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A crop load study on 'Nittany' apple on two size-controlling rootstocks.

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A Crop Load Study on 'Nittany' Apple on Two Size Controlling Rootstocks

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ABSTRACT

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A field study was conducted on the apple cultivar 'Nittany' on M.9 and M.26 rootstocks. Four crop load treatments levels: an unthinned check, 7.5, 5.0, and 2.5 fruit per centimeter trunk cross-sectional area (TCSA) were imposed on replicated trees of each rootstock to determine the effects on shoot growth and fruit size.

Average terminal and bourse shoot growth were greater for the M.26 rootstock than the M.9 rootstock. Crop load levels had no significant effect on shoot growth. Thinning fruit to the 2.5 fruit/cm2 TCSA level showed the most consistent results in fruit diameter, length, and weight.

Fruit size as determined by fruit weight, diameter, and length increased as crop load decreased. There was no significant difference between rootstocks. All fruit from crop load treatments were significantly larger than fruit from the unthinned check. Average fruit diameter, length, and weight were greater on M.9 rootstock than on M.26 rootstock.

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Introduction

Crop load, sometimes described as crop density, is a measure of an individual tree's cropping level. It is based on the number of fruit per square centimeter of trunk cross-sectional area.

The apple industry is under increasing pressure to increase fruit size to satisfy consumer demands. Commercial use of dwarfing rootstocks and their tendency to over crop further complicate the sizing problem. The early production and the growth control that these rootstocks provide make them a popular choice. Early fruiting, while a benefit, can also be a detriment. The crop load must be kept in balance with shoot growth to prevent "runting out" of the tree in early production years, while allowing the tree to develop sufficient framework to support a commercially acceptable crop.

The objective of this study was to establish different crop load levels on two dwarfing rootstocks, Malling 9 (M.9) and Malling 26 (M.26), and to determine how the crop load levels affect tree vegetative and bourse shoot growth, subsequent cropping, and fruit size. The results could be used to determine an optimum crop load based on rootstock.

Literature Review

Crop load, a quantitative parameter used by industry, is generally defined as the number of fruit per tree. It is often expressed in terms of number of fruit per trunk cross-sectional area (fruit/TCSA). Jones et al. (1992) described crop load as the number of fruit per 100 blossom clusters.

Crop load on a tree has been described as light (125 fruit/tree) or normal (300 fruit/tree) on M.26 rootstock by Franceseoni et al. (1996). Crop load was expressed later in this study in terms of fruit/TCSA because of some variation in tree size.

Crop load has been studied for individual cultivars. A mean fruit weight of 150 grams for 'Golden Delicious' was achieved by thinning to 30-50 fruit per 100 blossom clusters (Williams and Edgerton 1981; Jones et al. 1984; Koen and Jones 1985); this corresponds to 1.5 - 2.0 fruit per cm2 trunk area (fruit/TCSA) (Jones and Koen 1986; Jones et al. 1988a). Targets for 'Red Delicious' have been similar but slightly higher at 40-60 fruit per 100 blossom clusters and 2 to 4 fruit per cm2 trunk area (TCSA) (Koen et al. 1988; Jones et al. 1988b).

Crop load is the most important of all factors that influence fruit size, and the removing of a part of the crop is the most effective way to improve fruit size (Forshey, 1976). In a normal year, a tree setting 10% of its blossoms will have a full crop load (Williams and Edgerton, 1981). Overcropping results in a very poor fruit weight and size (Jones et al., 1992). Overcropping could have more far-reaching effects than poor performance at harvest. Stebbins (1989) showed that overcropping (7 - 13 fruit per cm2 cross-sectional area) in 10 apple cultivars led to a poor crop the next year.

Apple fruit size has always been a critical factor in determining market value. Early removal of fruit results in larger fruit size at harvest (Preston and Quinlan, 1968; Quinlan and Preston, 1968; Jones et al., 1992)
The potential size of a given pome fruit is determined early in the season and growth proceeds at a relatively uniform rate thereafter (Forshey and Elfving, 1977).

Batjer (1965) suggested that the increase in fruit size was roughly proportional to the degree of thinning. However, studies have shown the increase in fruit size was proportionately less than the reduction in fruit set (Batjer and Thomson, 1961; Rogers and Thompson, 1969) or in the number of fruits/tree (Southwick and Weeks, 1949a; Way, 1965). The close relationship between fruit numbers and yield regardless of tree size, clearly indicates that this is the dominant factor contributing towards economic yield. A negative correlation between fruit size and fruit numbers exists because the major objective of fruit thinning is an increase in fruit size (Forshey and Elfving, 1977).

Previous results with many cultivars (Batjer and Thomson, 1961; Batjer and Westwood, 1960; Rogers and Thompson, 1969; Southwick and Weeks, 1949b; Way, 1965) demonstrated that increases in fruit size were proportionately less than the reduction in fruit numbers. The primary effect of fruit thinning on fruit size is more often a reduction in the number of smaller fruits than a dramatic increase in the size of the remaining fruits (Forshey and Elfving, 1977).

The potential size of a given pome fruit is determined early in the season and growth proceeds at a relatively uniform rate thereafter. This uniform growth rate permits the accurate prediction of the harvest size of the fruit as early as mid-summer (Batjer et al., 1957). The growth rate, once established, is not easily altered, and fruit numbers, therefore, can affect fruit size only within definite limits and maximum effectiveness requires adjustment in fruit numbers relatively early in the season (Forshey and Elfving, 1977). Tukey (1970) states, “thinning does not change a potentially small fruit into a large fruit, but rather insures that a potentially large fruit will size properly.” Emphasis should be on estimating fruit numbers rather than fruit size. Fruit thinning can quickly reach the point of diminishing returns. Rather than a high percentage of large fruits, the objectives of thinning should be the elimination of the smallest fruits, improved fruit quality and annual production (Forshey and Elfving, 1977).

Fruit thinning is accomplished by hand or chemical thinning. Chemical thinners are separated into categories as bloom thinners and post-bloom thinners. Early removal of potential fruit (blossom thinning) is currently used in many apple producing areas to enhance flower initiation for next year’s crop and thus, return bloom (Fallahi, 1997a; Fallahi et al., 1997). It also results in reduced competition for photosynthates. Blossom thinners usually have a caustic effect on floral parts.

The practice of post-bloom thinning, which generally occurs at the 3-18 mm fruit size stage, is used to promote return bloom, as well as to regulate crop load. Fruit removal which occurs after the period of flower initiation (30 to 40 days after full bloom) will affect crop load only (Williams,1999). For this reason, hand thinning is used to balance crop load and to improve fruit size, rather than influence flower initiation.

The use of napthalene acetic acid (NAA), a synthetic auxin gained acceptance in the 1950's and 1960's. Another synthetic auxin, napthalene-acetamide (NAD), was found to be suitable for post-bloom thinning of many commercial apple varieties (Westwood and Batjer, 1960). In the 1960's carbaryl (Sevin), a commonly used insecticide was introduced as a post-bloom thinner (Williams, 1994a). In the 1970's combinations of carbaryl and NAA, or carbaryl and NAD, were adopted as commercially acceptable post- bloom thinning sprays. Also, in the 1970's most of the other plant bioregulators such as gibberellins, cytokinins, and ethylene were tested. In the 1980's, synthetic cytokinins such as 6-benzyladenine were used in chemical thinning experiments.

The mode of action of the post-bloom thinning chemicals is not entirely known. They are generally believed to interfere with the endogenous hormones that control the flow of nutrients to the developing fruit which leads to embryo abortion and fruit abscission (Williams and Edgerton, 1981).

<u>Factors that influence thinning response:</u>

Tree vigor is a major factor in thinning response. The physiological or growth status of the tree affects results with thinning sprays (Williams and Edgerton, 1981) The influence of spur vigor was illustrated by a positive correlation between bud diameter and resistance to action of NAA (Southwick and Weeks, 1949b).

Young trees are more easily thinned than older trees with established bearing habits. This response of young trees to thinning sprays is perhaps related to their more rapid vegetative growth and a consequent reduction in carbohydrate and other reserves available to the young, developing fruit in the early post-bloom period (Williams and Edgerton, 1981).

Cool, wet weather either before or after application will precondition the leaves and increase chemical absorption of all thinning agents. Absorption efficiency is influenced in part by the physiological status of the plant and particularly by the cuticle, which is considered a major barrier to absorption (Williams and Edgerton, 1981).

Environmental factors such as humidity, affect both thickness and composition of plant leaf cuticle (Lee and Priestly, 1924). Factors such as temperature and light further complicate post-bloom thinning. If cool, cloudy weather predominates during the fall, carbohydrate reserves may be reduced for the next spring (Byers et al., 1990). If temperatures are warm during bloom, carbohydrate reserves are used at a faster rate than if temeratures are cool. With fewer reserves available to both vegetative and fruit growth, fruit set and thus, yield may be reduced (Robinson et al., 1998; Williams and Edgerton, 1981).

Trees in low vigor are easy to thin or overthin, but adequate thinning of such trees does not necessarily result in good fruit size or in adequate repeat bloom. Low vigor is often due to inadequate nitrogen fertilizer (Forshey, 1976).

Light exposure also affects thinning responses. Heavily shaded wood, whether on lower branches that have been over-grown by the tops, or in the interior of dense, inadequately pruned trees, is easily over-thinned (Forshey, 1976).

An excessive crop reduces tree vigor the following season and at the same time increases susceptibility to thinning. Strongly biennial varieties are easier to thin in the "off" year (following a heavy crop) than in the "on" year (following a light crop) (Forshey, 1976).

Trees cropped heavily the previous year are more easily thinned. The amount of bloom on the tree affects the thinning response. Trees with heavy bloom are more susceptible to chemical treatments than trees with light bloom. Generally, when bloom is light, fruit set per spur is heavy, and the effect of chemical thinning reduced (Williams and Edgerton, 1981).

Prolonged soil moisture deficits can also affect tree vigor, fruit set, and the response to thinning the following year. Moisture stress of sufficient severity to induce wilting for 2-3 weeks will be reflected in increased effectiveness of thinning sprays (Forshey, 1976).

Nutritional factors affecting cropping and tree growth:

Regular cropping can be influenced by the nutrition management of the orchard. This management has an effect on the cropping cycle of the trees. The nutritional elements that affect cropping consist of major and minor elements. The three major elements include nitrogen, phosphorus, and potassium. The minor elements include magnesium, boron, manganese, zinc, and copper. Nitrogen has both direct and indirect effects on the regularity of cropping. The direct effects include flower initiation (Tami et. al., 1986) and development, length of the period of ovule receptivity, and fruit set (Williams, 1965). The indirect effects of nitrogen are those related to vigor of trees as indicated by shoot and spur growth, and leaf area to support photosynthesis and the production of carbohydrate reserves (Boynton and Anderson, 1956; Magness et al., 1948; Rogers and Thompson, 1962).

A deficiency of nitrogen (less than 1.5% in mid-summer shoot leaves) may prevent flower bud formation (Stiles, 1999). High nitrogen levels (more than 2.4%) can be associated with excessive vegetative growth and poor flower bud initiation in shaded interior portions of the trees (Stiles, 1999).

Tami et al. (1986) found that leaf nitrogen levels were positively correlated with percent floral buds and with fruit yield in the second year of soil applications of urea to ten-year-old ‘Starkspur Golden Delicious’ trees. In the first year, fruit set was increased 11% by the urea treatment. Floral bud initiation during the second year of treatment was increased 7%. Crop density (fruit per limb cross-sectional area) was increased both years but not at statistically significant levels.

Fallahi (1997b) observed lower yields of ‘Red Spur Delicious’ from trees that had recieved low annual nitrogen (45.3 g/tree) applications, but no significant differences in yields among trees that relieved nitrogen at 181.4 to 589.6 g/tree.

Current recommendations for nitrogen management include an application of a prebloom urea spray when the previous season analysis shows leaf nitrogen values of less than 2.4% (Stiles and Reid, 1991).

Phosphorus applications to established orchards have not resulted in a significant increase in cropping. Neilson et al. (1990) found that application of monoammonium phosphate (MAP) in the year of planting increased leaf phosphorus levels, blossoming and fruit set in the next year on trees planted in non-replant soil. In field trials in eight replant orchards, only one orchard had increased yield by the end of the third growing season (Neilsen, 1994).

Potassium affects cropping indirectly through effects on tree vigor. In a fertigation study (Stiles, 1998) trees established in 1993 and deblossomed during the first two seasons showed a significant increase in shoot growth in response to potassium. Yields during the first three cropping seasons were related positively with shoot growth during the first two growing seasons. The lowest rate of potassium used in this trial, 33.2 lbs./A (42 kg/ha) per year met requirements in terms of shoot growth, yield, and maintaining leaf potassium at the desired range of 1.35% to 1.80%. Potassium requirement is directly related to crop load. It is expected for this level to increase as the tree matures (Stiles, 1998).

Magnesium has both direct and indirect effects. Magnesium deficiency results in reduced vigor of shoots and spurs tend to be thin, weak, and brittle (Boynton and Oberly, 1966). Flowering may be reduced if excessive leaf drop occurs early in the season. Fisher et al. (1958) reported increased yield over four years after correcting magnesium deficiency with applications of dolomitic limestone. Greenham and White (1959) showed that post bloom Epsom salts (MgSO4.7H20) sprays applied to magnesium deficient 'Edward VII'/Malling 7 trees over a five year period did not increase the number of fruit buds produced but did improve fruit set set by an average of 68%. Crop production per tree increased significantly in two of the five years, and the total crop for the five year period was 80% greater with the Epsom salts sprays. Adequate magnesium levels occur between .35% to .50% and/or a potassium to magnesium ratio smaller than 4:1 in leaf samples collected 60 to 70 days after petal fall (Stiles and Reid, 1991).

Boron affects cropping in several ways. Boron deficiency has been shown to result in reduced flowering; abnormal development of flowers; reduced pollen tube development and germination; and severe reduction in fruit set. Severe boron deficiency results in death of meristematic tissues and poor development of conducting tissues (Stiles and Reid, 1991).

Reports indicate beneficial effects of foliar applications of boron, either postharvest or before bloom, in increasing fruit set of apples. Davison (1971) reported increases in fruit set of 6% to 29% in 11 trials when boron sprays were applied at open cluster (pink) and again at 80% to 100% petal fall.

Midsummer leaf sample contents of 35 to 50 ppm (mg.L-1) boron are considered to be adequate (Stiles and Reid, 1991). Woodbridge et al. (1971) found relatively high levels of boron in developing buds of apple, pear (Pyrus communis L.), and cherry (Prunus avium L.). They reported that both total boron per bud and concentration of boron on a dry weight basis gradually increased as buds enlarged and rapidly increased as the flowers opened to full bloom. The levels reached their maximum when pollination and fertilization occurred and the total boron decreased significantly at petal fall.

Boron toxicity can cause abnormal flower development and reduced cropping. Hansen (1981) found excessive boron to result in delayed development of buds and bloom, reduced blossom density, and reduced yields.

Mild deficiencies of manganese do not appear to influence cropping (Stiles, 1999). Maintaining a midsummer leaf content of at least 35 to 150 ppm (mg.L-1) manganese should minimize the possibility of manganese deficiency (Stiles and Reid, 1991).

Flowering and cropping are reduced by zinc deficiency and may be eliminated under severe deficiency (Stiles and Reid, 1991). Zinc deficiency reduces growth and general tree vigor and if severe can result in die back of shoots or limbs. This effect is often not uniform throughout the tree but may be more severe on individual limbs than on others. There is always a reduction in the number of flower buds on severely effected trees (Chandler, 1937). Average yield of ‘McIntosh’ trees, over a three year period, was increased 30% by receiving annual mid-June foliar sprays of EDTA-zinc chelate. A single application of EDTA-zinc at the pink stage increased yield of ‘McIntosh’ by 17% over a two year period (Stiles,1980).

Neilson (1988) showed that mid-shoot leaf zinc levels declined from a high of 40 ppm (mg.L-1) in early May to values approaching or below 14 ppm (mg.L-1) by midsummer. Thus, one of the difficulties in assessing zinc status is determining when to sample (Stiles, 1999).

Copper deficient trees may exhibit poor shoot growth or die back of shoots, reduced bloom, and poor fruit set (Stiles and Reid, 1991). Copper levels in bud tissues may be fairly high at the beginning of growth, but the level in leaf tissues declines rapidly as growth proceeds (Stiles, 1999). Experiments suggest a midsummer leaf level of 7 to 12 ppm (mg.L-1) to be optimal (Stiles and Reid, 1991).

Biennial bearing/return bloom:

Seeds contain relatively high concentrations of gibberellic acids (Luckwill et al., 1969), and Luckwill (1970) proposed that gibberellic acids from the seeds diffuse to the bourse shoot, where they inhibit flowering.

The most popular hypothesis to explain the effects of seeds on flowering is that seeds, being rich sources of hormones, export these compounds to the bourse bud, thus inhibiting flowering (Dennis and Neilson,1999). Direct evidence for this mechanism has yet to be obtained. A second hypothesis, which appears to be just as feasible, is that seeds compete with other plant tissues for a compound (florigen), produced by the leaves, that promote flowering (Dennis and Neilson, 1999). This reduces the quantity available for flower induction. A possible candidate for this promoter is cytokinin.

Hand thinning 'York'/M.26 trees at bloom by removal of 2/3 of the flower clusters or by hand thinning weekly up to 61 days after bloom did not provide adequate return bloom for even a partial crop the next year (Byers, 1999). Trees with a moderate level of flowering were more likely to give an adequate return bloom than if trees had near 100% of the spurs flowering and thinned at bloom or shortly thereafter (Byers, 1999).

Trees usually bear on alternate years because fruit set is excessive during the "on year". When the quantity of fruit on the tree in relation to the amount of foliage is excessive, fruit bud formation is reduced or entirely prevented. Thus, in the season following the "on year" the reduction in bloom results in a short crop; then under the conditions in the "off year", too many fruit buds form. Once begun, such a fruiting pattern tends to become established (Williams and Edgerton, 1981).

Perhaps the most outstanding feature of chemical thinning sprays is their effect on alternate bearing. These sprays reduce fruit set relatively early in the growing season, and the tree forms more fruit buds for the next year's crop (Williams and Edgerton, 1981).

Final Crop Load:

The amount of fruit left on a tree should be determined by the vigor and general condition of the tree. Leaf area per fruit affects the number of spurs flowering the following season (Harley et al., 1957; Williams and Edgerton, 1981). It can be difficult to separate timing and fruit number effects in crop loading studies, as abscission rates after hand thinning of retained flowers/fruitlets tend to very with the time of hand thinning (Palmer and Adams, 1996).

Crop load effects on fruit, fruiting, fruit quality, and vegetative growth:

Crop load affects fruit size of apples (Assaf et al., 1982; Erf and Proctor, 1987; Forshey and Elfving, 1989). A reduction in fruit numbers is associated with increased fruit growth. The primary effect of fruit thinning on fruit size is more often a reduction in the number of smaller fruits than a dramatic increase in the size of the remaining fruit (Forshey and Elfving, 1977). Reducing the number of fruits per tree will inevitably increase the leaf area per fruit, resulting in an increase in the availability of assimilates to the remaining fruitlets (Palmer et al., 1991).

Light-cropping apple trees tend to bear fruit that are more susceptible to storage disorders, such as bitter pit, than are fruit from medium to heavy cropping trees (Ferguson and Watkins, 1989). A heavy crop load being defined as 120-130 kg of fruit per tree, and a light crop load being defined as 80-90 kg of fruit per tree. Large fruit are more susceptible to bitter pit since they tend to have a lower calcium concentrations (Ferguson and Triggs, 1990).

Although vegetative growth may be stimulated by crop removal, naturally light-cropping trees may have less shoot growth than heavy-cropping trees (Forshey and Elfving, 1989). Light cropping and thinned trees have less flower bud density and greater fruit set than the heavy-cropped trees (Voltz et al., 1993).

When fruit numbers or crop load are reduced by thinning, the leaf/fruit ratio is improved, but a portion of any resultant increase in the supply of metabolites is diverted into vegetative growth (Forshey and Elfving, 1977).

When spurs with fruit of similar size at the end of the season were compared, those with lighter crop loads had greater primary and bourse leaf areas than those from heavier crop load treatments (Voltz et al., 1993).

Fruit from heavily cropped trees has been shown to have higher calcium and magnesium content, and lower potassium content than fruit from light cropped trees. Fruit from light cropped treatments had a higher incidence of internal breakdown after storage (Voltz et al., 1993).

Reducing crop load has been shown to increase fruit firmness at harvest. The greatest increase in fruit firmness at harvest was achieved by thinning during the period from five to fifteen days after full bloom with no increase when thinned at twenty-five days after full bloom for ‘Cox’s Orange Pippin’ (Johnson, 1994).

Increased crop load affects the dry-matter production of the tree. Increasing the fruit load on apple trees increased dry-matter production per leaf unit area and the amount of dry-matter partitioned into the crop (Palmer, 1992).

It is important that the crop load be evenly distributed throughout the tree. Flower clusters were removed at full bloom from ten year old ‘Cox’s Orange Pippin’ trees on M.9 rootstock, over the whole tree, on alternate branches or on a complete side of the canopy. Mean fruit weight per tree at harvest was linearly dependent on leaf area per fruit (Palmer et at., 1991). Treatments caused no overall effects on shoot growth or leaf area per side of canopy. Those sides of trees without fruit had greater leaf area and shoot growth than did sides bearing fruit (Palmer et al., 1991). Webb et al. (1980) found that the mean fruit weight of ‘Golden Delicious’ was not affected by fruit number per spur or fruit number per branch. They concluded that as a determinant of fruit size, fruit number should be considered on a whole tree basis. Hansen (1977) also reported that mean fruit size was not influenced by the number of fruit per spur.

Trees with a heavy crop load have fruit that is more dense than those with a lighter crop load. Fruit density, resulting from differences in intercellular air space, was greater in small than large fruits. Small fruits usually contain fewer and smaller cells than large fruits (Westwood et al., 1966).

The rootstock has a major effect on crop load. Apple rootstock genotypes produce large differences in tree size, precocity, yield, and yield efficiency (Elfving and McKibbon, 1991; NC 140 Cooperators, 1996).

Materials and Methods

I. Selection of Trees

Apple trees used were of the 'Nittany' cultivar located in two different blocks on Uphill Orchards in Berkeley County, seven miles west of Martinsburg, West Virginia. One group of 20 trees was seven-years-old and on Malling 9 (M.9) rootstock. A second group of 20 trees was six- year-old trees on Malling 26 (M.26) rootstock.

The soil type is classified as a Laidig gravelly loam. Trickle irrigation was available and used uniformly during times of low precipitation. A ground cover of Kentucky-31 fescue was established between rows. Herbicide, pesticide, and fertilizer programs recommended by the WVU Extension Service were uniformly followed in the test plot. The trees were planted 2.4 meters by 4.2 meters (8' X 14') in a north-south orientation and trained to a three wire trellis.

II. Treatments

Trunk circumference of individual trees was measured 30 cm above the graft union prior to assigning treatments. Trees were blocked into five groups based on trunk size. Each group consisted of four trees having similar circumference. The average circumference of each group on M.9 rootstock was as follows: Group 1) 17.9 cm, 2) 19.9 cm, 3) 21.4 cm, 4) 22.6cm, 5) 23.8 cm.

The average circumference of each group on M.26 was as follows: Group 1) 19.8 cm, 2) 22cm, 3) 23.9cm, 4) 24.5cm, 5) 26cm. Each tree in this group was randomly selected to receive one of four crop load treatments based on the number of fruit per square centimeter TCSA (Fig. 1). The four crop load levels based on TCSA were as follows: 1) unthinned, 2) 7.5 fruit/cm2, 3) 5 fruit/cm2, 4) 2.5 fruit/cm2.

A different group of 20 trees for each rootstock was used for each year of this study. ‘Nittany’ is a seedling selected from a group of open pollenated ‘York’ collected in 1962 and planted at the West Virginia Experiment Farm in Kearneysville, West Virginia. It has a tendency toward biennial bearing (Stouffer, et al., 1978). The ‘Nittany’ trees used in this study exhibited biennial bearing thus requiring the use of separate groups for the two-year study.

Blossom clusters were counted on all the trees at 50% bloom. All blossom clusters were counted, including those developing on one year wood. A blossom cluster consisted of the king blossom and all lateral blossoms that occurred in that cluster. Blossom clusters were again counted the following year on the same trees to determine the affect of the crop load levels on return bloom.

Crop load treatments were randomly selected and the level was achieved by hand thinning the respective tree to its assigned crop load level. Trees were thinned approximately four weeks after full bloom as close to their respective levels as possible. After June drop, the trees were given a final hand thinning to establish the desired crop level, approximately six weeks after bloom.

III. Preharvest Analyses

Terminal shoot growth and bourse shoot length was measured on ten randomly chosen shoots of each type, divided evenly between the east and west sides of the trees. Growth was measured after June drop and terminal bud set.

IV. Harvest Analyses

At harvest fruit was randomly picked from the tree and placed into cardboard bushel boxes. The boxes were tared and weighed. Total weight of fruit was measured in kilograms.

The total number of fruit on each tree was counted. Fruit samples were randomly chosen from various boxes for each tree sample. Five samples of ten apples each were selected from each individual tree within the treatments.

The ten apple samples were measured in a wooden measuring trough constructed of wood with a meter stick located in the bottom. This device was built specifically to measure the size of a multiple fruit sample (Fig. 20). With the aide of the trough measuring device, the total length (vertical position) and diameter (horizontal position) of a composite ten apple sample could be measured.

V. Data Analyses

All data was analyzed using a SAS PROC GLM program. The different treatments were compared using three orthogonal comparisons: 1) the three crop loads compared to the unthinned check, 2) the linear effect of the three crop load treatments, and 3) the quadratic effect of the three crop load treatments.

VI. Measuring Methods Study

A study investigating the different methods of measuring apple diameters was examined in greater detail. The purpose of this study was to compare the various methods available for measuring individual apple fruit diameters. The measuring trough device used in this project was compared to a digital caliper (Plasti-cal Digital Caliper, Forestry Suppliers, Jackson, MS) and to a band-type fruit gauge (Cranston Machinery Co., Oak Grove, OR).

The Cranston fruit gauge is specifically designed to measure fruit diameter. It has been considered the standard method for a number of years, and it is considered the most accurate device because it surrounds the fruit and incorporates the irregular shape of the fruit. The band circumferences the fruit but is scaled to give the reading as diameter. The other two methods only contact two sides of each fruit and therefore may not be as accurate.

Five groups of ten apples each on each rootstock were measured in sequence using all three methods on each apple. The measurements were recorded and compared using SAS PROC GLM programs to compare the means and the PROC VAR CAMP programs to estimate both tree-to-tree variance and sample-to-sample variance.

Figure 1. Diagram of experimental plots.

M.9 plot -> N X- trees not used in study
year 1
X X X X 5 X 7 8 9 10 11 12 13 14 X X 17 18 X 20 X
X 23 24 X X X X 29 30 31 32 X X X 36 37 X X X X X

M.26 plot
year 1
1 2 3 X 4 X 6 X X 8 X X X X X X X X X 14 X 16 17
X X 19 20 21 22 X X X 25 26 X 27 X X X 30 31 X 32 X 34 X

M.9 plot
year 2
X 1 2 X X X 3 4 5 6 7 X 8 X X 9 10 X X X X
X 11 12 13 X X X X X X X X X X X X 14 X X X X
15 X 16 X X X 17 18 19 20 X X X 21 22 X X X X 23 24

M.26 plot
year 2
X X X X X X X X 1 X X 2 3 4 X X 5 X 6 7 8 9 X 10 11
12 X 13 X X 14 X 15 16 X 17 X 18 19 X X 20 X X X X X X 21 22

thinning treatments corresponding to tree numbers:

Year 1

	M.9	M.26
unthinned	5,7,9,10,12	8,16,17,25,26
7.5 fruit/cm2	24,29,31,32,37	2,3,14,27,30
5.0 fruit/cm2	13,14,18,20,30	4,19,21,22,31
2.5 fruit/cm2	8,11,17,23,36	1,6,20,32,34

Year 2

	M.9	M.26
unthinned	2,9,12,18,20	1,3,8,11,22
7.5 fruit/cm2	1,4,13,15,23	2,10,16,17,19
5.0 fruit/cm2	5,10,16,17,21	4,7,9,12,18
2.5 fruit/cm2	3,8,11,14,19	5,6,14,15,2

Results

Growing Season 1997

I. Terminal Shoot Growth

Mean length of shoots was greater for M.26 than M.9 rootstock for all crop load treatments (Figure 2). Terminal shoot growth was not consistently affected by crop load treatments on either rootstock.

II. Bourse Shoot Growth

Mean length of bourse shoots was greater on M.26 than M.9. Crop load did not have a consistent effect on bourse shoot length (Figure 3).

III. Fruit Number and Weight

As the crop load level decreased, the mean total fruit number and total fruit weight decreased (Figures 4 and 5). The difference between the control (non-thinned check) and the average of the three crop load treatments is greater for M.9 rootstock than the M.26. There is insufficient statistical evidence that the crop load treatment means were affected by either rootstock.

Figure 2. Terminal shoot growth of 'Nittany' apple trees as affected by cropload treatments on M.9 and M.26 rootstocks in 1997. (S.E. +/- 1.55.)

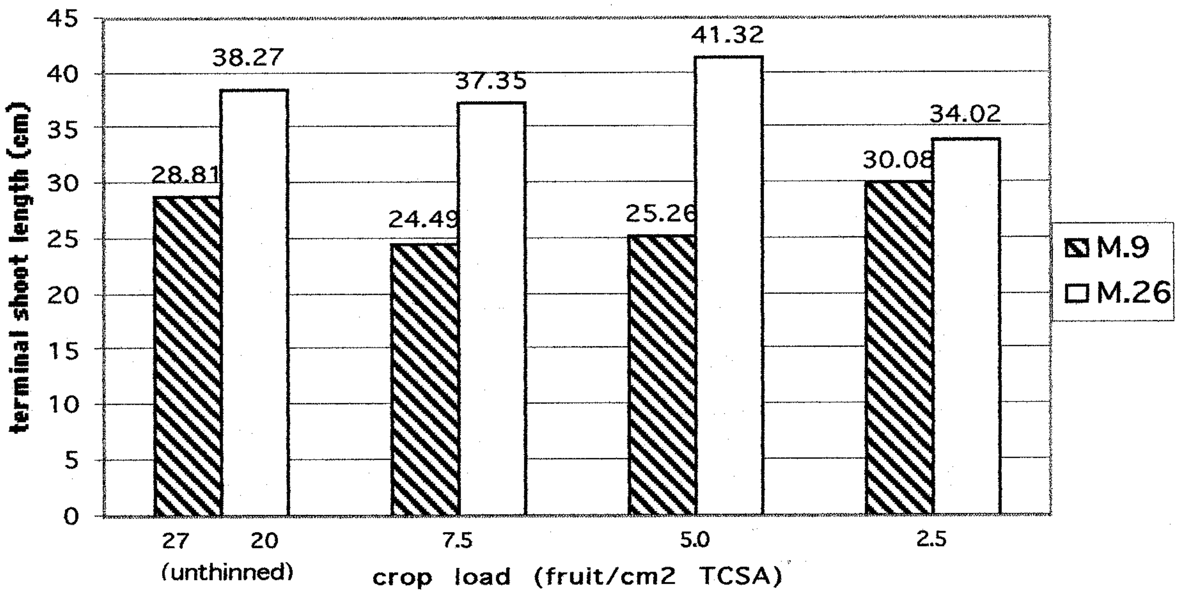


Figure 3. The effect of crop load treatments on mean bourse shoot length in 'Nittany' apple trees on M.9 and M.26 rootstocks in 1997. (S.E. +/- 0.24.)

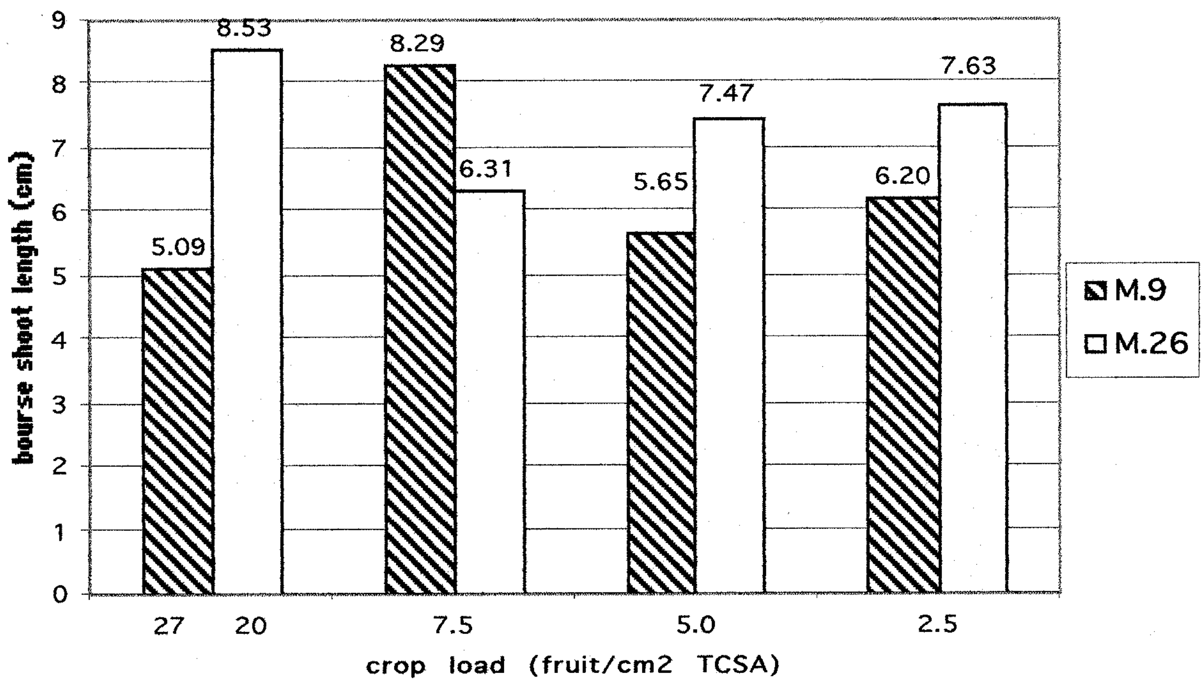


Figure 4. The effect of imposed crop load treatments on 'Nittany' apples on M.9 and M.26 rootstocks on total fruit number per tree in 1997. (S.E. +/- 23.55.)

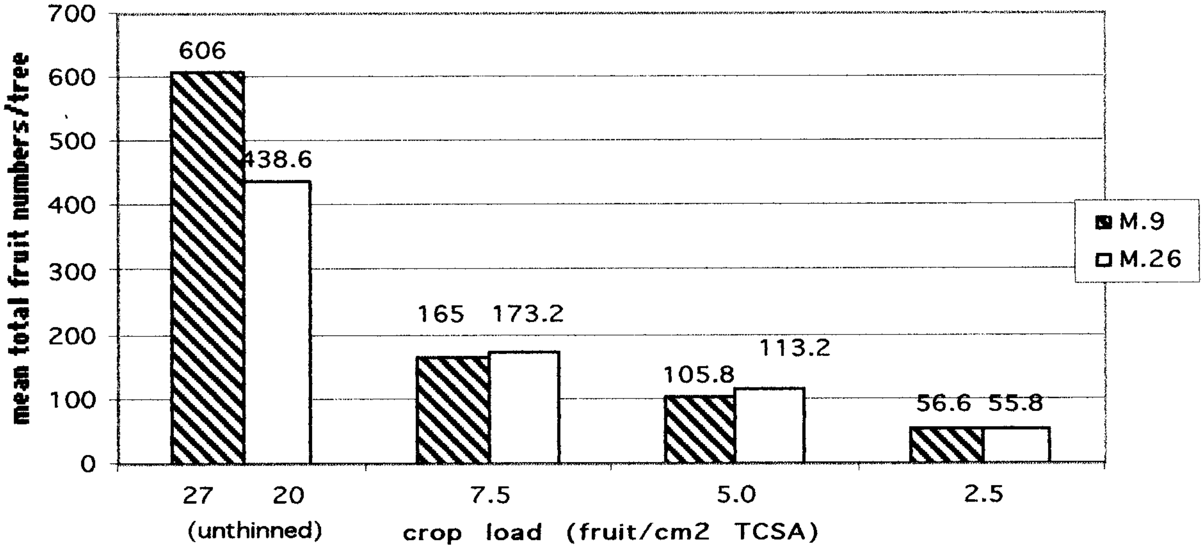
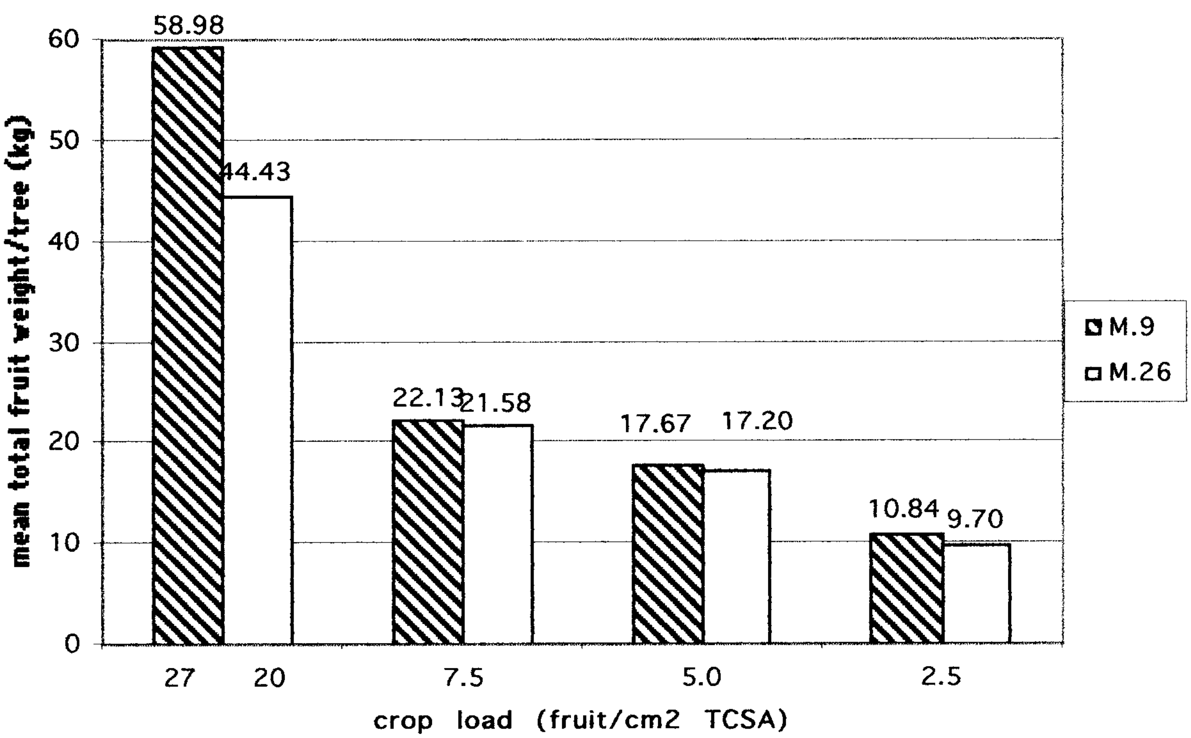


Figure 5. Mean total fruit weight as affected by crop load treatments for 'Nittany' apple on M.9 and M.26 rootstocks in 1997. (S.E. +/- 2.52.)



IV. Fruit Weight and Size

Fruit weight, length, and diameter increased as fruit/cm2 TCSA decreased (Figures 6, 7 and 8). The difference between untreated and the average of the three treatments is greater for the M.9 rootstock than the M.26 rootstock. Rootstocks responded similarly to changes in crop load level at significantly different levels.

V. Fruit diameter Measuring Study

The means for the three measuring devices were

digital caliper	69.82 cm/ten apple sample
Cranston fruit gauge	69.46 cm/ten apple sample
measuring trough	68.87 cm/ten apple sample

There was insufficient evidence of significant difference among the means of the three measuring devices. The measuring trough was the measuring device used in 1998 based on these results. The trough could measure ten apples at once while the other methods were limited to measuring individual apples.

Growing Season 1998

VI. Terminal Shoot Growth

Mean length of shoots is greater on M.26 than M.9 rootstock on all crop load treatments (Figure 9). Terminal shoot growth was not consistantly affected by crop load treatment on either rootstock. There was a slight trend for increased terminal growth on M.26 rootstock at the lowest crop load level.

VII. Bourse Shoot Growth

Mean length of bourse shoots was slightly greater on M.26 than M.9. Crop load did not have a consistant effect on bourse shoot length (Fig.10).

VIII. Total Fruit Number and Weight

As the crop load level decreased, the average total fruit number and total fruit weight decreased (Figs. 11 and 12). The difference between the untreated and average of the three crop load treatments is greater for M.9 rootstock than the M.26. The crop load treatment means were affected by each rootstock at all but the 5.0 crop load level in mean total fruit weight.

Figure 6. The mean fruit weight of 'Nittany' apples at four crop load levels on M.9 and M.26 rootstocks in 1997. (S.E> +/- 3.75.)

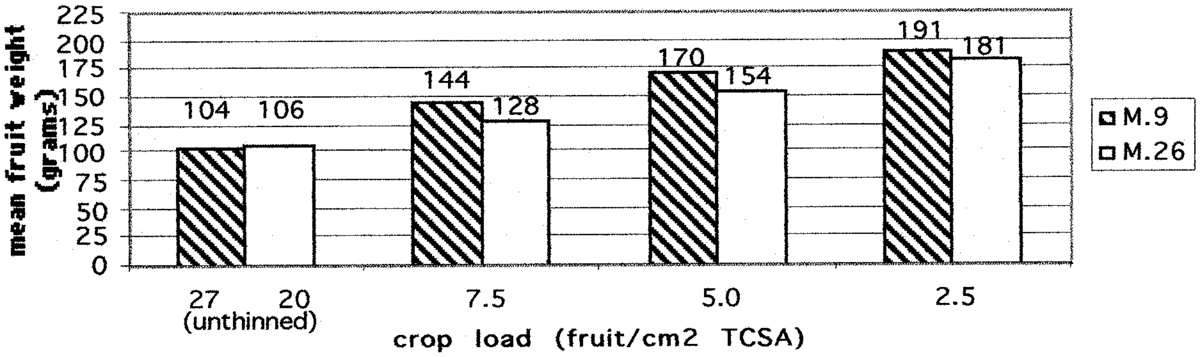


Figure 7. Mean fruit diameter of 'Nittany' apple at four crop load levels on M.9 and M.26 rootstocks in 1997. (S.E. +/- 0.68)

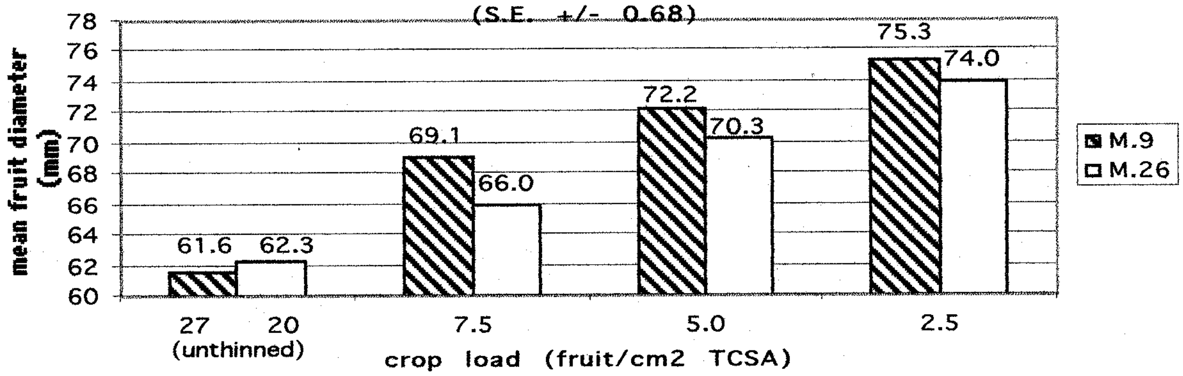


Figure 8. Mean fruit length of 'Nittany' apple at four crop load levels on M.9 and M.26 rootstocks in 1997. (S.E. +/- 0.64.)

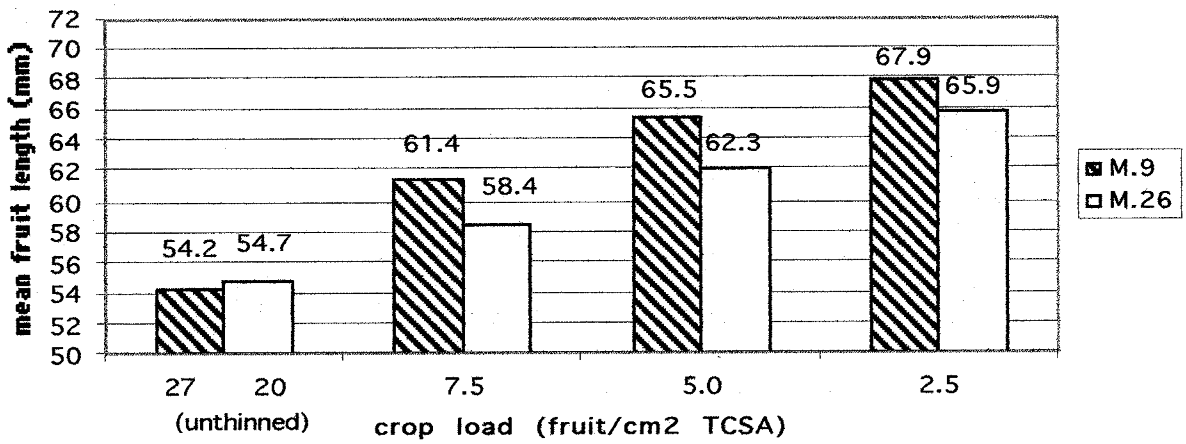


Figure 9. Terminal shoot growth of 'Nittany' apple trees as affected by crop load treatments on M.9 and M.26 rootstocks in 1998. (S.E. +/- 1.11)

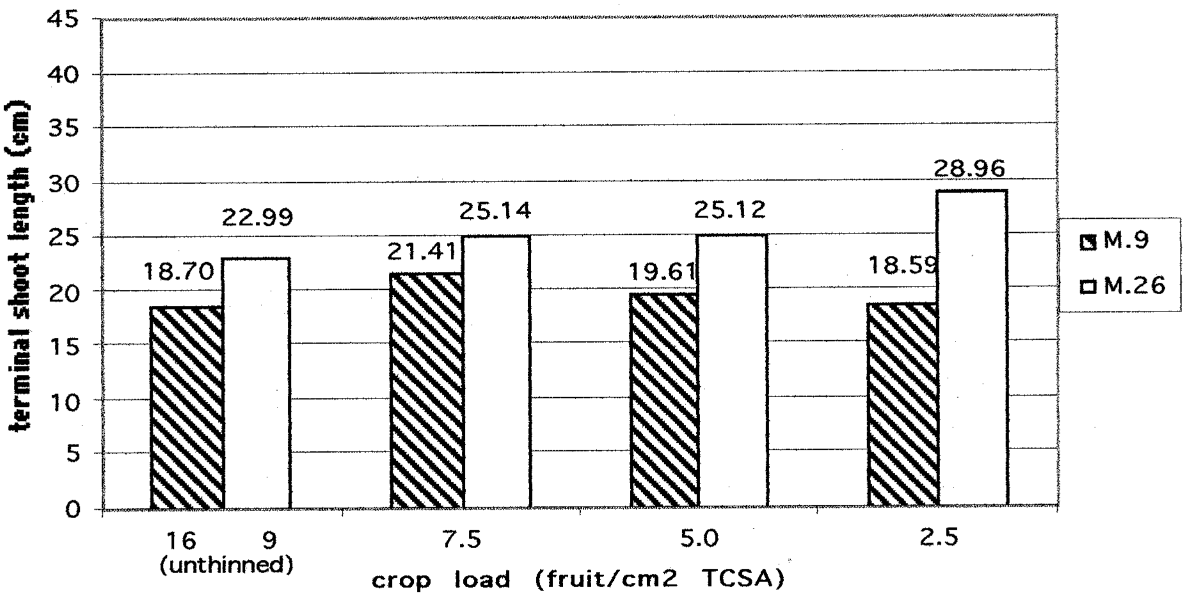


Figure 10. The effect of crop load treatments on mean bourse shoot length in 'Nittany' apple trees on M.9 and M.26 rootstocks in 1998. (S.E. +/- 0.15)

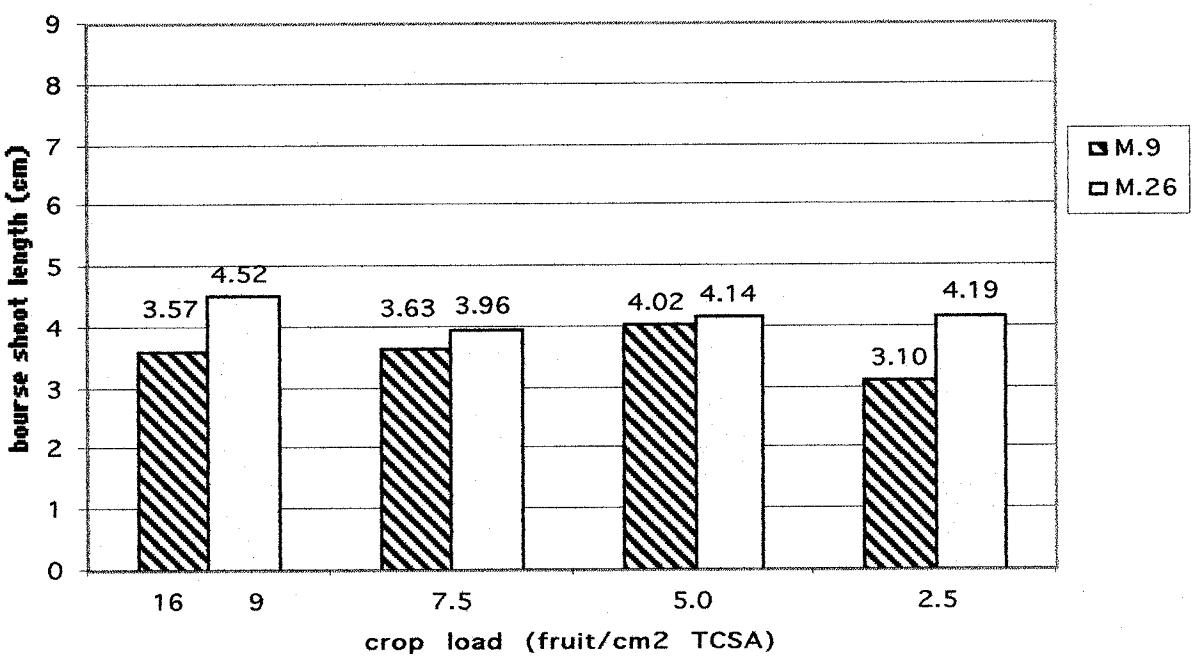


Figure 11. The effect of imposed crop load treatment levels on 'Nittany' apple on M.9 and M.26 rootstocks on total fruit number per tree in 1998. (S.E. +/- 17.6)

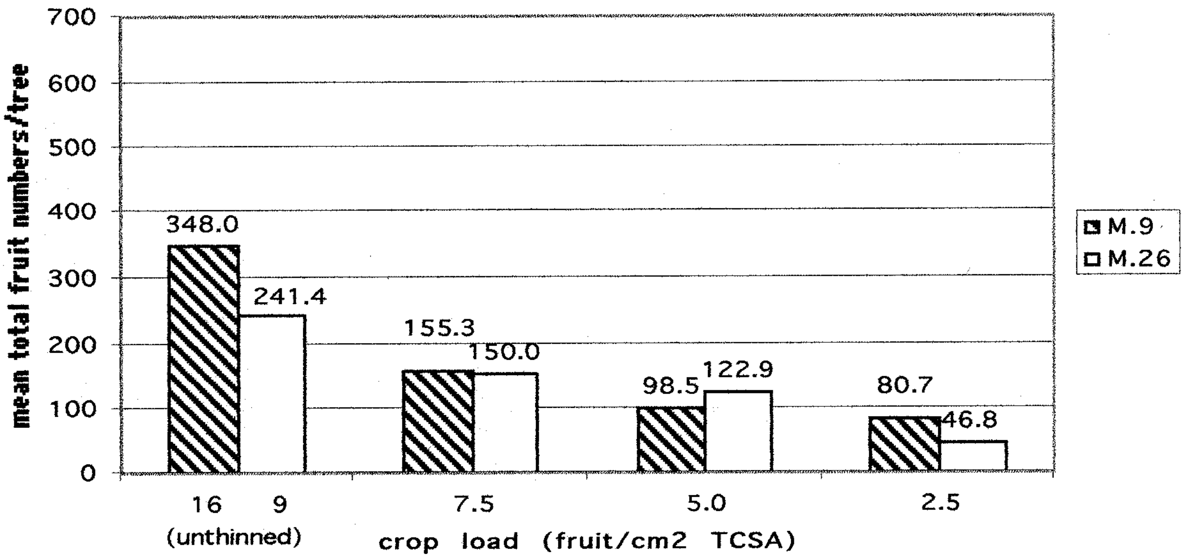
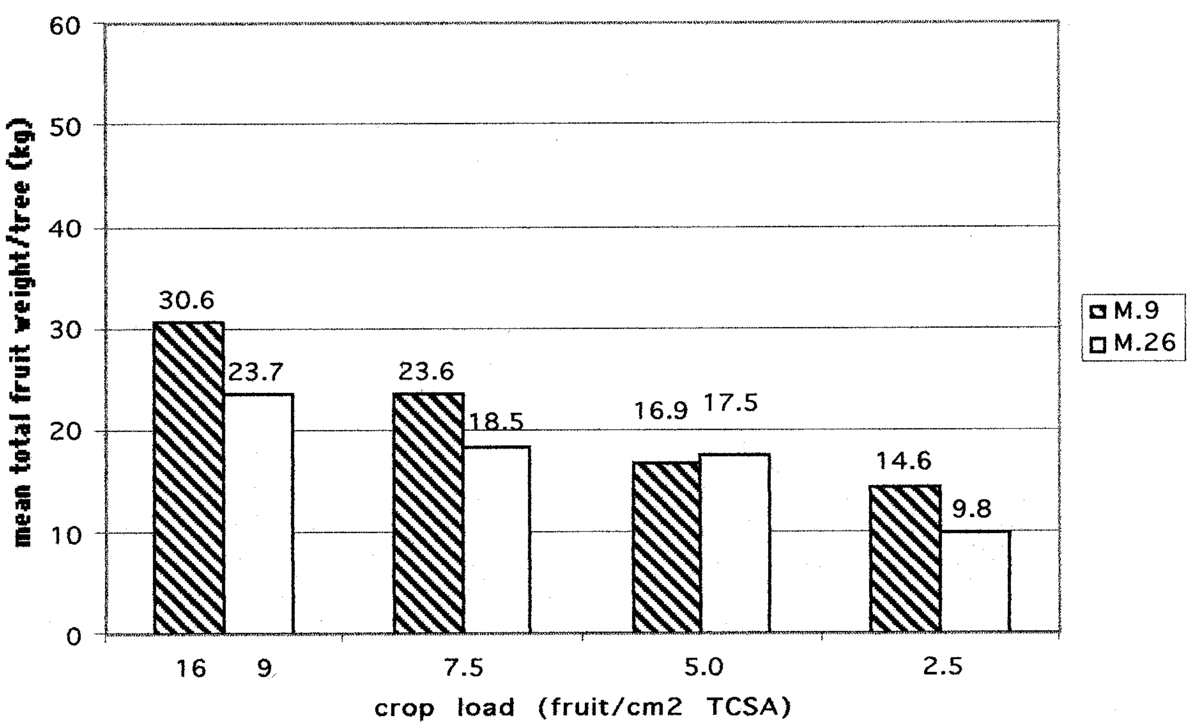


Figure 12. Mean total fruit weight at four crop load levels on M.9 and M.26 rootstocks in 1998. (S.E. +/- 1.93)



IX. Fruit Weight and Size

Mean fruit weight, length, and diameter for all crop load treatments was greater than the control (Figures 13,14, and 15). There is inconsistent evidence of significant differences among the treated groups.

There was a trend for weight, diameter, and length of fruit to increase as crop load level decreased. This was most significant at the 2.5 fruit/cm2 TCSA level where fruit length and fruit diameter were larger than the control and all other treatments.

X. Flower Cluster Count from 1997 to 1998

The change in the number of flower clusters from 1997 to 1998 did not establish any consistent effects in either the M.9 or M.26 rootstock (Figures 16 and 17). There was a slight increase in returning flowers as the 1997 crop level decreased on the trees on the M.26 rootstock and a greater effect for the trees on the M.9 rootstock at the two lowest cropping levels.

Figure 13. Mean fruit weight of 'Nittany' apple at four crop load levels on M.9 and M.26 rootstocks in 1998. (S.E. +/- 0.67)

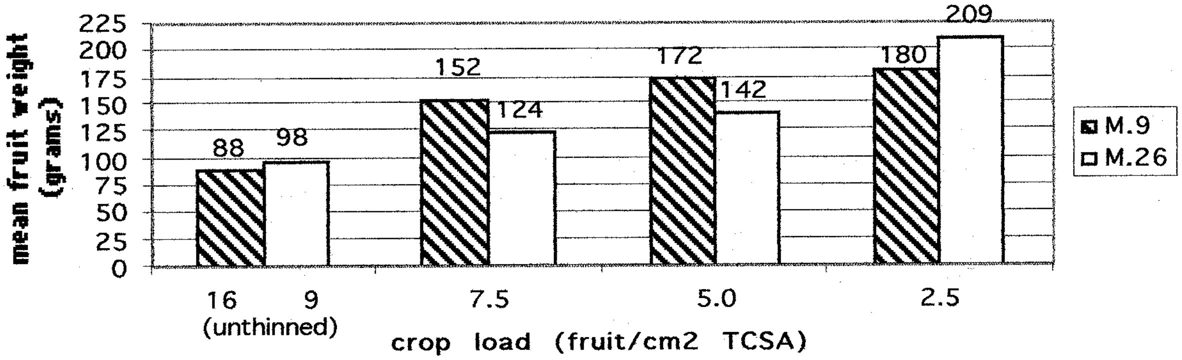


Figure 14. Mean fruit diameter of 'Nittany' apple at four crop load levels on M.9 and M.26 rootstocks in 1998. (S.E. +/- 0.70)

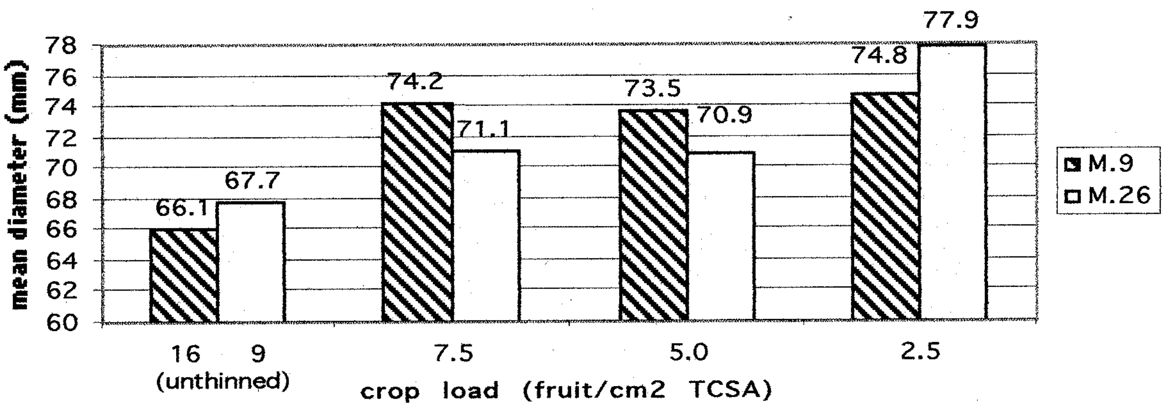


Figure 15. Mean fruit length of 'Nittany' apple at four crop load levels on M.9 and M.26 rootstocks in 1998. (S.E. +/- 0.67)

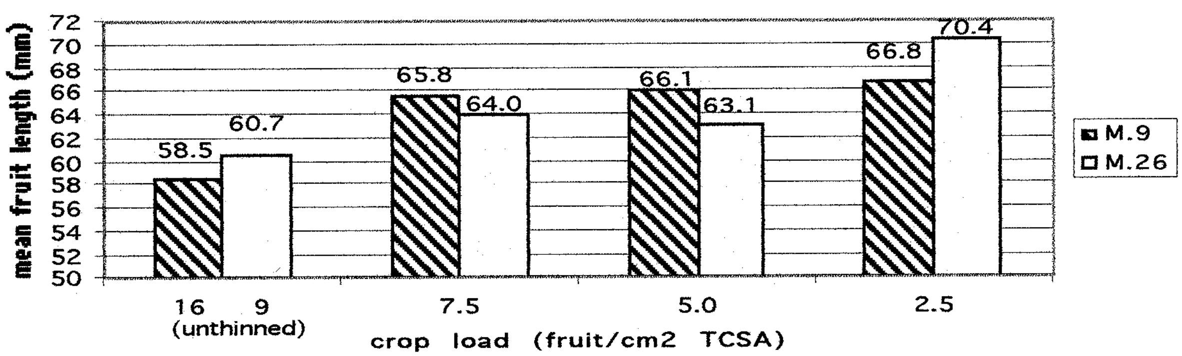


Figure 16. A comparison of initial flower cluster numbers/TCSA in relation to crop load treatments on M.9 and M.26 rootstocks in 1997.

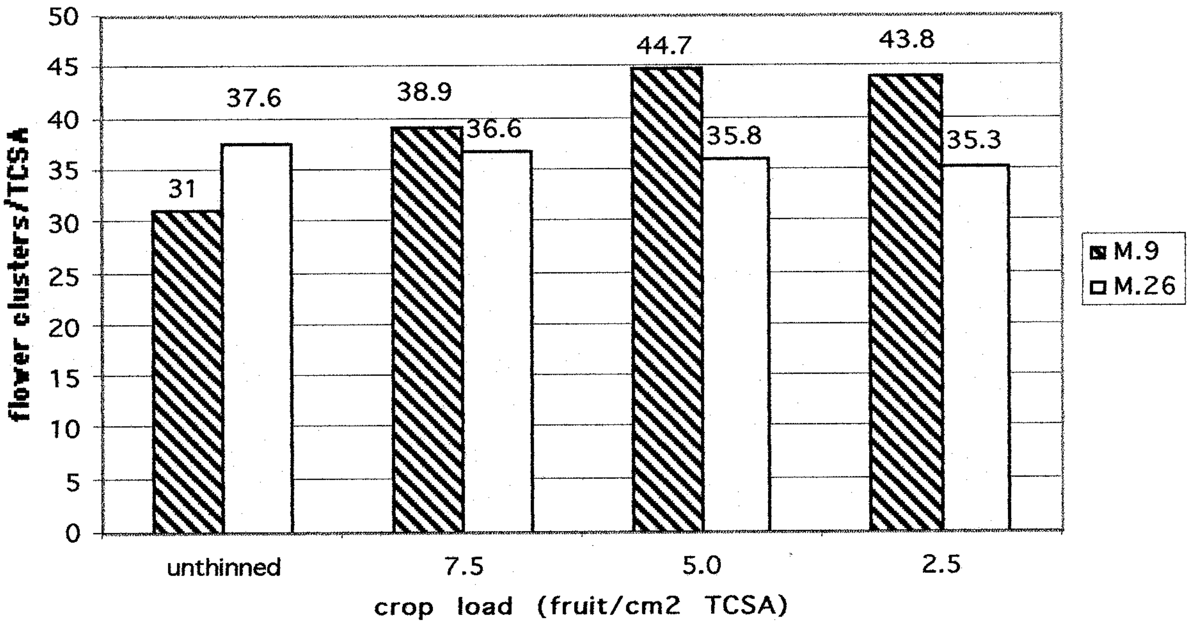


Figure 17. Return flower clusters/TCSA in relation to crop load treatments received during the 1997 season.

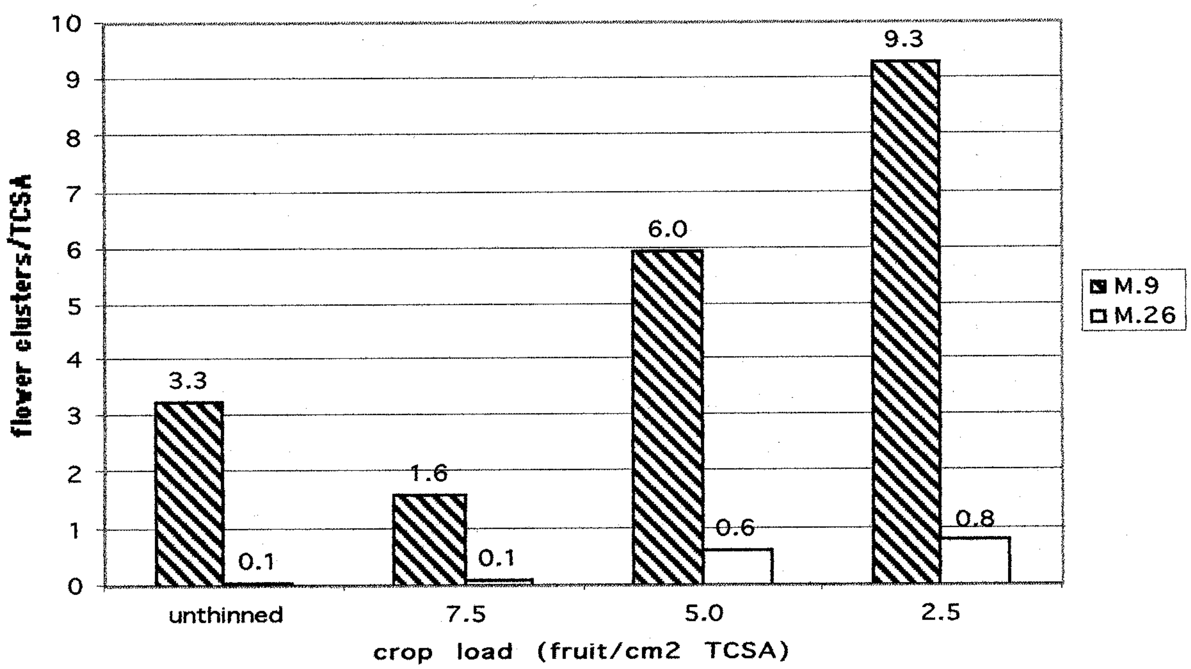


Figure 18. Examples of four crop load levels on ‘Nittany’ trees on M.9 rootstock.

(Photos taken 9-27-98.)

a) unthinned

b) 7.5 fruit/cm2 TCSA

c) 5.0 fruit/cm2 TCSA

d) 2.5 fruit/cm2 TCSA

Figure 19. Measuring trough used to determine the length and diameter of fruit at harvest.

Discussion

The results of this study were inconsistent. Crop load had no direct effect on vegetative shoot or bourse shoot growth. Fruit diameter, length, and weight showed trends toward an effect by crop load but not to a consistent degree. Most of the differences in fruit diameter, weight, and length were attributable to the rootstock.

Terminal Shoot and Bourse Shoot Growth

Terminal shoot growth and bourse shoot growth were greater on average on the M.26 rootstock than on the M.9 rootstock. In 1997 terminal shoot length averaged almost ten centimeters more for trees on the M.26 rootstock than for trees on M.9 rootstock. In 1998 the average was less, but still approximately five centimeters regardless of the crop load treatment. This difference is likely associated with rootstock vigor with M.26 being a more vigorous rootstock than M.9 (NC-140 Cooperators, 1996).

It has been known for some time that decreasing crop load increases vegetative growth (Maggs, 1963). The vegetative shoot growth in this study did not respond to the treatment levels. Quinlan and Preston (1968), and Palmer et al. (1991) also reported no overall effects on mean shoot growth.

The soil type in the orchards in this study is described as a Laidig gravelly loam, severely eroded with 8-15% slope. The fertility is an 80 on a 0 -100 scale that rates soils suitable for orchards as reported by the Soil Conservation Service (U.S.D.A., 1960). The low fertility of this soil may have affected the terminal and bourse shoot growth of all trees in this study compared to trees on a more highly rated soil. These soils are noted for low nitrogen content. Stiles (1999) has reported the effects of nitrogen are related to tree vigor as indicated by increasing shoot and spur growth.

Potential Nutritional Factors Influencing Shoot Growth

Soil samples and leaf tissue sample analysis were not included as part of this study to determine the nutritional status of the trees used in this experiment. These tests have been conducted over the past five years and may provide additional insight into the results of this study.

Leaf tissue sample analysis was conducted in 1995 on the ‘Nittany’ trees in the orchard blocks where this study was conducted. Leaf nitrogen levels were in the 1.9% DW range (low normal). Potassium ranged from .78% to .97% DW range (low). Boron was at 32 ppm DW level (low). Zinc was at 15 ppm DW level (low). The leaf analysis tests conducted in the last five years on various varieties in the same orchard blocks have all produced similar results.

During the spring of 2000, soil samples were collected from the blocks used in this study. Results from these samples determined that phosphorus was 17 to 20 ppm (very low), potassium was 59 to 71 ppm (low), and magnesium was 46 to 75 ppm (low).

All nutritional elements are important to regular cropping. Optimum fruit size requires optimum vigor and growing conditions (Forshey and Elfving, 1977). Some nutritional elements have a direct role in growth and vigor of the tree.

Nitrogen has a positive influence on shoot growth (Benson et al., 1957). Leaf nitrogen in these orchards occurs within the normal range. All trees receive an annual application of four ounces of urea broadcast at the trees' drip line to maintain this level.

Soil samples collected in the spring of 2000 determined potassium levels were low (59 to 71 ppm). From leaf tissue samples taken, results determined that potassium levels were consistently low (ranging from .78% to .97% DW levels) during the five year period. Stiles (1998) recommends a leaf potassium level at a range of 1.35% to 1.8%. These low potassium levels may have affected tree vigor as potassium has an effect on vegetative growth. In a fertigation study (Stiles, 1998) trees established in 1993 and deblossomed during the first two seasons showed a significant increase in shoot growth in response to potassium. Yields during the first three cropping seasons were related positively with shoot growth during the first two growing seasons. Potassium requirement is directly related to crop load level, as trees mature the requirement for potassium increases (Stiles, 1998).

In the leaf tissue sample analysis, low zinc levels were also consistently low . Zinc deficiency reduces growth and general tree vigor, and if severe, can result in die back of shoots or limbs (Chandler, 1937). Magnesium levels were in the normal range for all leaf tissue samples during the five year period , but soil samples ranged from low (75 to 87 ppm) to very low (46 ppm). Magnesium deficiency results in reduced shoot vigor and spurs tend to be thin, weak, and brittle (Boynton and Oberly, 1966). The nutritional status of elements involved in vegetative growth may have played a role in the trees' lack of response to the imposed crop load levels.

Total Fruit Numbers and Individual Fruit Weight

There was a significant, but not consistant, difference in fruit crop load treatments for both rootstocks. Only the crop load at the 2.5 fruit/cm2 TCSA approached the 200 gram weight. (Jones et al., 1989) have suggested that a target weight of 200 grams be achieved where there is an increasing emphasis on large fruit.) There is a close relationship between fruit numbers and fruit weight. The negative correlation between fruit numbers and weight is predictable because the fruit numbers were reduced at progressive levels based on crop load treatment levels.

Fruit Size and Weight

Fruit diameter of apples thinned to the 2.5 fruit/cm2 TCSA or 5.0 fruit/cm2 TCSA levels averaged seven centimeters on both M.9 and M.26 rootstocks (Figures 6 and 13). The crop load at 2.5 fruit/cm2 approached the 200 gram weight. Fruit in this study were thinned four weeks after full bloom to simplify the hand thinning process. Apple fruit cell division is most active in the first three weeks after bloom and only lasts for about four to five weeks (Lakso et al., 1996). Apple fruit size potential is generally determined by cell numbers and air space. In a mature apple, 25% of the fruit is air space (Leopold and Kriedemann, 1975). When cell division is reduced by fruit competition during early growth, optimum fruit size is not achieved. The timing of thinning in this study may have affected the optimum fruit size. Jones et al. (1992) reported a linear decrease in fruit size as hand thinning was progressively delayed.

Earlier thinning can increase mean fruit weight (Bergh, 1990). Compared to thinning at full bloom, fruit weight was reduced by 16% when thinning was delayed three to four weeks after bloom as reported by McArtney et al. (1996).

Return Bloom

'Nittany' is characterized as a biennial apple cultivar (Stouffer et al., 1978). Once this habit is established, it is difficult to prevent (Aldrich and Fletcher, 1932). Trees used in this study on both rootstocks exhibited this tendency as demonstrated in Figures 16 and 17. The importance of early fruit thinning to decrease biennial bearing has been known for some time (Potter, 1936). In this study thinning was delayed four weeks after bloom and encouraged the biennial bearing. Thinning as early as full bloom has improved yields significantly during consecutive seasons when compared to delaying thinning (Bergh, 1992).

Cropping Level

A cropping level has never been determined for the apple variety 'Nittany'. Target weights for 'Fuji' and 'Golden Delicious' fall between 150 and 200 grams as determined by Jones et al. (1989). Based on this range, the 5.0 fruit/cm2 TCSA and the 2.5 fruit/cm2 TCSA levels produced similar results based on the mean fruit weight for ‘Nittany’ (Figures 5 and 12). This range corresponds to 1.5 - 2.5 fruit/cm2 TCSA level for ‘Nittany’ to achieve an approximate weight of 200 grams and reduce the potential for biennial bearing.

Differing Results in 1997 and 1998

The difference between harvest data in 1997 and 1998 may be attributed to several factors. The bloom period during 1998 occurred during a period of above-average rainfall (4 inches in April). This rainfall occurred over a ten day period, and six of those days were during bloom. These conditions may have affected pollination by limiting bee activity. Average high temperature for the month (67ºF) was slightly below the average (70º F) and may have also limited bee activity. Poor pollination reduces the number of seeds per fruit and affects fruit size (Weinbaum and Simons, 1976). These lower temperatures may have also slowed pollen germination and pollen tube growth and may have decreased fertilizaton. Pollen germination and growth of the pollen tube are faster when temperature is above 70º F (McDaniels and Heinicke, 1930).

Low seed numbers increased the occurrence of pygmy fruit (fruit less than five cm in diameter) which were noticeable in 1998. The pygmy fruit affected the mean fruit weight. Pygmy fruit numbers represented 16% of mean total fruit numbers for all four crop load level treatments on M.9 rootstock and 28% of mean total fruit numbers at all crop load level treatments on M.26 rootstock. The pygmy fruit represented 9% of average total fruit weight for all crop load treatments on M.9 rootstock and 16% of average total fruit weight for all crop load treatments on M.26 rootstock. This had a negative effect on fruit size (length and diameter).

Summary and Conclusions

1) Mean terminal shoot growth and bourse shoot growth was greater for M.26 rootstock than for M.9 rootstock.

2) Mean fruit size (diameter and length) and weight were greater for M.9 rootstock than for M.26 rootstock.

3) Thinning fruit to a crop load of 2.5 fruit/cm2 TCSA showed the most consistent results in increasing fruit size and weight when compared to other crop load treatments in the two year study.

4) Crop load level was not a limiting factor in shoot growth for trees on M.9 and M.26 rootstocks on this site.

5) Further research is warranted to determine an optimum crop load level for 'Nittany', but future studies should include earlier thinning and a wider range of crop load levels.

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