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Title: Effect of Crop Load on Mineral Uptake and Partitioning
in D'Anjou Pears.

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Three thinning levels were applied to
twenty-five-year-old D'Anjou pear trees in a completely
randomized design with five single-tree replicates on June 2,
1985. Samples of wood, shoot leaves, shoot twigs, spur
leaves, spur twigs and fruits were taken every month during
the season of growth for mineral analysis. Sampling an entire
tree was not logistically possible, so biomass estimates were
made on a branch basis using two branches from each tree.
Leaf shoots and spurs were counted for each branch at every
sampling time, and representative spurs and leaf shoots were
collected from the entire tree. By determining average shoot
dry weights, leaf dry weights, fruit dry weights and spur leaf
dry weights for the entire tree, it was possible to estimate

biomass and mineral partitioning for each branch. Thinning
did not increase shoot growth, and both total dry matter
production and minerals uptake were higher in the unthinned
trees. Fruit removal altered spur and shoot leaf mineral
concentrations of N, P, Ca, and Mg but most other tissues were
unaffected and most other elements did not show treatment
effects. Thinning reduced total demand for nutrients. In the
case of N and P, the input into the branches was not reduced
by thinning as much as dry matter, thus concentration
increases were apparent in the leaves. Although more
magnesium and calcium was required for the larger biomass in
unthinned branches, the additional fruit appeared to enhance
uptake and translocation, and Mg and Ca leaf concentrations
also increased. Shifts in leaf mineral content would only
severely alter diagnostic interpretation for N. Vigor and
crop load must be evaluated in interpreting N concentrations.
Unless partitioning between leaf and fruit biomass is known,
nitrogen concentrations are difficult to interpret.

Effect of Crop Load on Mineral Uptake and
Partitioning in D'Anjou Pears

by

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INTRODUCTION

Mineral deficiencies are a major problem for tree fruit growers because they reduce production, fruit quality, and tree growth. The use of deficiency symptoms has long been a criterion for evaluating fertilizer requirements, and typical deficiency symptoms have been described for each mineral. Studies by many authors both under field and greenhouse conditions suggest that deficiency symptoms cannot routinely predict plant responses to a deficiency of a particular element. Other complications in interpreting visual symptoms are due to similar symptoms resulting from non-nutritional causes, such as herbicide damage, diseases, or physiological responses to other stresses. There has been increasing interest in the value of tissue analysis for the diagnosis of nutritional deficiencies and this technique is often more consistent than approaches using deficiency symptoms. The fundamental idea behind the use of tissue analysis as a means of determining the nutritional requirement of plants is that the plant is the best indicator of nutrient availability and it provides a satisfactory basis for the determination of both

the relative and absolute proportion of plant nutrients present in the soil.

Leaves are the major tissue used in plant analysis, because the leaf is the focal point of many plant functions and is a relatively sensitive indicator for mineral elements. The approach to interpreting leaf analysis is to compare observed concentrations in leaves collected at a specific time to critical concentrations or values. Normally leaves from the middle section of current year's shoots are used for this purpose. Leaf analysis has become more widely used in recent years. This is particularly true in studies on perennial plants, where leaf analysis seems to be a more appropriate tool than it is in studies on rapidly growing annual plants. Tree crops are relatively slow growing with long periods for absorption, accumulation or expulsion of minerals interposed between periods of expansion. Long term management is feasible and annual sampling allows one to modify fertilizer practices in response to changes in mineral composition.

Most plant analysis laboratories establish a computer devised recommendation which has led to rigid diagnostic criteria rather than flexible recommendations based on the general physiology of the plant. When evaluating nutrition status by leaf analysis it is important to know factors, other than the nutrient supply, which may affect the content of the leaves. Dry matter partitioning between leaves and fruits

affects mineral composition. Since fruit mineral content is often quite different than leaf mineral content, we would expect a difference in total mineral requirements between trees having different crop loads, pruning levels or thinning systems. For example, nitrogen concentrations may easily vary by 10-15% due to differences in crop load regardless of nutrient supply in the soil. This is critical because the range between deficiency and sufficiency (2.0-2.3 normal range for pears) is less than the variation caused by non-nutritional factors. Despite a long tradition of diagnostic services, based on nitrogen concentrations more information is required to make N recommendations. Similar arguments apply to other minerals. In this study the main focus will be on the effect of the crop load on mineral uptake and partitioning in D'Anjou pears.

REVIEW OF THE LITERATURE

Effect of Crop Load on Tree Growth

Hansen (1973) reported that crop load strongly inhibits the growth in the vegetative parts of apple trees. The total amount of dry matter in fruit-bearing trees exceeds that of the non-bearing trees, but the difference is small. Results have been inconsistent. In the case of the apple variety Worcester the development of a fruit crop amounting to one-fourth of the tree dry weight resulted in a lower total annual dry matter production than in corresponding specimens without fruits (Maggs, 1963). Although specific studies differ, in general total biomass production is relatively constant and differences between fruiting and non-fruiting trees are small.

When increased photosynthate is partitioned to fruit tissue it is usually at the expense of shoots, roots, and other plant tissues rather than the result of a change in total biomass. Large amounts of fruit strongly reduce the amounts of assimalates available for other growing regions, and produce a result similar to reducing the amounts of available assimilates by defoliation or shading (Maggs, 1965). Loomis (1953) reported that fruits are a greater sink for carbohydrates than other organs.

The growth in width of branches and trunk in apple trees is depressed when large amounts of fruit are produced (Hansen, 1966). In certain apple varieties, the formation of flower buds is impeded (Hansen, 1967). Singh (1948) has reported increased root growth in observation trenches following destruction of the apple crop by frost. Most pome fruits behave similarly (Mochizuki, 1959). The development of fruits and seeds requires considerable amounts of photosynthates and also reduces vegetative growth in other tree species (Kozlowski and Keller, 1966).

Potato plants from which tuberbearing side shoots were removed, flowered more freely, set more and larger fruits and developed more seeds (Werner, 1954). Fruiting may also alter photosynthetic efficiency. Mochizuki (1959) reported for the herbaceous Solanum melongena a reduced efficiency of leaves on cropping plants which he attributed to the excessive deterioration of the root system. However in tree fruits, leaves appear to become more efficient as crop load increases. Total biomass accumulation is often similar even though heavily fruiting trees have fewer leaves. The total area of leaves per tree is decreased by crop load but the efficiency with respect to photosynthesis and translocation of assimlates may be increased (Hansen, 1967, 1970, 1971). Although no direct evidence has been adduced, it is generally concluded that increased efficiency is due to a more rapid translocation of

water, CO_2 and photosynthetic products rather than to changes in the antecedent photosynthetic steps (Maggs, 1963).

Growth of leaves is at peak level during June, whereas the main new growth in branches, trunk and roots takes place proportionately later in the summer (Poulsen and Jensen, 1974; Mead, 1968). During this later period, growth and consumption in fruits reach a particularly high level, therefore competition between fruit and branches, trunk, or roots can be more severe than competition between fruits and leaves.

Crop load also affects tree growth in subsequent seasons. Hansen (1970) found that trees without fruits in the previous year continue to have more new growth than trees bearing fruits the previous year. Differences are largest early in the season and result in more total dry matter production in current year's shoots. On the other hand, trees showed a tendency towards slightly smaller area and thinner leaves. Flowering took place a little later for trees not bearing fruits the previous year.

Residual effects of the fruiting conditions on the following year's growth may be due to the differences in tree sizes fruiting initially produced. Most studies have been conducted on young growing trees, and the faster growth of non-fruiting trees allows more shoot biomass to be produced. Early shoot growth is also assumed to be related to varying extent on the amount of photosynthate reserves (Robers, 1926;

Wilcox, 1937, 1944; Harley, et al., 1952; Priestley, 1962; Maggs, 1963; Koslowski and Keller, 1966). Reduced accumulation of the reserves is assumed to be a common result of fruit-bearing (Priestley, 1962; Kazaryan and Arutyunyan, 1966; Ursulenko, 1967). According to Hansen (1967) the accumulation of reserves appears to be particularly extensive in roots.

Other possible explanations relating to the fruiting condition in one year and the shoot growth activity in the following spring may lie in differences in the contents of other more specific substances transmitted from other organs to the shoots during the spring (Luckwill and White, 1968). Growth factors induced in the previous year may have a role in regulating development early in the season. Changes in bud activity and initial terminal growth, consequently affect the number of shoots, and to some extent the length of the shoots and the internodes. Tissue levels of specific substances are likely dependent on the previous year's fruiting condition, and may be linked to differences in the accumulation of reserves from the previous year.

The effect of crop load on tree growth is commonly dependent on the availability of nitrogen and potassium, but other elements while sometimes important generally have only limited effects on the growth of the tree. Nitrogen effects vary among different organs and between fruiting and non-fruiting trees. Root growth is strongest in the case of

nitrogen deficiency, particularly in non-bearing specimens (Avery, 1969). Trees without fruit show only slight development of shoots when nitrogen is deficient. These processes are strongly promoted by the addition of nitrogen, although at high levels excess growth is at the expense of other tree parts. In the case of fruit bearing trees, additional supplies of nitrogen cause a minor increase in the fruit yields and the growth of other parts is even less affected (Hansen, 1979). Some crop load nitrogen availability interactions can be explained by the large differences in total nitrogen content between bearing and non-bearing trees. Non-fruiting trees with considerably more shoots and leaves have a higher total nitrogen content. This is due to the greater nitrogen concentration found in leaves relative to fruits (Hansen, 1973). A fruiting tree accumulates less total nitrogen than a non-fruiting tree with similar annual biomass production. Fruiting trees therefore require less nitrogen and may not respond to nitrogen additions as much as non-fruiting trees. Additional supplies of potassium cause an increase in the amount of fruits in case of mild nitrogen deficiency and current year's shoots respond more strongly if potassium is supplemented with a large nitrogen addition (Hansen, 1971).

Effect of Crop Load on Mineral Uptake
and Mineral Concentration

The total uptake of nutrients by the plant depends on the
size of the plant, the nutrients' availability and the
distribution of growth of the different organs. For elements
that have wide differences in mineral concentrations for
leaves and fruit, total nutrient uptake is more affected by
crop load than soil nutrient availability (Hansen, 1971). To
a great extent, the total uptake of nitrogen and phosphorus is
determined by the amount of vegetative growth during the
summer season (Poulsen and Jensen, 1964; Hansen, 1968), and in
the autumn in particular to the growth of the roots (Mochizuki
and Kamakura, 1968). The very high consumption of potassium
(Quinlan, 1964) but very low consumption of calcium by the
fruits also influences the total uptake by the tree. Fruiting
trees often contain less total calcium than non-fruiting trees
(Hansen, 1971). Although the fruits are a large sink for
potassium, total potassium uptake often remains relatively
constant, thus increased K in fruit is at the expense of other
organs. The high consumption in fruits may explain why fruit
yield proved to be affected by potassium supply more than .
other elements (Dullom and Dalbro, 1956; Greenham, 1965).

Since crop load alters total mineral uptake and
partitioning, the concentration of nutrients in individual
organs may also be affected. The leaves of trees with fruit

generally have a higher concentration of nitrogen, calcium and magnesium, but a lower percentage of potassium (Bould, 1966; L Jones, 1953, 1954; L. Jones and Broadic, 1954; Gruppe, 1954; Weeks, et al., 1958; Hansen, 1965; Ktossowski, 1967). These differences are usually explained by greater total uptake and demand for nitrogen, calcium and magnesium in non-fruiting trees and the competition for limited amounts of potassium when a large portion of available K is partitioned to fruit tissue. Phosphorus concentrations generally follow the same pattern as nitrogen, calcium, and magnesium, but the results are not equivocal. The phosphorus percentages also may in some cases be higher in fruit bearing specimens and in other cases in the non-bearing ones (Hansen, 1971). Only in rare cases do the nitrogen percentages in leaves and the phosphorus percentages in roots reach higher values in non-bearing trees than in fruit-bearing ones. Deviations may occur for other elements (Emmert, 1954; Hansen, 1965; L. Jones, 1954; Mason, 1955).

Differences between potassium or calcium concentration changes in response to crop load variations may be explained by high K consumption and low Ca consumption in fruit tissue. The difference between the total new growth in the fruiting and non-fruiting trees is small (Hansen, 1971), thus fruiting does not create additional Ca demand even though K requirements of fruit may be at the expense of other plant parts.

Therefore a decrease and increase in the K and Ca percentages, respectively, commonly occurs in leaf tissue with increased fruiting. Similar explanations of the potassium relations have been proposed by Lilleland and Brown (1938), Cain and Boynton (1948), Popenoe and Scott (1956), Weeks, et al. (1958), and Sato (1969). The nitrogen concentration in organs other than leaves, e.g., spurs, buds, shoots, or roots, may be affected in different ways (Davis, 1931; Harley, et al., 1962; Kato and Ito, 1962; Sahulka, 1962; Feucht, 1965, 1966, 1967); although in general the concentration was found to be highest in the fruit-bearing specimens (Hooker, 1920; Kraybill, et al., 1925; Bielinska, 1965; Dziecot and Bielinska, 1956; Mochizuki, 1962; Dzieciot and Bielinska- Czarnecka, 1962; Bielinska, et al., 1966; Kazaryan and Arutyunyan, 1966).

As tree size increases and growth and total nutrient requirements become greater, differences between bearing and non-bearing trees become more apparent (Hansen, 1971). Very young non-bearing trees often have higher N and P percentages than older bearing trees. This shift may be explained by a change in the conditions for nutrient uptake. Initially, unrestricted uptake of nitrogen and phosphorus and a high availability of assimilates for vegetative growth results in the formation of vigorous tissues of a high N and P percentages. When limitations for the uptake of nitrogen and

phosphorus develop as total demand increases, a relative deficiency will first turn up for the large, non-fruiting trees with greater nutrient demand, resulting in a reduced percentage compared to the fruiting trees of lower nutrient demand (but with equal supply). For nitrogen this will first be seen in the leaves, for phosphorus in the strongly P-consuming roots.

Residual effects of the fruiting conditions on the following year's mineral composition are 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 effects that crop load has on the establishment of these reserves is manifest in the following season. Mason and Whitfield (1959) found three different periods of accumulation and distribution of dry matter and mineral elements.

1) A period of formation of new tissue, where both photosynthate compounds are drawn from reserves in the tree laid down the previous year or years.

. 2) A period toward the end of May, when the new leaves are able to contribute photosynthesized compounds and acquire mineral components currently absorbed through the roots. Newly formed components are translocated to support the

formation and expansion of further new tissue up to about the end of August.

3) With the cessation of further growth, nutrient elements are redistributed in various tissues, in some of which the concentrations are increased, e.g., nitrogen in the branches, magnesium in the younger wood, and calcium in the bark. Other workers have clearly shown that the minerals tend to migrate from the foliage very rapidly before leaf fall (Wallace, et al., 1951).

Cropload 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. Biennially bearing patterns can complicate crop load effects. There is occasionally higher potassium content in the leaves of the non-bearing trees that doesn't manifest itself until late in the season (Mochizuki, 1967) possibly after having been higher in the leaves of the bearing trees at the beginning of the season (Davis, 1934).

Crop load clearly affects mineral uptake and tissue concentration. In the case of bearing specimens, as compared to non-bearing ones, it is necessary to anticipate higher values by 10-15 percent in the case of nitrogen, and 18-25 percent for calcium, but lower by 10-15 percent in the case of potassium. However, the difference may vary considerably in value, probably depending on the amount of fruit.

Effect of Crop Load on Mineral Uptake at Different Levels of Fertilizers

Due to the specific requirements of growing organs (Hansen, 1971), the non-bearing trees react with the most extensive additional uptake to increased availability of nitrogen, phosphorus, calcium and magnesium. In the case of nitrogen, the moderate consumption by fruit-bearing trees causes them to reach optimum values more rapidly, and to react less strongly to nitrogen deficiency. Increased nitrogen to non-bearing trees on the other hand, causes a strong increase especially in leaf and shoot growth, to some extent at the expense of root growth. The total uptake and consumption of nitrogen increase strongly, and optimum values are reached only at the application of greater amounts of nitrogen than in the case of fruit-bearing specimens. However, striving to maintain optimum leaf values may not be desirable because

efforts to do so create even more leaf and shoot growth rather than promoting fruit production.

Fruits and storage organs require considerable amounts of potassium (Bunemann, 1972), and there appears to be no great difference between the two kinds of trees as far as the total potassium uptake when potassium is not a limiting factor. Therefore, the increased potassium demand caused by high fruit production can lessen leaf K levels. In the case of potassium at deficient levels, there is no distinct difference between the leaf content of bearing and non-bearing trees (L Jones, 1954) However, reports differ on the level of leaf K that is associated with K deficiency. Even at the lowest level of potassium, no equivocal decrease in growth or yield was found (Hansen, 1971) in spite of potassium percentages in the leaves indicating deficiency. However, it is possible that the potassium deficiency has become considerable only towards the latter part of the growth season.

With unlimited availability of nitrogen that occurs in artifical environments, nitrogen contents may not be reduced by crop load. Nitrogen percentages are found to be highest in trees without fruit, perhaps because a simultaneous high availability of assimilates and nitrogen provide the basis for a qualitative change of the tissues to a structure richer in protein (Lenz and Bunemann, 1969; Hansen, 1971)1, while at the same time the amount of total growth is decreasing. Increased

availability of phosphorus and magnesium does not, to any particular extent, affect growth and development (Hansen, 1971).

Effect of Crop Load on Physiological Parameters

Crop load can also alter other physiological parameters that directly affect nutrient uptake and translocation. The influence of the distribution of growth on the uptake of nutrients causes changes in the pH values of nutrient solutions (Hansen, 1971). There is a steeper pH increase in the case of non-bearing trees which may have been due to increased ion uptake. Particularly high uptake of anions (nitrate, phosphate) compared to the uptake of cations, is common in fruit trees and results in the release of HCO_3^- ions by the roots exceeding that of H^+. Therefore more rapid uptake by non-bearing trees results in different rhizosphere pHs. Changes in the pH of the rhizosphere and synergistic or antagonistic relationship associated with altered ion uptake obviously affect nutrient uptake.

The total area of leaves per tree is decreased by crop load but the efficiency with respect to photosynthesis and translocation of assimilates may be increased by fruiting (Hansen, 1967, 1970). Thus the translocation and distribution of water as well as nutrients in the xylem may be affected. Accelerated phloem transport may increase the export of

phloem-mobile elements from the leaves. There is a great consumption of water by the fruit bearing trees which may be due not only to production of fruits of a high water content but may be to an even greater extent be caused by a higher transpiration intensity, since the leaf area is smaller for the bearing specimens (Hansen, 1971). This follows the photosynthetic intensity which has also been found to be higher in the case of bearing trees (Hansen, 1970). Other studies suggest that this is related to a higher degree of opening of the stomata (Hansen, 1970). Regardless of the cause, increased transpiration to leaf surfaces and altered water consumption will affect nutrient transport.

Transport in Tree Fruits

Long distance transport of mineral elements may take place in the xylem and the phloem (Lyttge, 1973). Fruits are supplied through the phloem with most of their organic compounds (carbon and nitrogen) and part of their water (Pate, 1976). In apples the major part of their potassium, phosphorus, nitrogen and magnesium, is translocated into the fruits nearly linearly with dry matter (Tromp, 1975), indicating phloem transport of these compounds. In contrast, calcium is transported into the fruits in only small quantities, mainly following the water distribution via the xylem (Wiersumn, 1966) during the early stages of fruit

development, as a shift from xylem into phloem transport may occur at a fruit size of about 30 g (Redmond, 1975).

There is a continual seasonal movement into the apple fruits of all the elements, even though the rate of movement is more steady in the case of potassium, phosphorus and boron than for nitrogen, calcium and magnesium (Rogers and Batjer, 1956). The concentrations of most of the elements in the fruits decline throughout the season, even though there is continued delivery (Wallace, et al., 1961). This can be explained by the fact that a relatively small amount of these elements moves into the fruits compared to dry weight increase, thus causing a concentration decline while an actual increase occurred on a per fruit basis.

Effects of Crop Load on Potassium Translocation

Fruiting affects dry matter and potassium in very similar ways. Fruits are strong sinks of both (Buneman, 1972). Xylem transport of potassium is reduced by fruiting (Hansen, 1971) and this could be the result of the strong attraction by fruits. The smaller amounts of potassium arriving at the roots in fruiting trees might stimulate the roots with respect to uptake of potassium, so that the total uptake per tree, despite a probably smaller absorbing root surface, would be higher than defruited trees. The absorption efficiency of roots may be increased if the ratio of plant demand/absorbing

root surface is enhanced (Clarkson, 1974; Frith and Nichols, 1975). With this interpretation, the xylem transport of potassium in fruiting trees would consist mainly of newly absorbed potassium, while in defruited trees, it would include a large amount of recirculated potassium. The drop in potassium concentration with fruiting seems to occur in particular in the range of low fruit/leaf ratio. Fruits of heavily thinned trees or the larger fruits from the outer parts of the tree have the higher concentrations of potassium (Sharples, 1964; Schumacher and Frankauser, 1974). In the range of higher fruit/leaf ratios concentrations of potassium may vary little. Positive correlation between potassium and the soluble dry matter or acid contents of fruits have been demonstrated (Wilkinson, 1958; Perring and Preston, 1974).

Reduction in potassium concentration by fruiting does not necessarily occur in all fruit species, as leaves on bearing branches of the pistachio have higher concentrations of potassium than those on defruited branches (Uriu and Crane, 1977), but the fruits here, which are nuts, may have a very low demand for potassium.

Effect of Crop Load on Phosphorus
and Nitrogen Translocation

In fruiting trees, total uptake of phosphorus and nitrogen is reduced to about half of that in non-fruiting trees, and the concentration in the xylem sap is only about half as high (Hansen, 1978). This could be related to the fact that the fruits which constitute the greater part of the total dry matter in fruiting trees, have a much lower concentration of phosphorus and nitrogen in their dry matter than is found in the new growth of non-fruiting trees.

Hansen in 1978 measured the xylem transport and found that the newly absorbed phosphorus and nitrogen are transported primarily to the leaves and are greater in the defruited plants which have more leaves. It is probable that part of the phosphorus and nitrogen is exported from the leaves to the phloem, and some going into the fruits of fruiting trees (Tromp, 1975; Pate, 1976) but some also further down into the tree. In non-fruiting trees, root growth requires large amounts of nitrogen and, especially of phosphorus (Hansen, 1971) and the uptake ratio P/N is higher at the time of rapid root growth. The author found that the xylem transport of phosphorus is higher at the time of rapid root growth in September. The xylem transport of phosphorus was known to be 47% of that of nitrogen in September while in a similar investigation in July, it was only 30%. This could

indicate that phosphorus is being circulated in the phloem and that, when root growth is not vigorous, the circulated phosphorus reaching the roots slows down uptake and transport.

Effect of Crop Load on Calcium Translocation

Calcium is normally not translocated to any appreciable extent in the phloem. This may explain why the very low calcium demand by fruiting trees compared to non-fruiting ones is not accompanied by a low total calcium uptake per tree (Hansen, 1978). Transport through the phloem cannot be a regulatory mechanism for uptake, so regulation must occur through the xylem, which may be less efficient. In the roots and fruits a steady increase in calcium concentrations as demonstrated with increasing fruit/leaf ratios (Drake, Bramlage and Baker, 1974). The calcium content of fruits is very low, but the change with crop load is relatively large. The authors found a substantial increase in the calcium concentration of the peel with higher crop load. Perring (1968) and Perring and Preston (1974) demonstrated a negative correlation between fruit size and calcium concentration, the calcium content being augmented in very small fruits in particular. At increasing crop load the growth of individual fruits is reduced, and this may prolong the duration of xylem translocation into fruits or otherwise favor xylem at the

expense of phloem translocation into fruits, which as already mentioned, would promote calcium accumulation in the fruits.

MATERIAL AND METHODS

Introduction

Understanding the role of the fruit in the uptake and distribution of minerals is of major significance when evaluating the nutritional requirements of the tree. Dry matter partitioning between fruits and other tissues affects mineral composition (Hansen, 1971). Since fruit mineral content is often different than leaf mineral content, we would expect a difference in total requirements between trees accumulating similar biomass but having different leaf/fruit ratios. In general, the absence of fruits increases growth of other tissues predominantly in the leaves and shoots (Poulsen and Jensen, 1966).

The increased leaf production often leads to higher nutrient demand due to much higher mineral content in leaves than fruit. Non-fruiting trees can have greater nutrient uptake and reduced mineral concentrations. Leaf mineral levels would reflect differences in crop load, rather than nutrient supply, making diagnosis based on leaf analysis tenuous. For example, nitrogen concentrations in apples have been reported to decrease by 10-15% when crop load is reduced (Hansen, 1973). This is critical because the range between

deficiency and sufficiency is less than the variation caused by non-nutritional factors. It is conceivable that a non-cropping tree with greater N uptake would be diagnosed as deficient, where a cropping tree with less N requirements growing on the same site would reveal adequate leaf nitrogen levels. Similar arguments apply to other minerals.

The demands of a crop on the tree's metabolism vary in quantity and kind as the season progresses (Abbott, 1960; Priestly, 1962), so that crop removal might vary in its effects according to when it was done. Denne (1961) reported that there are two stages for crop removal that produce large differences in tree response: at blossoming (April for D'Anjou pears), and about six weeks after pollination (June for D'Anjou pears), when cell division in the fruit is becoming less frequent. Since changes in nutrient uptake in response to thinning are generally explained by an increase in demand resulting from greater leaf production, delaying thinning until mid-June could alter thinning effects. Induced growth of leaves is likely lessened with later thinning.

Most work on crop load has dealt with young apple trees. Previous experimenters have totally removed fruits in order to determine the effect of crop load on growth and mineral uptake in trees. Little is known about the effects of less drastic crop load alterations on mineral composition of mature pears, and current fertilizer recommendations are given without

considering the crop load of trees. The objectives of these experiments are: 1) To examine the effect of various thinning levels on the vegetative growth of the tree over the growing season; 2) Investigate the effect of various thinning levels on the partitioning of minerals in various tissues; and 3) Determine if crop load induced changes in mineral composition would alter standard computer devised recommendations based on our current leaf analysis guidelines.

Material and Methods

The experiments were conducted in 1985 at the Hood River Experimental Station, located fifty miles northeast of Portland, Oregon, at latitude 47°N. Twenty-five-year-old D'Anjou pear trees were employed in a completely randomized design. Five single-tree replicates were used for each of the following treatments:

1. High thinning: 2/3 of the fruits of each tree were removed.

2. Low thinning: 1/3 of the fruits of each tree were removed.

3. No thinning: No removal.

All treatments were initiated on June 21, 1985.

A means of estimating biomass partitioning in leaves, fruits and shoots was desired. Sampling an entire tree was not logistically possible, so estimates were made on a branch

basis using two branches from each tree. Since several sampling dates were planned, it would not be reasonable to continuously sample these branches. To do so would severely deplete the fruits on the branches by the end of the season. Therefore, no samples were collected from these branches. Leaf shoots and spurs were counted for each branch at every sampling time, and representative spurs and leaf shoots were collected from the entire tree. By determining average shoot dry weights, leaf dry weights, fruit dry weights and spur leaf dry weights for the entire tree, it was possible to estimate biomass partitioning for each branch. Sampling was initiated prior to initiating treatments to allow detection of variability in crop load, shoot growth, and mineral composition that could complicate interpretations.

Sampling dates were: March 15, April 23, May 16, June 21, July 26, August 15, and September 20. Samples of wood shoot leaves, spur leaves, shoot twigs, spur twigs and fruits were taken at each sampling time (when appropriate). Wood was sampled with an electric drill, and fruits were divided into core and slices. At the end of the season (September 20), the branches being monitored were removed and fresh and dry weights calculated. Samples were brought to the lab in plastic bags, washed with soap and distilled water to remove surface dust, then dried in an air dryer at $55^{o}C$ for 3 (non-fruits) to 7 (fruits) days. Samples were ground in a

Wiley Mill. Each sample was analyzed for nitrogen using an autoanalyzer after microkjeldhal digestion. All other mineral analysis (K, P, Ca, Mg, S, Mn, Cu, Zn, B, Al) was done by inductively coupled Argon spectrometry after dry ashing at $550^{O}C$ and dissolving in 5% HNO_3.

Mineral content for each tissue was expressed both as a tissue concentration, and as total amount of the element in the tissue per kilogram branch. At harvesting, the yield of each tree was measured in order to determine the effect of thinning. One box of fruits from each tree was randomly selected and fruits were weighed individually to examine the influence of thinning on fruit size. From these fruits, four per box were selected by weight between 200 and 210 grams to see the variation in mineral content between these similarly sized fruits. An analysis of variance was performed to evaluate differences between treatments and sampling dates for the parameters evaluated.

RESULTS AND DISCUSSION

Fruit set and crop load was not uniform, thus large variability between single tree replicates obscured treatment differences in yield, growth, and mineral content. Main effects were significantly different for thinning treatments only for N, P, Ca, and Mg concentrations. Treatment x part, and treatment x sample time interactions were not significant. Although P concentrations were significantly different for thinning treatments, this may have been due to differences in initial concentrations rather than treatment affects (Appendix 2). Differences between treatments were only significantly detected between no thinning and high thinning treatments, therefore only these two treatments are further discussed.

Yields were not significantly different when expressed on a per tree basis (Table 1). Trends become more apparent when comparisons are made on a branch basis (Table 2). Thinning did not increase the growth of the shoots. The total dry matter produced in the unthinned trees in the shoots and fruits was higher than in the thinned trees. However, this difference was significant only at P < 10%. A decrease in shoot growth and total dry matter production with thinning is not consistent with studies on younger trees. Hansen (1973)

using three-year-old Golden Delicious trees found that fruits strongly inhibited the growth of the vegetative parts of the trees, thus shoot dry matter production. Part of the inconsistancy may be explained by the later thinning treatment imposed in the current study. Thinning in mid-June, which is after the peak level of shoot growth, would not induce the increased shoot vigor commonly found with earlier fruit removal. It is also possible that increased photosynthetic efficiency of the leaves from fruiting trees (Hansen, 1971) accounts for the apparent decrease in dry matter accumulation in the branches of thinned trees. The effect of crop load on the growth of the trees depends on multiple factors such as the age of the trees and the degree of fruiting. Rogers and Booth (1964) also found no increase in shoot growth with lower cropping trees. There was no correlation between crop and shoot growth in 25 year old Prince Albert apples within the same year while a negative correlation between shoot growth and the previous year crop was observed.

Since thinned trees accumulated less biomass than non-thinned trees, one would expect them to have a smaller. nutrient demand and different mineral concentrations (Table 3). Nitrogen content in the leaves decreased as the season progressed. The decrease was steeper in the case of the unthinned trees than the highly thinned trees (Appendix 1). Similar decreases in N content occurred in the twigs until the

end of the season when migration of N from the leaves
occurred. The removal of the fruits decreased total nitrogen
demand in fruiting branches. Since nitrogen movement into the
branch was not decreased as much as the decline in dry matter,
higher concentrations are possible. Most tissues were
unaffected, but nitrogen concentrations in both spur and shoot
leaves of the thinned trees were higher than in the unthinned
trees (Table 3). The results contradict Hansen (1971) in
fruiting and non-fruiting five-year-old Golden Delicious. The
main difference is that defruiting in studies on young apple
trees increased vegetative growth. This increase in the
growth of the shoots and the leaves, which have high nitrogen
content, led to competition beteen the vegetative parts for
the available N which decreased leaf N concentrations.
Although the total uptake of nitrogen is higher in the case of
defruited trees, N concentrations are lower than fruiting
trees. In this study, no increase in vegetative growth
resulted from thinning. The absence of the fruits left more
nitrogen available for the leaves and shoots, and the N
concentrations were higher than the unthinned trees. Removing
fruit can either increase or decrease leaf N concentrations
depending on how shoot growth and nitrogen demand change.

Phosphorus concentrations in wood, spurs and fruits were
not highly affected by thinning (Table 3), but levels in shoot
twigs and leaves increased. P changes are similar to nitrogen

responses. Phosphorus movement into the branch was decreased less than dry matter, thus the absence of the fruits left more P available for the leaves and shoots. Results in the literature are inconsistent for fruiting effects on phosphorus content and partitioning. In general changes in P content reflect changes in the total demand but this is not always the case. The uptake of phosphorus is related to the vegetative growth (Poulsen and Jensen, 1966; Hansen, 1968), in the autumn in particular, to the growth of the roots (Mochizuki and Karnakura, 1968). Hansen (1971) found that phosphorus content may in some cases be higher in fruit-bearing trees and in other cases in the non-bearing ones. Only in rare cases do the phosphorus percentages in roots reach higher values in non-bearing trees than in bearing ones.

Potassium content in the tissues was not greatly affected by the treatments (Table 3). The potassium content of the spurs and the fruits was higher in the unthinned trees. The difference in values between the different treatments was almost the same since the time of thinning throughout the season, which might be due to variations in initial K content (Appendix 3) rather than to the effect of treatments. The total amount of potassium was higher in the unthinned trees than the highly thinned trees, but the decline in K movement into the branches was similar to the decline in biomass, thus concentrations were not affected. This is consistent with

observations where K uptake is related to biomass accumulation. The uptake of potassium tends to be higher in trees with high crop than trees with low crop (Hansen, 1971), due to the high consumption of potassium by the fruits.

Calcium content in the leaves increased along the season in all the trees (Table 4). The unthinned trees showed, however, higher increase in Ca content in the leaves, wood and twigs, even though it was lower before the thinning (Appendix 5). Even though fruiting increased dry matter accumulation and calcium demand, Ca uptake increased more than dry matter. Circulation through the phloem cannot be a regulatory mechanism for uptake. So regulation may occur through the xylem, which may be less efficient. One of the factors that might have affected this increase could be related to the high water uptake in the fruiting trees (Wiersum, 1966; Stebbins and Dewey, 1972) accompanied with high calcium uptake. Since the fruits have very low Ca requirements, more calcium would be available for the shoots and spurs. Although fruiting also increased leaf calcium content in five-year-old apples (Hansen, 1973), the mechanism was different in this study. In Hansen's study, fruiting decreased shoot growth and lessened calcium demand allowing for an increase in leaf concentrations.

Fruit calcium concentrations generally increase with crop load (Hansen, 1973), but this did not occur in this study

(Table 4). Most fruit calcium concentration increases are due
to the effect of crop load on fruit size. Perring and Preston
(1974) demonstrated a negative correlation between fruit size
and calcium concentrations. The calcium content being
augmented in very small fruits in particular. At increasing
crop load, the growth of individual fruits is reduced, and
this may prolong the duration of xylem translocation into
fruits, which as already mentioned would promote calcium
accumulation in the fruits. There was no effect of thinning
on the fruit size of D'Anjou pears, which might explain the
lack of difference in fruit Ca concentration between the
treatments. Fruit mineral concentration for all elements were
generally similar regardless of treatment if either random or
similar size (200-210 grams) fruit were analyzed.

Magnesium concentrations in most tissues were not highly
affected by thinning (Table 4), but they increased in both
shoot leaves and spur leaves. Mg changes are similar to
calcium responses. Fruiting increased Mg requirements, but Mg
uptake increased more than dry matter. There is a similarity
between magnesium and calcium with respect to total uptake and
xylem transport (Hansen,1973), but magnesium is also mobile in
the phloem as indicated by the transport of magnesium into
fruits (Tromp, 1975). There was no effect of thinning on
sulfur content (Table 3), or micronutrients content (Tables 5
and 6) in plant tissues with the exception of zinc. Zn

concentrations were higher in unthinned trees. Although S and
micronutrient content of the branches of the thinned trees
were in general lower than the unthinned trees, biomass
declines were similar to elemental declines and concentrations
were similar.

Conclusion

Fruit removal altered spur and shoot leaf mineral
concentrations of N, P, Ca, and Mg, but most other tissues
were unaffected and most other elements did not show treatment
effects. Thinning obviously affects the number of fruits, but
it has no effect on fruit mineral composition or fruit size.
Thinning reduced total demand for nutrients. In the case of N
and P, the input into the branches was not reduced by thinning
as much as dry matter, thus concentration increases were
apparent in the leaves. Although more magnesium and calcium
were required for the larger biomass in unthinned branches,
the additional fruit appeared to enhance uptake and trans-
location and Mg and Ca leaf concentrations also increased.

Shifts in leaf mineral content would only severely alter
diagnostic interpretation for N. Using current OSU guidelines
for D'Anjou pear, unthinned trees would have been diagnosed as
normal (2.0-2.3%) and unthinned trees diagnosed as below
normal (1.8-2.0%). The greater dry matter production in non-
thinned trees created more demand that resulted in the

detection of a deficiency that was not detected in trees with lower crop load. Vigor and crop load must be evaluated in interpreting N concentrations. Crop load can either increase total N demand as it did in this study, or decrease demand as previously reported (Hansen, 1971). Unless partitioning between leaf and fruit biomass is known, nitrogen concentrations are difficult to interpret.

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Table 1

Effect of Thinning on Yield (boxes) and Fruit Size (grams)

	High Thinning	Low Thinning	No Thinning	LSD
Average Yield	8	10	10.6	ns
Fruit Size	221.93	225.25	224.65	ns

Table 2

Effect of Thinning on Partitioning of Dry Matter

	Total	Shoot Leaves	Shoot Twig	Core	Slices
Unthinned	630	213.45	217.85	11.81	189.84
Thinned	466	159.46	163.43	9.44	134.02
L.S.D. p < .05	ns	ns	ns	ns	ns

Table 3

Effect of Thinning on N, P, K contents (%) and Partitioning (g/Kg branch)

	N		P		K	
	%	g/Kg	%	g/Kg	%	g/Kg
Wood						
Thinned	.428	-	.038	-	.206	-
Unthinned	.438	-	.040	-	.198	-
Spur Leaves						
Thinned	1.97	-	.158	-	1.59	-
Unthinned	1.85	-	.152	-	1.71	-
Spur Twigs						
Thinned	.82	-	.162	-	.66	-
Unthinned	.79	-	.148	-	.62	-
Shoot Leaves						
Thinned	2.16	2.58	.202	.258	1.58	2.37
Unthinned	1.90	3.90	.176	.269	1.48	3.19
Shoot Twigs						
Thinned	.90	1.82	.166	.233	.55	1.32
Unthinned	.88	1.83	.136	.235	.48	1.29
Core						
Thinned	.49	.045	.096	.010	.80	.075
Unthinned	.48	.054	.102	.012	.82	.100
Slices						
Thinned	.73	1.00	.130	.175	.84	1.14
Unthinned	.68	1.30	.134	.242	.89	1.67
L.S.D. $p < .05$	.23	ns	.027	ns	ns	ns

Table 4

Effect of Thinning on S, Ca, Mg contents (%) and Partitioning
(g/Kg branch)

	S		Ca		Mg	
	%	g/Kg	%	g/Kg	%	g/Kg
Wood						
Thinned	.11	-	1.08	-	.058	-
Unthinned	.08	-	1.10	-	.06	-
Spur Leaves						
Thinned	.156	-	1.75	-	.342	-
Unthinned	.148	-	1.91	-	.374	-
Spur Twigs						
Thinned	.072	-	1.50	-	.128	-
Unthinned	.08	-	1.84	-	.138	-
Shoot Leaves						
Thinned	.17	.232	1.60	2.52	.352	.550
Unthinned	.15	.320	1.74	3.70	.390	.774
Shoot Twigs						
Thinned	.08	.145	1.41	2.33	.248	.427
Unthinned	.07	.165	1.42	3.10	.252	.560
Core						
Thinned	.064	.006	.086	.008	.056	.005
Unthinned	.062	.007	.078	.009	.052	.006
Slices						
Thinned	.068	.092	.186	.245	.070	.096
Unthinned	.060	.117	.190	.361	.068	.127
L.S.D. $p < .05$	ns	ns	.24	ns	.12	ns

Table 5

Effect of Thinning on Mn, Fe, Cu content (ppm) and
Partitioning (g/Kg branch)

	Mn		Fe		Cu	
	ppm	g/Kg	ppm	g/Kg	ppm	g/Kg
Wood						
Thinned	48.2	-	249	-	480	-
Unthinned	51.0	-	339	-	378	-
Spur Leaves						
Thinned	72	-	249	-	7.4	-
Unthinned	78	-	222	-	7.8	-
Spur Twigs						
Thinned	24	-	69	-	8.2	-
Unthinned	29	-	105	-	13.6	-
Shoot Leaves						
Thinned	96.2	16.80	211	31.08	8.6	11.26
Unthinned	99.2	22.09	202	49.75	8.6	12.92
Shoot Twigs						
Thinned	32.8	9.89	47	13.79	9.0	13.56
Unthinned	29.2	8.06	48	13.06	8.6	15.20
Core						
Thinned	6.2	.058	17	.157	6.8	.645
Unthinned	6.0	.070	17	.204	8	.906
Slices						
Thinned	10.2	1.35	30	4.10	14	18.77
Unthinned	9.8	1.78	28	5.20	20.2	38.03
L.S.D. $p < .05$	ns	ns	ns	ns	ns	ns

Table 6

Effect of Thinning on B, Zn, Al contents (ppm) and
Partitioning (g/Kg branch)

	B		Zn		Al	
	ppm	g/Kg	ppm	g/Kg	ppm	g/Kg
Wood						
Thinned	16	-	184	-	148	-
Unthinned	16	-	173	-	68	-
Spur Leaves						
Thinned	39	-	97	-	194	-
Unthinned	36	-	110	-	194	-
Spur Twigs						
Thinned	25	-	31	-	33	-
Unthinned	22	-	45	-	65	
Shoot Leaves						
Thinned	39	79.2	95	20.5	189	205
Unthinned	31	101.4	114	30.8	151	308
Shoot Twigs						
Thinned	18	60.1	31	9.1	20	91
Unthinned	16	70.2	29	9.0	33	88
Core						
Thinned	34	3.05	9	.084	6	.084
Unthinned	34	4.24	10	.120	6	.120
Slices						
Thinned	42	53.60	15	2.04	11	2.04
Unthinned	43	81.87	21	3.93	10	2.82
L.S.D. p < .05	ns	ns	ns	ns	ns	ns

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APPENDICES

Appendix 1

Effect of Thinning on N Content (%) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	.382	2.31	1.07	.466	2.53	1.34	.398	2.37	1.07
June	-	2.36	0.95	-	2.25	1.00	-	2.54	0.83
July	-	2.39	0.91	-	2.21	0.89	-	2.19	0.86
August	.428	2.16	0.90	.438	2.00	0.64	.438	1.90	0.88
September	.450	1.84	0.81	.496	1.90	0.82	.496	1.81	0.83

Appendix 2

Effect of Thinning on P Content (%) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	.034	.226	.204	.034	.272	.200	.030	.222	.176
June	.032	.206	.188	.030	.188	.160	.036	.170	.144
July	.038	.184	.156	.036	.138	.116	.036	.162	.146
August	.038	.202	.166	.040	.166	.138	.040	.176	.134
September	.036	.178	.140	.038	.156	.130	.036	.132	.108

Appendix 3

Effect of Thinning on K Content (%) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	.174	1.68	.99	.180	1.71	1.14	.168	1.79	1.03
June	.206	1.55	.73	.194	1.47	0.72	.212	1.28	0.53
July	.192	1.94	.76	.188	1.83	.70	.176	1.63	.69
August	.206	1.58	.55	.216	1.44	.47	.198	1.48	.48
September	.194	1.71	.59	.192	1.50	.58	.192	1.53	.59

Appendix 4

Effect of Thinning on S Content (%) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	.076	.130	.082	.096	.144	.150	.078	.136	.076
June	.110	.146	.078	.110	.136	.078	.122	.136	.066
July	.126	.176	.084	.100	.166	.086	.082	.190	.098
August	.112	.168	.082	.106	.154	.076	.104	.154	.072
September	.086	.158	.076	.108	.156	.074	.100	.152	.076

Appendix 5

Effect of Thinning on Ca Content (%) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	1.03	1.08	0.95	1.05	0.98	1.34	0.95	0.95	0.86
June	1.32	1.21	0.85	1.16	1.09	0.86	1.53	0.96	0.69
July	1.41	1.52	1.26	1.38	1.49	1.30	1.15	1.76	1.53
August	1.08	1.60	1.41	1.11	1.62	1.19	1.10	1.74	1.42
September	1.15	1.70	1.26	1.21	1.85	1.30	1:17	1.70	1.40

Appendix 6

Effect of Thinning on Mg Content (%) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	.050	.342	.216	.060	.340	.280	.060	.320	.194
June	.060	.408	.218	.062	.372	.226	.064	.396	.198
July	.056	.406	.238	.068	.388	.258	.058	.422	.260
August	.058	.352	.248	.060	.366	.216	.060	.390	.252
September	.054	.368	.234	.056	.412	.248	.058	.348	.250

Appendix 7

Effect of Thinning on Mn Content (ppm) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	44.4	62.0	22.2	56.8	61.4	27.4	36.8	60.4	22.2
June	63.0	97.6	25.6	55.8	82.6	24.8	53.4	96.6	24.8
July	52.2	126.8	31.2	48.0	90.0	29.0	41.0	94.8	27.8
August	48.2	96.2	32.8	36.6	91.8	28.6	51.0	99.2	29.2
September	50.0	126.6	42.2	75.6	113.6	36.4	58.2	103.6	36.8

Appendix 8

Effect of Thinning on Fe Content (ppm) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	183.2	143.8	47.0	314.4	148.0	85.6	178.4	128.4	47.6
June	222.2	203.0	41.0	275.8	196.2	46.0	375.8	202.6	42.4
July	249.8	242.2	55.4	269.4	192.0	58.8	219.2	235.0	60.2
August	249.2	211.2	47.0	298.2	210.4	43.4	339.6	202.0	48.6
September	343.4	206.0	61.2	445.6	215.2	63.6	407.8	214.8	59.6

Appendix 9

Effect of Thinning on Cu Content (ppm) in Wood and Shoots

	High Thinning			Low Thinning			No Thinning		
Month	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	305.4	11.6	10.8	447.8	13.0	10.0	266.6	13.2	9.8
June	606.4	12.4	10.2	486.6	11.4	8.4	710.4	10.8	8.8
July	705.4	11.6	9.8	490.4	9.4	8.6	280.2	9.6	10.6
August	480.8	8.6	9.0	350.4	8.6	7.8	378.8	8.6	8.6
September	350.4	7.8	9.8	654.0	7.6	8.2	500.8	6.6	7.2

Appendix 10

Effect of Thinning on B Content (ppm) in Wood and Shoots

	High Thinning			Low Thinning			No Thinning		
Month	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	16.8	45.2	28.4	18.6	45.2	32.4	17.4	37.6	24.8
June	24.0	63.4	31.4	16.0	54.8	28.6	22.0	56.4	24.0
July	25.0	59.6	27.4	19.6	52.4	22.2	20.0	47.8	24.4
August	16.2	38.8	18.4	13.6	33.6	16.2	16.6	31.4	16.0
September	21.2	55.4	31.8	29.6	55.0	35.0	24.4	46.8	31.4

Appendix 11

Effect of Thinning on N Content (%) in Wood and Shoots

Month	High Thinning			Low Thinning			No Thinning		
	Wood	Leaves	Twigs	Wood	Leaves	Twigs	Wood	Leaves	Twigs
May	140.2	21.8	23.0	186.2	23.2	28.8	115.4	21.0	19.6
June	242.4	24.4	20.2	229.2	64.6	25.2	248.0	50.4	20.4
July	269.2	172.4	39.4	226.8	137.6	34.0	153.6	213.8	43.2
August	184.8	95.0	31.0	137.0	121.2	28.2	173.0	114.0	29.2
September	170.6	146.2	41.4	293.0	163.4	41.6	209.8	147.2	41.0

Appendix 12

Effect of Thinning on N Composition (%) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	1.114	.962	1.082	.852	1.008	.780
July	.788	.592	.844	.564	.866	.542
August	.490	.732	.506	.680	.478	.682

Appendix 13

Effect of Thinning on P Composition (%) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	.182	.156	.164	.138	.168	.140
July	.136	.122	.114	.098	.132	.110
August	.096	.130	.092	.116	.102	.134

Appendix 14

Effect of Thinning on K Composition (%) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	.978	1.016	1.042	1.058	1.044	1.064
July	.900	.920	.872	.890	1.018	10.12
August	.804	.844	.836	.898	.818	.888

Appendix 15

Effect of Thinning on S Composition (%) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	.104	.014	.094	.096	.096	.096
July	.082	.094	.072	.080	.082	.090
August	.064	.068	.058	.062	.062	.060

Appendix 16

Effect of Thinning on Ca Composition (%) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	.196	.148	.184	.144	.212	.198
July	.186	.100	.188	.102	.194	.110
August	.086	.186	.102	.160	.078	.190

Appendix 17

Effect of Thinning on Mg Composition (%) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	.108	.088	.100	.092	.110	.104
July	.086	.068	.074	.064	.076	.064
August	.056	.070	.056	.064	.052	.068

Appendix 18

Effect of Thinning on Mn Composition (ppm) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	17.2	12.6	13.6	10.8	15.6	12.4
July	13.0	8.6	9.6	6.8	10.4	7.2
August	6.2	10.2	6.4	8.2	6.0	9.8

Appendix 19

Effect of Thinning on Fe Composition (ppm) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	40.8	30.0	38.6	26.0	41.0	27.2
July	34.4	21.2	29.0	21.0	40.8	20.6
August	17.0	30.8	19.6	27.0	17.2	28.0

Appendix 20

Effect of Thinning on Cu Composition (ppm) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	22.2	9.0	23.2	8.4	21.6	9.6
July	18.0	9.2	16.4	7.0	23.6	8.6
August	6.8	14.0	7.4	10.2	8.0	20.2

Appendix 21

Effect of Thinning on B Composition (ppm) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	38.6	35.2	40.8	36.2	36.8	34.6
July	40.6	34.6	42.2	34.0	48.8	41.8
August	33.8	41.8	34.0	40.0	33.8	42.6

Appendix 22

Effect of Thinning on Zn Composition (ppm) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	21.0	11.6	23.0	12.2	19.8	11.4
July	19.6	11.8	17.2	11.0	28.0	12.0
August	9.0	15.4	9.2	12.2	10.2	21.0

Appendix 23

Effect of Thinning on Al Composition (ppm) in Fruits

Month	High Thinning		Low Thinning		No Thinning	
	Core	Slices	Core	Slices	Core	Slices
June	10.0	4.9	8.2	4.2	9.4	5.6
July	8.0	4.2	8.6	5.4	8.6	4.4
August	5.8	10.6	6.4	8.8	6.4	10.0

Appendix 24

Partitioning of dry matter (grams dry weight/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	159.46	156.61	213.45
Shoot Twigs	163.43	140.18	217.85
Core	9.44	16.03	11.81
Slices	134.02	221.43	189.84
Total	466	534	630

Appendix 25

Partitioning of N (grams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	2.58	2.43	3.90
Shoot Twigs	1.62	1.48	1.83
Core	.045	.078	.054
Slices	1.001	1.666	1.295
Total	5.24	5.65	7.07

Appendix 26

Partitioning of P (grams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	.258	.377	.269
Shoot Twigs	.233	.393	.235
Core	.01	.013	.012
Slices	.175	.255	.242
Total	.509	1.038	.758

Appendix 27

Partitioning of K (grams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	2.37	1.93	3.19
Shoot Twigs	1.32	.99	1.29
Core	.078	.131	.100
Slices	1.14	1.95	1.67
Total	4.9	5.0	6.25

Appendix 28

Partitioning of S (grams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	.232	.214	.320
Shoot Twigs	.145	.129	.165
Core	.006	.010	.007
Slices	.092	.147	.117
Total	.475	.500	.609

Appendix 29

Partitioning of Ca (grams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	2.52	2.57	3.7
Shoot Twigs	2.33	2.03	3.10
Core	.008	.014	.009
Slices	.245	.381	.361
Total	5.1	4.9	7.17

Appendix 30

Partitioning of Mg (grams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	.550	.567	.774
Shoot Twigs	.427	.365	.560
Core	.005	.008	.006
Slices	.096	.148	.127
Total	1.08	1.09	1.47

Appendix 31

Partitioning of Mn (grams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	16.8	15.3	22.09
Shoot Twigs	9.89	7.12	8.06
Core	.058	.091	.070
Slices	1.35	2.05	1.78
Total	28.1	24.56	32.0

Appendix 32

Partitioning of Fe (milligrams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	31.08	26.10	49.65
Shoot Twigs	13.79	11.46	13.06
Core	.204	.290	.157
Slices	4.10	6.83	5.20
Total	49.12	44.68	68.11

Appendix 33

Partitioning of Cu (milligrams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	11.26	11.51	12.92
Shoot Twigs	13.56	11.10	15.2
Core	.645	.975	.906
Slices	18.77	24.09	38.03
Total	44.23	47.67	67.06

Appendix 34

Partitioning of B (milligrams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	79.2	73.6	101.4
Shoot Twigs	60.1	51.7	70.2
Core	3.05	5.24	4.24
Slices	53.6	93.06	81.87
Total	195.95	223.6	257.7

Appendix 35

Partitioning of Zn (milligrams/Kg branch dry weight)

	High Thinning	Low Thinning	No Thinning
Shoot Leaves	20.5	20.8	30.8
Shoot Twigs	91.1	8.9	9.0
Core	.084	.129	.120
Slices	2.04	2.82	3.93
Total	31.72	32.15	43.85

Appendix 36

Effect of Thinning on N and P Content (%) in Spurs

Month		High Thinning N	High Thinning P	Low Thinning N	Low Thinning P	No Thinning N	No Thinning P
June	Spur Leaves	2.44	.148	2.53	.160	2.27	.136
	Spur Twigs	1.50	.216	1.88	.272	1.26	.174
July	Spur Leaves	1.93	.162	2.07	.120	1.8	.136
	Spur Twigs	1.43	.194	1.24	.148	1.22	.174
August	Spur Leaves	1.97	.158	1.96	.136	1.85	.152
	Spur Twigs	.82	.162	.83	.142	.79	.148

Appendix 37

Effect of Thinning on K and S Content (%) in Spurs

Month		High Thinning		Low Thinning		No Thinning	
		K	S	K	S	K	S
June	Spur Leaves	1.93	.132	2.02	.128	2.15	.126
	Spur Twigs	1.08	.084	1.30	.096	1.04	.070
July	Spur Leaves	1.79	.182	1.79	.156	1.98	.166
	Spur Twigs	.99	.096	.95	.086	1.06	.096
August	Spur Leaves	1.59	.156	1.50	.146	1.71	.148
	Spur Twigs	.66	.072	.68	.082	.62	.080

Appendix 38

Effect of Thinning on Ca and Mg Content (%) in Spurs

Month		High Thinning		Low Thinning		No Thinning	
		Ca	Mg	Ca	Mg	Ca	Mg
June	Spur Leaves	1.53	.414	1.40	.384	1.58	.384
	Spur Twigs	1.50	.156	1.42	.186	1.43	.140
July	Spur Leaves	1.84	.396	1.89	.384	2.00	.328
	Spur Twigs	1.62	.170	1.69	.140	1.72	.138
August	Spur Leaves	1.75	.342	1.92	.362	1.91	.374
	Spur Twigs	1.50	.128	1.79	.132	1.84	.138

Appendix 39

Effect of Thinning on Mn and Fe Content (ppm) in Spurs

Month		High Thinning		Low Thinning		No Thinning	
		Mn	Fe	Mn	Fe	Mn	Fe
June	Spur Leaves	89.0	293.4	81.2	246.4	67.2	284.8
	Spur Twigs	31.8	67.8	30.8	57.8	24.4	50.8
July	Spur Leaves	99.8	238.2	70.2	214.0	74.6	234.6
	Spur Twigs	34.2	63.6	23.8	62.4	27.0	90.8
August	Spur Leaves	72.0	249.4	69.2	246.6	78.2	222.4
	Spur Twigs	24.4	69.9	26.4	106.0	28.6	105.0

Appendix 40

Effect of Thinning on Cu and B Content (ppm) in Spurs

Month		High Thinning		Low Thinning		No Thinning	
		Cu	B	Cu	B	Cu	B
June	Spur Leaves	9.60	50.20	10.20	42.80	8.80	49.0
	Spur Twigs	11.60	37.40	11.60	38.80	9.20	32.0
July	Spur Leaves	8.60	50.40	8.40	50.00	8.40	55.20
	Spur Twigs	11.80	32.40	8.40	32.60	9.60	32.40
August	Spur Leaves	7.40	39.40	7.80	41.00	7.80	36.40
	Spur Twigs	8.20	25.20	13.00	27.00	13.60	22.40

Appendix 41

Effect of Thinning on Zn and Al Content (ppm) in Spurs

Month		High Thinning		Low Thinning		No Thinning	
		Zn	Al	Zn	Al	Zn	Al
June	Spur Leaves	18.6	224.6	21.2	188.6	36.6	234.6
	Spur Twigs	28.4	34.6	30.4	27.2	25.8	22.0
July	Spur Leaves	126.2	181.0	99.0	172.6	125.8	183.0
	Spur Twigs	44.2	30.2	33.8	33.4	39.4	49.8
August	Spur Leaves	96.8	194.6	104.2	195.4	110.6	194.4
	Spur Twigs	31.2	33.6	40.4	61.2	45.2	64.8

Appendix 42

Effect of Thinning on Fruit Size

Replicates

Treatments	1	2	3	4	5	Average
High Thinning	184.41	224.36	243.36	221.52	236.00	221.93
Low Thinning	216.48	234.71	230.59	235.88	208.57	225.25
No Thinning	222.59	241.05	215.10	237.63	206.89	224.65