
3	56.85	0.95 b	57.79	98.35 b	1.66 c
5	50.97	1.16 b	52.13	97.78 c	2.22 b
7	51.51	1.93 a	53.45	96.36 d	3.64 a
Mg 1	4.85	0.34 d	5.19 b	93.79 a	6.21 d
3	5.07	1.12 c	6.19 ab	81.90 b	18.10 c
5	4.36	1.55 b	5.92 ab	73.79 c	26.21 b
7	4.75	2.22 a	6.97 a	68.16 d	31.84 a

* Mean separation in columns within each element by Duncan's
multiple range test, p = 5%.

Table 4-5. The effect of crop density on total content
of micro-nutrients in leaves and/or fruit and the partitioning
between leaves and fruit in Nijiseiki pear (1987)

	crop density (fruit cm^{-2} TCSA)	total content (g/tree)			partitioning (%)	
		leaves	fruit	leaf + fruit	leaves	fruit
Mn	1	0.14	0.0027 d	0.15	98.33 a	1.67 d
	3	0.15	0.0097 c	0.16	93.54 b	6.46 c
	5	0.13	0.0130 b	0.14	90.30 c	9.70 b
	7	0.13	0.0209 a	0.15	85.91 d	14.09 a
Fe	1	0.22	0.0091 d	0.21	95.78 a	4.22 d
	3	0.20	0.0288 c	0.23	87.40 b	12.60 c
	5	0.18	0.0411 b	0.22	81.19 c	18.81 b
	7	0.18	0.0534 a	0.23	76.51 d	23.49 a
Cu	1	0.013	0.0041 c	0.017 c	77.66 a	22.34 c
	3	0.013	0.0137 b	0.027 b	49.91 b	50.09 b
	5	0.012	0.0179 b	0.030 b	40.42 b	59.58 b
	7	0.014	0.0246 a	0.038 a	35.76 c	64.24 a
B	1	0.037	0.0090 c	0.044 b	82.43 a	17.57 c
	3	0.040	0.0302 b	0.070 a	57.53 b	42.47 b
	5	0.033	0.0377 b	0.071 a	47.32 c	52.68 a
	7	0.035	0.0511 a	0.087 a	41.33 c	58.67 a
Zn	1	0.062	0.0036 c	0.068	95.01 a	4.99 d
	3	0.074	0.0122 b	0.086	85.71 b	14.29 c
	5	0.063	0.0150 b	0.078	80.69 c	19.13 b
	7	0.061	0.0215 a	0.083	73.45 d	26.55 a
Al	1	0.12	0.0066 c	0.13	94.88 a	5.12 c
	3	0.13	0.0199 b	0.15	87.00 b	13.00 b
	5	0.12	0.0403 a	0.16	74.44 c	25.56 a
	7	0.12	0.0499 a	0.17	70.40 c	29.60 a

* Mean separation in columns within each element by Duncan's
multiple range test, p = 5%.

Literature Cited

1. Cain, J. C. and D. Boynton. 1948. Some effects of season, fruit crop and nitrogen fertilization on the mineral composition of 'McIntosh' apple leaves. Proc. Amer. Soc. Hort. Sci. 51:13-22.

2. Ferree, D. C. and G. A. Cahoon. 1987. Influence of leaf to fruit ratios and nutrient sprays on fruiting, mineral elements, and carbohydrates of apple trees. J. Amer. Soc. Hort. Sci. 112:445-449.

3. Hanson, P. 1971. The effect of cropping on the uptake, contents, and distribution of nutrients in apple trees. Tidsskr. Planteavl 75:615-625.

4. Hansen, P. 1980. Crop load and nutrient translation. In: Mineral Nutrition of Fruit Trees. Eds D. Atkinson, J. E. Jackson, R. O. Sharples, and W. M. Waller, Butterworths, London, 201-212.

5. Ljones, B. and O. Braadlie. 1954. The content of nutrient elements in apple leaves from commercial orchards in Norway. Forskn. Fors. Landbr. 5:115-139.

6. Lord, W. J. and W. J. Bramlage. 1983. Factors affecting nutrient content of the foliage and fruits of apple trees. Fruit Notes 48:17-23.

7. Mason, A. C. 1955. A note on differences in mineral content of apple leaves associated with fruiting and non-fruiting biennial trees. Ann. Rep. E. Malling Res. Sta. 1954:122-125.

8. Messaoud, M. 1986. Effect of crop load on mineral uptake and partitioning in 'D'Anjou' pears. M. S. Thesis. Oregon State University.

9. Popenoe, J. and L. E. Scott. 1956. Some effects of potassium nutrition and fruit load on the peach as indicated by foliar analysis. Proc. Amer. Soc. Hort. Sci. 68:56-62.

10. Sharples, R. O. 1964. The effects of fruiting on the development of 'Cox's Orange Pippin' apples in relation to the incidence of storage disorders. J. Hort. Sci. 39:224-235.

11. Taylor, B. H. and D. C. Ferree. 1986. The influence of summer prunning and fruit cropping on the carbohydrate, nitrogen, and nutrient composition of apple trees. J. Amer. Soc. Hort. Sci. 111:342-346.

12. Tromp, J. 1975. The effect of temperature on growth and mineral nutrition of fruits of apple, with special reference to calcium. Physiologia Pl. 33:87-93.

13. Van Den Ende, B. and D. R. Leece. 1975. Leaf analysis for pear: development of standards and the nutritional status of orchards in the Goulburn Valley and Murrumbidgee Irrigation Areas. Austr. J. Expt. Agric. and Anim. Husb. 15:129-135.

BIBLIOGRAPHY

Aldrich, W. W. 1931. Effect of fruit thinning upon carbohydrate accumulation, formation of fruit buds and set of bloom in apple trees. Proc. Amer. Soc. Hort. Sci. 28:599-604.

Aldrich, W. W. 1938. Pear fruit thinning, in relation to yield and size of fruit for the same season. Proc. Amer. Soc. Hort. Sci. 36:332-339.

Aldrich, W. W. and L. A. Fletcher. 1932. Relation of foliage system and fruit thinning to biennial bearing in apples. Proc. Amer. Soc. Hort. Sci. 29:56-61.

Aldrich, W. W. and R. A. Work. 1934. Effect of leaf-fruit ratio and available soil moisture in heavy clay soil upon amount of bloom of pear trees. Proc. Amer. Soc. Hort. Sci. 31:57-74.

Anthony, R. D. 1941. Further studies of the value of trunk measurement in interpreting apple tree growth. Proc. Amer. Soc. Hort. Sci. 39:19-22.

Auchter, E. C. 1919. Some influences of thinning, pollination, and fruit, spur growth on the yearly performance record of fruit spurs and on the size of fruit produced. Proc. Amer. Soc. Hort. Sci. 16:118-131.

Avery. D. J. 1969. Comparisons of fruiting and deblossomed maiden apple trees and of non-fruiting trees on a dwarfing and in invigorating rootstock. New Phytol. 68:323-336.

Avery. D. J. 1970. Effects of fruiting on the growth of apple trees on four rootstock varieties. New Phytol. 69:19-30.

Avery, D. J. 1975. Effects of fruits on photosynthetic efficiency. In: Climate and the orchard. H. C. Pereira (editor), Comm. Agr. Bur., England, 110-112.

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. Sta. 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. Sta. 1965:120-124.

Beers, E. H., L. A. Hull, and J. W. Grimm. 1987. Relationships between leaf:fruit ratio and varying levels of European red mite stress on fruit size and return bloom of apple. J. Amer.

Soc. Hort. Sci. 112:608-612.

Bobb, A. C. and M. A. Blake. 1938. Annual bearing of the
    'Wealthy' apple as induced by blossom thinning. Pro. Amer. Soc.
    Hort. Sci. 36:321-327.

Cain, J. C. and D. Boynton. 1948. Some effects of season, fruit
    crop and nitrogen fertilization on the mineral composition of
    'McIntosh' apple leaves. Proc. Amer. Soc. Hort. Sci. 51:13-
    22.

Chalmers, D. J., R. L. Canterford, P. H. Jerie, T. R. Jones and
    T. D. Ugalde. 1975. Photosynthesis in relation to growth and
    distribution of fruit in peach trees. Aust. J. Plant Physiol.
    2:635-645.

Chalmers, D. J. and I. B. Wilson. 1978. Productivity of peach
    trees: tree growth and water stress in relation to fruit growth
    and assimilate demand. Ann. Bot. 42:285-294.

Chandler, W. H. and A. J. Heinicke. 1926. The effect of fruiting
    on the growth of 'Oldenberg' apple trees. Proc. Amer. Soc.
    Hort. Sci. 23:36-46.

Crews, C. E., S. L. Williams and H. M. Vines. 1975.
    Characteristics of photosynthesis in peach leaves. Planta. 126:
    97-104.

Curry, E. A. 1986. Effect of cropping on shoot growth of spur-
    type 'Golden Delicious' trees. HortScience 21:1015-1017.

DeJong, T. M. 1986. Fruit effects on photosynthesis in Prunus
    persica. Physiol. Plant. 66:149-153.

Denne, M. P. 1960. The growth of apple fruitlets, and the effect
    of early thinning on fruit development. Ann. Bot., N. S. 24:
    397-406.

Deake, M., W. J. Bramlage and J. H. Barker. 1974. Correlations
    of calcium content of 'Balbwin' apples with leaf calcium, tree
    yield, and occurrences of physiological disorders and decay. J.
    Amer. Soc. Hort. Sci. 99:379-380.

Erf, J. A. and J. T. A. Proctor. 1987. Changes in apple leaf
    water status and vegetative growth as influenced by crop load.
    J. Amer. Soc. Hort. Sci. 112:617-620.

Facteau, T. J., N. E. Chestnut, and K. E. Rowe. 1983.
    Relationship between fruit weight, firmness, and leaf/fruit
    ratio in 'Lambert' and 'Bing' cherries. Can. J. Plant Sci.
    63:763-765.

Ferree, D. C. 1980. Canopy development and yield efficiency of 'Golden Delicious' apple trees in four orchard management systems. J Amer. Soc. Hort. Sci. 105:376-380.

Ferree, D. C. and G. A. Cahoon. 1987. Influence of leaf to fruit ratios and nutrient sprays on fruiting, mineral elements, and carbohydrates of apple trees. J. Amer. Soc. Hort. Sci. 112:445-449.

Fletcher, L. A. 1932. Effect of thinning on size and color of apples. Proc. Amer. Soc. Hort. Sci. 29:51-55.

Flore, J. A. 1986. Does sink strength control photosynthetic rate. In: Regulation of Photosynthesis in fruit crops. Univ. Cal. at Davis, 30-32.

Forshey, C. G. 1975. 'McIntosh' apple crop prediction studies. Proc. N. Y. State Hort. Soc. 120:139-144.

Forshey, C. G. 1976. 'McIntosh' apple crop prediction studies, 1975. Proc. N. Y. State Hort. Soc. 121:139-144.

Forshey, C. G. 1977. 'McIntosh' apple crop prediction. Grower sampling instructions. N. Y. Food and Life Sci. Bul. 65:1-3.

Forshey, C. G. 1982. Effects of fruiting, prunning, and nitrogen fertilization on shoot growth of 'Empire' apple trees. J. Amer. Soc. Hort. Sci. 107:1092-1097.

Forshey, C. G. and D. C. Elfving. 1977. Fruit numbers, fruit size, and yield relationships in 'McIntosh' apples. J. Amer. Soc. Hort. Sci. 102:399-402.

Forshey, C. G. and D. C. Elfving. 1979a. Branch samples for yield and fruit size comparisons in apple. HortScience 14:143-144.

Forshey, C. G. and D. C. Elfving. 1979b. Estimating yield and fruit numbers of apple trees from branch samples. J. Amer. Soc. Hort. Sci. 104:897-900.

Forshey, C. G. and C. A. Marmo. 1985. Prunning and deblossoming effects on shoot growth and leaf area of 'McIntosh' apple trees. J. Amer. Soc. Hort. Sci. 110:128-132.

Forshey, C. G. and R. W. Weires. 1983. Dry weight partitioning of 'McIntosh' apple trees. J. Amer. Soc. Hort. Sci. 108:149-154.

Ghosh, S. P. 1973. Internal structure and photosynthetic activity of different leaves of apple. J. Hort. Sci. 48:1-9.

Grochowska, M. and A. Lubinska. 1973. Comparative studies on physiological and morphological features of bearing and non-

bearing spurs of apple trees: II. The effect of fruiting and growth regulator sprays on the respiration rate of leaves. Physiol. Plant. 29:425-429

Hansen, P. 1967. ^{14}C studies on apple trees: I. The effects of fruit on the translocation and distribution of photosynthates. Physiol. Plant. 20:382-391.

Hansen, P. 1970a. ^{14}C studies on apple trees: VI. The influence of the fruit on the photosynthesis of leaves, and the relative photosynthetic yields of fruit and leaves. Physiologia Pl. 23:805-810.

Hanson, P. 1970b. The influence of fruit yield on the content and distribution of carbohydrates in apple trees. Tidsskr. Planteavl. 74:589-597.

Hanson, P. 1971a. The effect of cropping on the distribution of growth in apple trees. Tidsskr. Planteavl. 75:119-127.

Hanson, P. 1971b. The effect of fruiting upon transpiration rate and stomatal opening in apple leaves. Physiologia Pl. 25:181-183.

Hanson, P. 1971c. The effect of cropping on the uptake, contents, and distribution of nutrients in apple trees. Tidsskr. Planteavl 75:615-625.

Hanson, P. 1973. The effect of cropping on the growth and uptake of nutrients by apple trees at different levels of nitrogen, potassium, magnessium, and phosphorus. Acta Agric. Scand. 23:87-92.

Hansen, P. 1977. The relative importance of fruit and leaves for the cultivar -- specific growth rate of apple fruits. J. Hort. Sci. 52:501-508.

Hansen, P. 1980. Crop load and nutrient translation. In: Mineral Nutrition of Fruit Trees. Eds D. Atkinson, J. E. Jackson, R. O. Sharples, and W. M. Waller, Butterworths, London, 201-212.

Harley, M. H., and J. R. Magness. 1925. The relation of leaf area to growth and composition of apples. Proc. Amer. Soc. Hort. Sci. 22:189-196.

Harley, C. P., M. P. Masure, and J. R. Magness. 1933. Fruit thinning and biennial bearing in 'Yellow Newtown' apples. Proc. Amer. Soc. Hort. Sci. 30:330-331.

Head, G. C. 1969. The effects of fruiting and defoliation on seasonal trends in new root production in apple trees. J. Hort. Sci. 44:175-181.

Heinicke, A. J. 1920. Some relations between circumference and weight, and between root and top growth of 'Young' apple trees. Proc. Amer. Soc. Hort. Sci. 17:222-227.

Hennerty, M. J. 1971. Effects of defruiting, scoring, defoliation and shading on the carbohydrate content of 'Golden Delicious' apple trees. J. Hort. Sci. 46:153-161.

Holland, D. A. 1959. Studies in the measurement of apple trees. IV: The use of branch girths to estimate tree size. Ann. Rep. E. Malling Res. Sta. 1958:77-79.

Jackson, J. E. 1984. Effects of cropping on tree vigor. Acta Horticulturae 146:83-88.

Jones, H. G. and I. G. Cumming. 1984. Variation of leaf conductance and leaf water potential in apple orchard. J. Hort. Sci. 59:329-336.

Kazaryan, V. O. and R. G. Arutzuryan. 1966. On nitrogen and carbohydrate metabolism of the roots of fruit bearing and non-fruit bearing apple trees. Soviet Plant Physiol. 13:292-297.

Kazaryan, V. O., N. V. Balagezyan and K. A. Karapetyan. 1975. Influence of the fruits of apple trees on the physiological activity of the leaves. Soviet Plant Physiol. 12:265-269.

Khatamian, H. and R. J. Hilton. 1977. The relationship between shoot growth and area of trunk cross-section in several woody plant species. HortScience 12:255-257.

Kishimoto, O. 1975. Estimation of optimum range of degree of fruit thinning and desirable fruit weight in Japanese pear and Persimmon Tree. J. Japan Soc. Hort. Sci. 43:368-376.

Landsberg, J. J. 1980. Limits to apple yields imposed by weather. In: Opportunities for Increasing Crop Yields. 1980:161-180.

Lenz, F. 1979. Fruit effects on photosynthesis, light- and dark-respiration. In: Photosynthesis and Plant Development (R. Marcell, H. Clijsters and M. Van Pouche, eds). PP. 271-281. Dr. W. Junk, The Hague, ISBN 9-06-193594-6.

Lenz, F. 1986. Fruit effects on transpiration and dry matter production in apple. pp. 101-104. In: A. Lakso, and F. Lenz (eds.) The regulation of photosynthesis in fruit trees. Symp. Proc. Publ. N. Y. State Agr. Exper. Sta. Geneva, N. Y.

Lewak, St., M. J. Grochowska, T. Kuryl and D. Wyzinska. 1970. Change in the leucoanthocyanidin content in the leaves of biennially bearing apple trees. Acta Soc. Bot. Pol. 39:141-

150.

Ljones, B. and O. Braadlie. 1954. The content of nutrient
elements in apple leaves from commercial orchards in Norway.
Forskn. Fors. Landbr. 5:115-139.

Lombard, P. B. 1986. Fruit thinning of pears. pp. 215-119. In:
M. Willett and R. L. Stebbins (eds). Pear Production in the
Pacific Northwest.

Lombard, P. B. 1988. Terminology, procedures and parameter ranges
for measuring temperate zone tree fruit and nut species
performance. HortScience (Accepted).

Lord, W. J. and W. J. Bramlage. 1983. Factors affecting nutrient
content of the foliage and fruits of apple trees.
Fruit Notes 48:17-23.

Maggs, D. H. 1963. The reduction in growth of apple trees brought
about by fruiting. J. Hort. Sci. 38:119-128.

Magness, J. R. 1928. Relation of leaf area to size and quality
in apples. Proc. Amer. Soc. Hort. Sci. 25:285-288.

Magness, J. R. and F. L. Overley. 1929. Relation of leaf area to
size and quality of apples and pears. Proc. Amer. Soc. Hort.
Sci. 26:160-162.

Marquard, R. D. 1987. Influence of leaf to fruit ratio on nut
quality, shoot carbohydrates, and photosynthesis of pecan.
HortScience 22:256-257.

Mason, A. C. 1955. A note on differences in mineral content of
apple leaves associated with fruiting and non-fruiting biennial
trees. Ann. Rep. E. Malling Res. Sta. 1954:122-125.

Messaoud, M. 1986. Effect of crop load on mineral uptake and
partitioning in 'D'Anjou' pears. M. S. Thesis. Oregon State
University.

Miller, S. S. and G. W. Lightner. 1987. Computer-assisted
determination of apple tree canopy volume. HortScience 22:393-
395.

Mochizuki, T. 1962. Studies on the elucidation of factors
affecting the decline in tree vigor in apples as induced by
fruit load. Bull. Fac. Agric. Hirosaki Univ. No. 8:40-124.

Mochizuki, T. and J. Kamakura. 1968. Studies on the nutrition of
apple trees. I. Preliminary experiments utilizing N-labeled
fertilizers. Ibid. No. 14:27-32.

Monselise, S. P. and F. Lenz. 1980a. Effects of fruit load on stomatal resistance, specific leaf weight, and water content of apple leaves. Garenbau. 45:188-191.

Monselise, S. P. and F. Lenz. 1980b. Effect of fruit load on photosynthetic rate of budded apple trees. Garenbau. 45:220-224.

Overholser, E. L., F. L. overley and J. C. Wilcox. 1941. Some correlations between growth and yield of apple in Central Washington. Proc. Amer. Soc. Hort. Sci. 39:11-15.

Palmer, J. W. 1984. Seasonal variation of light saturated photosynthetic rate of 'Golden Delicious' apple leaves as influenced by leaf type and crop load. In: A. N. Lokso and F. Lenz (eds.). Regulation of Photosynthesis in Fruit Trees. Spec. Pub. New York State Agr. Expt. St., Geneva.

Palmer, J. W. 1986. Effects of varying crop load on photosynthesis and dry matter production of 'Crispin'/M.27 apple trees. In: Regulation of Photosynthesis in Fruit Crops. Univ. Cal. at Davis, 33-34.

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. Sta. 1951:101-104.

Perring, M. A. 1968. Recent work at the Ditton laboratory on the chemical composition and storage characteristics of apples in relation to orchard factors. Ann. Rep. E. Malling Res. Sta. 1967:191-198.

Perring, M. A. and A. P. Preston. 1974. The effect of orchard factors on the chemical composition of apple. III. Some effects of prunning and nitrogen application in 'Cox's Orange Pippin' fruit. J. Hort. Sci. 49:85-93.

Popenoe, J. and L. E. Scott. 1956. Some effects of potassium nutrition and fruit load on the peach as indicated by foliar analysis. Proc. Amer. Soc. Hort. Sci. 68:56-62.

Preston, A. P. 1954. Effects of fruit thinning by the leaf count method on yield, size and biennial bearing of apple 'Duchess Favourite'. J. Hort. Sci. 29:269-277.

Preston, A. P. 1969. Prunning and fruit thinning trials with 'Laxton's Superb' apple on two rootstocks. Rep. E. Malling Res. Sta. for 1968.

Preston, A. P. and J. D. Quinlan. 1968. A fruit thinning experiment with 'Cox's Orange Pippin' apple. Rep. E. Malling Res. Sta. 1967:75-78.

Priesley, C. A. 1970. Some observations on the effect of cropping on the carbohydrate content in trunks of apple trees over a long period. Rep. E. Malling Res. Sta. 1969(1970):121-123.

Proctor, J. T. A. 1981. Stomatal conductance changes in leaves of 'McIntosh' apple trees before and after fruit removal. Can. J. Bat. 59:50-53.

Proebsting, E. L. and H. H. Mills. 1981. Effects of season and crop load on Maturity characteristics of 'Bing' cherry. J. Amer. Soc. Hort. Sci. 106:144-146.

Quinlan, J. D. and A. P. Preston. 1968. Effects of thinning blossom and fruitlets on growth and cropping of 'Sunset' apple. J. Hort. Sci. 43:373-381.

Quinlan, J. D. and A. P. Preston. 1971. The influence of shoot competition on fruit retention and cropping of apple trees. J. Hort. Sci. 46:525-534.

Rogers, W. S. and G. A. Booth. 1964. Relationship of crop and shoot growth in apple. J. Hort. Sci. 39:61-65.

Rom, C. R. and D. C. Ferree, 1986a. The influence of fruiting and shading of spurs and shoots on spur performance. J. Amer. Soc. Hort. Sci. 111:352-356.

Rom, C. R. and D. C. Ferree. 1986b. Influence of fruit on spur leaf photosynthesis and transpiration of 'Golden Delicious' apple. HortScience 21:1026-1029.

Sharples, R. O. 1964. The effects of fruiting on the development of 'Cox's Orange Pippin' apples in relation to the incidence of storage disorders. J. Hort. Sci. 39:224-235.

Sharples, R. O. 1968. Fruit-thinning effects on the development and storage quality of 'Cox's Orange Pippin' apple trees. J. Hort. Sci. 43:359-71.

Singh, L. B. 1948. Studies in biennial bearing, III. Growth studies in 'on' year trees. J. Hort. Sci. 33:29-38.

Spayd, S. E., E. L. Proebsting and L. D. Hayrynen. 1986. Influence of crop load and maturity on quality and susceptibility to bruising of 'Bing' sweet cherries. J. Amer. Soc. Hort. Sci. 111:678-682.

Sudds, R. H. and R. D. Anthony. 1929. The correlation of trunk measurements with tree performance in apples. Proc. Amer. Soc. Hort Sci. 25:244-249.

Taylor, B. H. and D. C. Ferree. 1984. The influence of summer prunning and cropping on growth and fruiting of apple. J. Amer. Soc. Hort. Sci. 109:19-24.

Taylor, B. H. and D. C. Ferree. 1986. The influence of summer prunning and fruit cropping on the carbohydrate, nitrogen, and nutrient composition of apple trees. J. Amer. Soc. Hort. Sci. 111:342-346.

Tromp, J. 1975. The effect of temperature on growth and mineral nutrition of fruits of apple, with special reference to calcium. Physiologia Pl. 33:87-93.

Tromp, J. and L. H. M. M. Penders. 1986. Leaf diffusion resistance as affected by fruiting and ring in apple. Gartenbauwissenschaft. 51:11-14.

Tukey, R. B. 1965. Predicting the harvest size of 'Bartlett' pears. Wash. State Univ. Ext. Pub. E. M. 3403:1-7.

Uriu, K. and O. Lilleland. 1959. Limb circumference measurements as an aid in the better evaluation of apple fruit thinning data. Proc. Amer. Soc. Hort. Sci. 70:67-71.

Van Der Boon, J. 1980. Prediction and control of bitter pit in apples: II. Control by summer prunning, fruit thinning, delayed harvesting and soil calcium dressings. J. Hort. Sci. 55:313-321.

Van Der Ende, B. and D. R. Leece. 1975. leaf analysis for pear: development of standards and the nutritional status of orchards in the Goulburn Valley and Murrumbidgee Irrigation Areas. Austr. J. Expt. Agric. and Anim. Husb. 15:129-135.

Waring, J. H. 1920. The probable value of trunk circumference as an adjunct to fruit yield in interpreting apple orchard experiments. Proc. Amer. Soc. Hort. Sci. 17:179-186.

Webster, D. H. and G. L. Brown. 1980. Trunk growth of apple trees as affected by crop load. Can. J. Plant Sci. 60:1383-1391.

Weinberger, J. H. and F. P. Cullinan. 1932. Further studies on the relation between leaf area and size of fruit, chemical composition and fruit bud formation in 'Elberta' peaches. Proc. Amer. Soc. Hort. Sci. 29:23-27.

Westwood, M. N. 1978. Temperate zone pomology. W. H. Freeman. San Francisco. pp.428.

Westwood, M. N. and H. O. Bjornstad. 1974. Fruit set as related to girdling, early cluster thinning and prunning of 'Anjou' and

'Comice' pear. HortScience 9:342-344.

Westwood, M. N. and A. N. Roberts. 1970. The relationship between trunk cross-sectional area and weight of apple trees. J. Amer. Soc. Hort. Sci. 95:28-30.

Wilcox, J. C. 1937. Field studies of apple tree growth and fruiting: II. Correlations between growth and fruiting. Sci. Agr. 17:573-586.

Wilkinson, B. G. 1958. The effect of orchard factors on the chemical composition of apples. II. The relationship between potassium and titratable acidity, and between potassium and magnessium, in the fruit. J. Hort. Sci. 33:49-57.

Yearger, A. F. and L. P. Latimer. 1940. Girth and yield as indicators of apple tree productivity. Proc. Amer. Soc. Hort. Sci. 37:101-105.

Appendices

APPENDIX

A. Estimating Leaf Number from Shoot Length
in Nijiseiki Pear

Forty terminal shoots were chosen from Nijiseiki pear trees, ranging from 18 to 120 cm, leaves were counted for each shoot. Linear correlation and regression were developed between shoot length and leaf number (Fig. A-1). The regression can be used for estimating the leaf number from shoot length.

B. Estimating Fresh Weight from Diameter
and Length of Fruit in Nijiseiki Pear

Forty-eight fruit of Nijiseiki pear were taken from two weeks after full bloom to harvest. Diameter, length and fresh weight were measured for each fruit. Correlations were run among the fruit size parameters and several combinations and transformations of them (Table A-1). Diameter and length bore very significant curvilinear correlations to fresh weight (Fig. A-2). $Diameter^2$*Length bore a very significant linear correlation to fresh weight (Fig. A-3). The regressions could be used for estimating fresh weight from diameter and/or length of fruit in Nijiseiki pear.
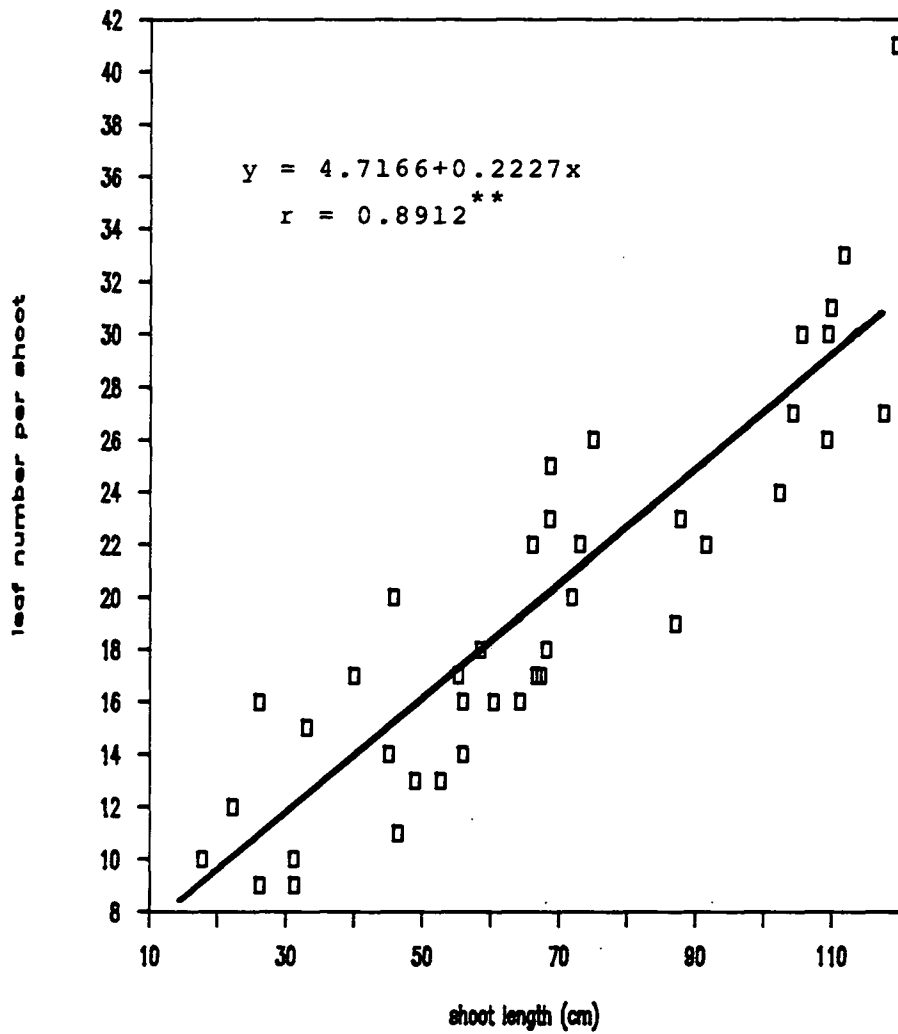
Fig. A-1. The relationship between leaf number and
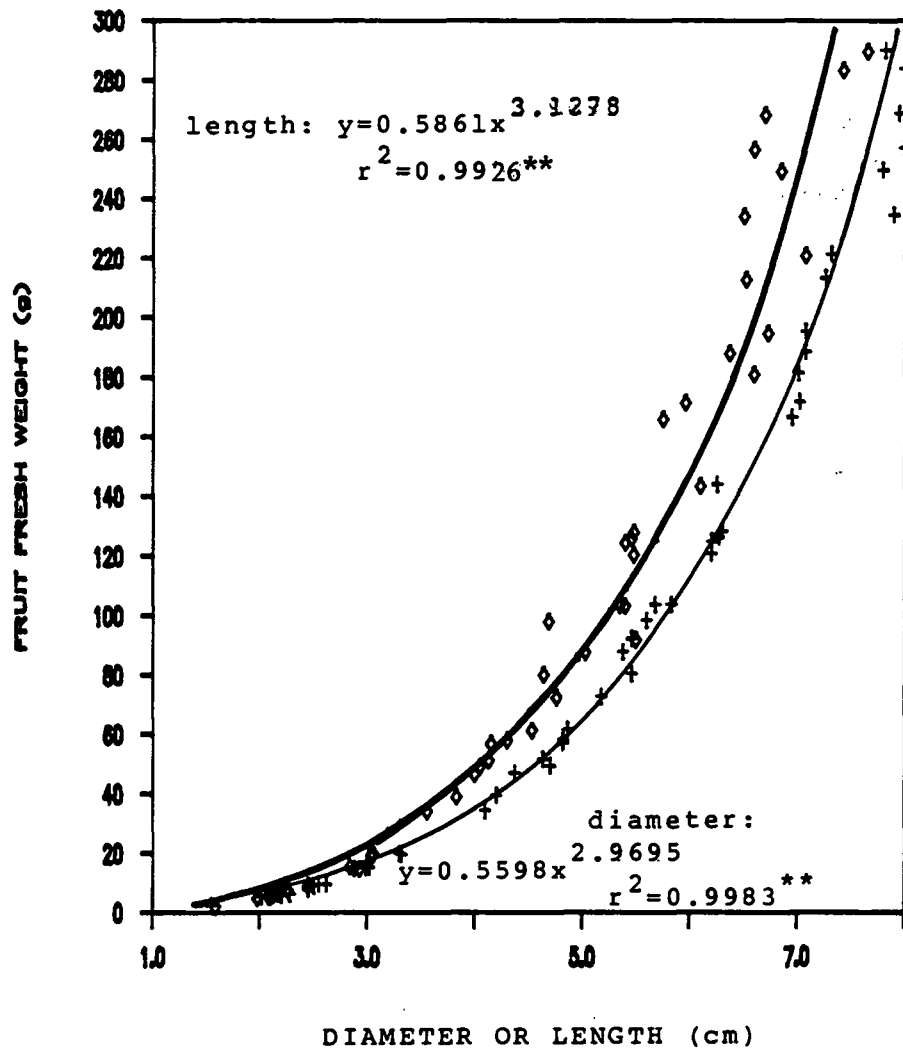shoot length in Nijiseiki pear.

** significant at 1% level.

Fig. A-2. The relationships between fresh weight and
diameter and length of fruit in Nijiseiki pear.
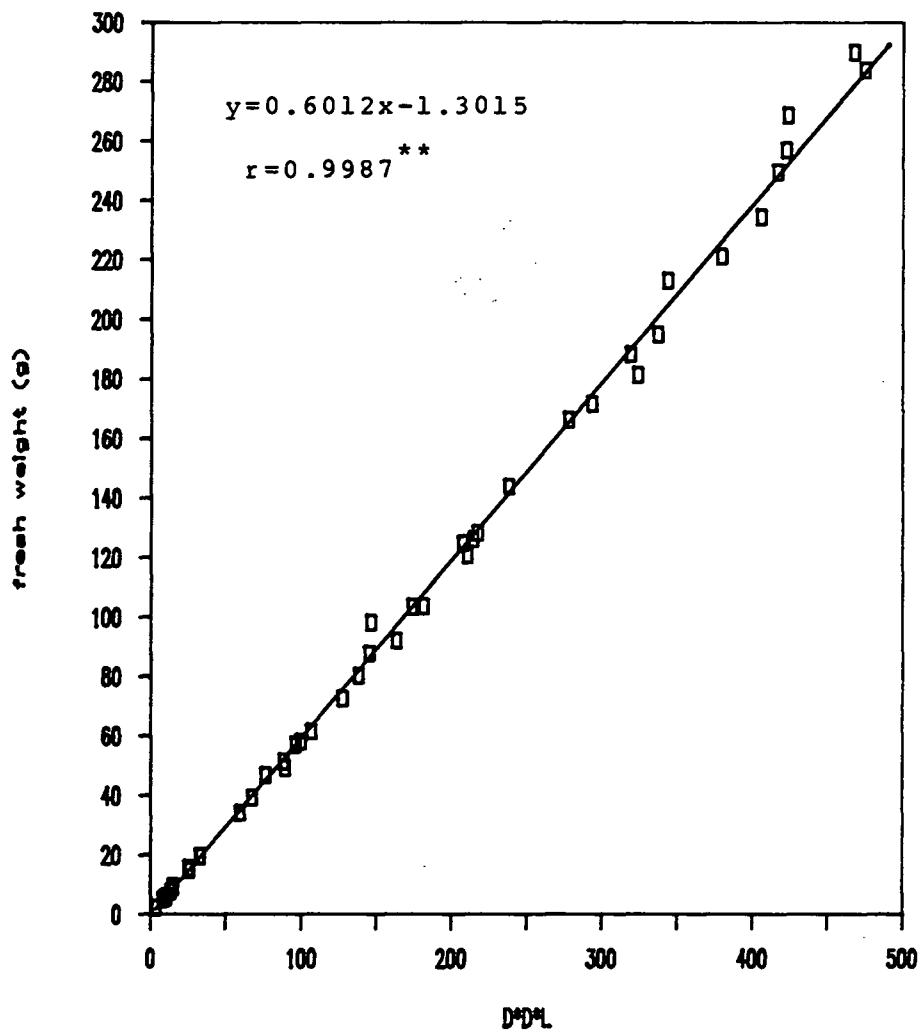
** significant at 1% level.

Fig. A-3. The relationship between fresh weight and diameter^2*length of fruit in Nijiseiki pear.

** significant at 1% level.

Table A-1. The correlation coefficients fresh weight and
several linear measurements of fruit in Nijiseiki pear

	fresh weight	Ln (fresh weight)
diameter	0.9477^{**}	0.9828^{**}
length	0.9460^{**}	0.9757^{**}
Ln (diameter)	0.8769^{**}	0.9992^{**}
Ln (length)	0.8837^{**}	0.9963^{**}
diameter*length	0.9864^{**}	0.9399^{**}
diameter^2*length	0.9987^{**}	0.8881^{**}
diameter^2*length^2	0.9917^{**}	0.8332^{**}

** significant at 1% level.