INHIBITION OF FLOWER BUD INITIATION AND DEVELOPMENT IN APPLE BY DEFOLIATION, GIBBERELLIC ACID AND CROP LOAD MANIPULATION

by

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ABSTRACT

Biennial bearing has been investigated longer and more extensively in apple than in any other fruit tree; however, it remains a serious problem in commercial apple production all over the world. Trees that have become biennial flower profusely and carry a heavy crop in the "on" year, and flower sparsely or not at all and carry little or no crop the following year, the "off" year. Fruit in the "on" year tend to be small, poorly colored, and of low quality, while the few fruit in the "off" year are usually too large, become susceptible to physiological disorders, and also are of poor quality. Without intervention, the crops in both the "on" and "off" years are undesirable and uneconomical. The most common method used by commercial apple growers to try to prevent biennial bearing is chemical fruit thinning, which is an "on" year method of removing a part of the crop before it matures on the tree. In general, growers don't do anything in the "off" year to prevent biennial bearing with the exceptions of fertilizing and pruning lightly. In this study, several experiments were conducted with the cultivars 'Braeburn', 'Golden Delicious', 'Ramey York',

and ‘Fuji’ in the “off” year to try and suppress FBI and thus prevent a biennial bearing situation in the following year. The first set of experiments studied the effect of whole-tree and partial-tree defoliation on suppressing spur and lateral flowering and fruit set. Flowering and fruit set were suppressed with defoliation in most cases. Defoliation in early July caused the least amount of flowering the following year and in some cases it was zero. As the defoliation timing and severity was delayed, there was less suppression of flowering and fruit set. Ammonium thiosulfate and Endothal increased flowering but decreased fruit set compared to a control. Gramoxone suppressed flowering and fruit set. In another set of experiments, gibberellic acid (GA) treatments were evaluated to suppress FBI in “off” or light crop years. The GA_{4+7} treatments suppressed return bloom of both spur and lateral flowers more than the GA_3 treatments. The effectiveness of GA declined with delayed application. Both GA treatments reduced lateral flowering the most on the basal 1/3 of the shoot. In a four year study, apple trees were thinned to one fruit per flowering cluster every year from 1997 to 2000. Other trees were thinned to zero fruit or two fruit per flowering cluster in alternate years from 1997 to 2000. Trees thinned to one fruit per flowering cluster had moderate flowering and fruit set the following year. Trees thinned to two fruit per flowering cluster had very little to no flowering the following year. Trees thinned to zero fruit per flowering cluster had a “snowball” bloom the following year. Trees that were alternately thinned to two or zero fruit per flowering cluster were in a biennial bearing situation.

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INTRODUCTION

The purpose of this work was to develop cultural practices that will either prevent or disrupt biennial bearing in apple. Biennial bearing or alternate year cropping has long been a serious problem of apple production. Fruit spurs of many apple cultivars tend to be biennial. When flowering is heavy, during the "on" year, trees generally set too much fruit resulting in small, poorly colored, low quality fruit. The following year, the "off" year, flowering is light resulting in too few fruit which typically grow too large and become susceptible to physiological disorders such as bitter pit or cork spot. Both situations are undesirable and uneconomical. The alternation of too much and too little crop may persist with great regularity.

Virginia typically ranks sixth in the United States for apple production, with an average yield of 10 million bushels from over 20,000 acres. Virginia is susceptible to spring frosts, which are one of the leading causes of biennial bearing. Frosts can kill or injure developing flower clusters, which causes too few or no fruit to set, which results in an "off" year. Another leading cause of biennial bearing is when, in the "on" year, the trees are not thinned to a crop load that will ensure flowering and fruit set the following year. Inadequate thinning results in the trees being in the "off" year the following year. In a heavy flowering and fruit set year, only 5 to10% of the fruit that set need to remain on the tree to have a full crop of good sized fruit.

Considerable research applying cultural practices such as chemical thinners, growth regulators, foliar nutrients, pruning, girdling and defoliation have proven somewhat effective for disrupting the biennial bearing cycle of apple. However, such practices have not been sufficiently researched to ensure adequate return bloom year after year. Also, much of this work has been

done on atypical cultivars and rootstocks or done in areas of the world that are unlike Virginia's climate. The most common cultural practice for preventing biennial bearing is thinning the fruit from trees, which is an "on" year strategy. In general, growers don't do anything in the "off" year to prevent biennial bearing with the exceptions of fertilizing and pruning lightly.

The objectives of this dissertation were to examine some cultural practices for possibly disrupting biennial bearing in the "off" year. The approaches used in the first set of experiments were to 1) defoliate trees in the "off" year or trees thinned to a crop load of four or less fruit/cm^2 trunk cross sectional area (TCSA), 2) apply various timings and severities of defoliation and determine fruit drop, and 3) measure the suppression of return bloom and fruit set of both spurs and laterals the following year. The objective of the second set of experiments was to evaluate various gibberellic acid treatments applied in the "off" year to suppress flowering and reduce fruit set in the subsequent "on" year. The rates and timings of the applications were designed to result in moderate flowering and fruiting the following year instead of a "snowball" bloom and a heavy fruit set which typically occurs after the "off year". The objective of the third experiment was to determine how crop load affects shoot length, the increase in TCSA, and flowering and fruit set the following year.

CHAPTER ONE

LITERATURE REVIEW

The literature covering biennial bearing is extensive. Several review papers have been written in the last fifty years. These include: Singh, 1948a,b; Davis, 1957; Singh, 1971; Williams and Edgerton, 1974; Jonkers, 1979; Monselise and Goldschmidt, 1982. Although biennial bearing has been investigated longer and more extensively in apple than in any other fruit tree (Monselise and Goldschmidt, 1982), it remains a serious problem in commercial apple production all over the world. Trees that have become biennial carry a heavy crop in one year, the "on" year, and little or no crop the following year, the "off" year (Singh, 1948a). Fruit in the "on" year tend to be small, poorly colored, and of low quality, while the few fruit in the "off" year are usually too large, become susceptible to physiological disorders, and also are of poor quality (Monselise and Goldschmidt, 1982). Without intervention, the crops in both the "on" and "off" years are undesirable and uneconomical.

The alternation of crops that are too large or too small may persist with great regularity. It may be brought about by or interrupted by climatic factors such as spring frosts (Singh, 1948a). All cultivars may become biennial in bearing habit under certain conditions, and once the habit becomes established it has usually been extremely difficult to correct (Harley et al., 1942). Controlling flower bud initiation is necessary for successful fruit growing (Buban and Faust, 1982). When apple growers are able to manipulate trees to flower and set fruit consistently, fruit size and yields will also become more consistent.

The annual vegetative growth of an apple tree is distributed in a definite pattern between leaves, shoots and roots (Maggs, 1963). There are three kinds of apple shoots: terminal, lateral and bourse (Avery, 1969; Barlow, 1964; Forshey, 1982). Terminal shoots develop from apical buds, lateral shoots develop from axillary buds on the previous season's shoots and bourse shoots develop from axillary buds at the base of a flower cluster (Forshey, 1985). When a crop is borne, there becomes an additional sink for growth materials (Maggs, 1963).

Flower formation results from an activation of floral genes in a meristem by deblocking through floral hormone(s) and external factors (Wellensiek, 1977). The beginning of the process is often referred to as induction and is followed by differentiation of growing point and, later, by differentiation of flower primordia. In essence, induction is the ceasing of repression of genes responsible for flower bud development. After induction, the differentiation of the flower bud begins. This process includes changes in the apex resulting in the development of the flower primordia and later the distinguishable parts of the complete flower (Buban and Faust, 1982).

In temperate zones, flower bud development in apple trees occurs on terminal buds on short shoots (spurs) and in axillary buds of elongated shoots. Flower bud development on elongated shoots does not occur with all cultivars, nor does it occur every year. In most apple growing areas, the lateral flowers on the one-year-old shoots only become important when the earlier-opening spur flowers suffer frost damage. The most valuable flowers of the apple tree develop in the terminal buds of the spurs (Buban and Faust, 1982). The value of the spurs differs with age and location within the tree canopy. Spurs that are young and receive ample sunlight tend to develop better fruit-bearing flowers than older spurs and spurs growing in low sunlight. Typically five to six flowers are produced per bud. A "king" flower is produced along with four to

five side flowers. The “king” flower is more advanced in development than the side flowers and typically produces the largest fruit.

Flower bud initiation (FBI) on spurs is generally considered to occur approximately three to six weeks after bloom (Singh, 1948a; Jonkers, 1979; Childers et al., 1995). FBI on spurs is generally finished by the time extension shoots cease growth (Goff, 1899; Tromp, 1973). Depending on cultivar, a variation of several weeks may occur in the timing of FBI on spurs (Tufts and Morrow, 1925). FBI in buds on current season shoots occurs four to six weeks later than flower buds on spurs (Childers et al., 1995). Luckwill (1970) stated that FBI on one-year-old shoots did not begin until the termination of shoot growth.

Biennial bearing in apples is influenced by many factors such as cultivar, crop load, the ratio between carbohydrates and nitrogen, pruning, and hormonal activity. Considerable research applying cultural practices such as chemical thinners, growth regulators, foliar nutrients, pruning, girdling, and defoliation have proven somewhat effective for disrupting the biennial bearing habit of apple. However, such practices have not been sufficiently researched to ensure adequate return bloom year after year.

The theory for the failure of FBI in trees carrying a heavy crop of fruit has changed through the years. Kraus and Kraybill (1918) proposed the C:N hypothesis for fruitfulness in tomato and subsequently other fruit crops. The C:N ratio plays an important role, despite the fact that it is not a primary cause (Hennerty and Forshey, 1971). Carbohydrates, which serve as an energy source, are essential for flower bud formation. Thus, any factor which reduces the carbon exchange rate may contribute to reducing flower bud formation (Childers et al., 1995). Auchter and Schrader (1932) found little effect of nitrogen application in offsetting biennial bearing. When

large amounts of nitrogen are applied, it can actually increase the biennial bearing phenomenon (McCormick, 1933; Titus, 1960). The fertilization program should be developed as follows: little nitrogen in the spring time of an "off" year and large quantities in the autumn of the same year or in the spring of the following "on" year (Jonkers, 1979).

The most common method used by commercial growers to try to ensure annual bearing is fruit thinning which is an "on " year method of reducing the crop load. Thinning is the removal of a part of the crop before it matures on the tree. Chemical fruit thinning to reduce the drain of a heavy fruit set early in the season has done more than any other factor to correct "on-off" years of bearing (Childers et al., 1995). Hand thinning will also lead to an increase in FBI if completed early enough. Hand thinning of fruits, however, is one of the most expensive practices in the orchard and would rarely be advisable merely for a slight increase in FBI for the succeeding crop (Chandler, 1957). As early as the 1930s, it was known that fruit thinning led to an increase in FBI in apple (Aldrich and Fletcher, 1932; Harley et al., 1942; Magness et al., 1933). The earlier the thinning, the greater will be the response in increasing FBI (Aldrich and Fletcher, 1932; Preston, 1954; Williams and Edgerton, 1974; Greene, 2000). Thinning just after bloom instead of up to eight weeks later increased FBI the most (McCormick, 1933; Meland and Gjerde, 1993). Often two or three chemical thinning sprays are needed to adequately thin the trees to an acceptable crop load. Fruit set from less than 5% of the blossoms on a "snowball" bloom tree is enough for a full crop (Williams and Edgerton, 1981). However, a "snowball" bloom is an indication that the trees may become biennial and should be avoided. Heavy flowering 'York' and 'Golden Delicious' trees thinned at bloom did not have adequate return bloom the following year (Byers and Carbaugh, 2002).

Some researchers refer to thinning as adjusting the leaf:fruit ratio. Davis (1957) reported that a certain number of leaves was necessary for adequate FBI. Small apple trees require 10 to 20 leaves/fruit for adequate FBI, while large trees require 30 to 40 leaves/fruit for FBI (Williams and Edgerton, 1974; Jonkers, 1979). Total leaf area in an "off" year can be two to three times greater than in an "on" year (Buban and Faust, 1982).

Pruning is another cultural practice used to promote annual bearing. Pruning reduces the amount of spurs on the tree that might otherwise flower and produce fruit. Severe pruning to reduce flowering points before the expected heavy-blossom year is practiced to bring a tree back into annual bearing (Childers et al., 1995). Such a practice presumably reduces the competition between the remaining flowers for carbohydrates, water and nutrients. Under Wisconsin conditions, Roberts (1951) devised a system whereby he pruned all multiple spurs and small branches in half. This had a dramatic effect on fruit size but also resulted in sufficient formation of blossom buds for a good "off" year crop. It is generally accepted that pruning should be severe in the spring of the "on" year and light in the spring of the "off" year (Jonkers, 1979).

Defoliation has been used successfully in the "off" year to suppress flowering in the following year in apple (Harley et al., 1942; Fulford, 1960). It seems reasonable to suppose that if the leaf area of an apple tree is reduced beyond a certain point, the carbohydrate supply may be restricted to a level at which flower bud differentiation will be prevented (Singh, 1948b). The defoliation can be done by hand (Raven, 1968) or chemically (Fulford, 1970) and can be partial or complete. Hand defoliation can remove only spur leaves, only extension, or only bourse shoot leaves, or combinations of all three. Singh (1948b) removed two out of every three fully expanded leaves by hand on spurs which reduced the amount of shoot growth but did not reduce flower bud

formation. On the other hand, complete defoliation of young trees prevented flower bud differentiation. The earlier the leaves are removed, the greater the suppression of flowering the following year (Davis, 1957; Llewelyn, 1968). The more severe the defoliation, the greater will be the suppression of flowering the following year (Harley et al., 1942; Tustin et al., 1997). Thus both the degree and the timing appear to be important factors in determining the success of defoliation as a control measure against biennial bearing (Fulford, 1960). Defoliation can also cause fruit abscission. Defoliation of individual fruit spurs just after full bloom resulted in severe fruit drop, whereas defoliation 30 days after full bloom resulted in no more drop than the control (Llewelyn, 1968; Schumacher and Stadler, 1993).

Self-pollinated cultivars tend to be more biennial than self-sterile cultivars (Williams and Edgerton, 1974). In the northwestern United States, self-pollinated cultivars such as 'Golden Delicious' and 'Yellow Newtown' often set more than 100 fruit per 100 blossoming clusters, whereas the cross-pollinated or self-sterile cultivar 'Starking Red Delicious' seldom sets more than 60 fruit per 100 blossoming clusters.

The failure of apple trees to flower is now widely recognized to be due in part to hormonal causes. Both auxins and gibberellic acid (GA) are involved in control of flower bud development (Buban and Faust,1982). These hormones can be exported from the fruit as well as from the shoot tips (Prang et al., 1997). There are more than 80 known gibberellins (Fosket, 1994). GA is only partially responsible for inhibiting FBI (Looney et al., 1978). A high level of starch and a low level of GAs appear to be most favorable for FBI (Singh, 1971).

The discovery of GA in apple seeds and its inhibiting effect on FBI was first observed by Tumanou and Gareeu (1951, cited by Luckwill 1977). However, it has become widely known on

the basis of research published by Chan and Cain (1967). They showed a strong relationship between the seed content of the fruits in one year and the proportion of flowering spurs the next year. They found that when the spurs bore seedless fruit, 90% of the spurs flowered the following year. When seeded fruit were present, only 13% of spurs developed flowers the following year. Seeds produce relatively large amounts of GA that stimulate growth and reduce FBI (Guttridge, 1962; Marcelle and Sironval, 1963; Jonkers, 1979). GA has been reported to decrease FBI and increase shoot growth in several other fruit crops such as almond, cherry, pear, plum, orange, and strawberry (Hull and Lewis, 1959; Taiz and Zeiger, 1998). However, GA promotes flowering in long day rosette type plants such as cabbage, lettuce, and radish (Luckwill, 1977). The development of seeds is thought to be a greater factor in the cause of biennial bearing than the competition of fruits for nutrients (Fulford, 1965). Another theory is that GA prolongs the plastochron, which is the time interval between initiation of appendages in the developing buds (Luckwill, 1974). If the plastochron becomes too long, developing buds will be vegetative.

GAs form in large quantities in young developing apple seeds (Sinska et al., 1973). GA_4 and GA_7 predominate in apple (Dennis and Nitsch, 1966; Hoad, 1978). However, at least eleven other GAs are found in apple seeds (Dennis and Nitsch, 1966). GA activity in young developing apple seeds is 3,000 times greater (per unit fresh weight) than in the fruit flesh (Dennis, 1976). GA levels in apple fruit peak at approximately 4 to 6 weeks after full bloom (Luckwill, 1974; Prang et al., 1997). GAs are exported from the fruit to spurs, and the length of the pedicel may affect the biennial bearing habit of a particular cultivar (Hoad, 1978). Marino and Greene (1981) reported that fruiting spurs had higher levels of GAs than did vegetative spurs. GA levels in apple leaves of "on" and "off" year trees in May were equal, but in June, GA activity was found only in

leaves of "on" year trees (Lacey et al., 1976). More GA-like substances occur in the fruit of biennial cultivars than in annual cultivars a few weeks after full bloom (Hoad, 1978; Marino and Greene, 1981).

After the discovery of GA in apple seeds and its effect on FBI, researchers began applying GAs exogenously at various rates and timings with inconsistent results. Of the known GAs, GA_4, GA_7, $GA_{4+7,}$ and GA_3 are most often used to suppress flowering. It appears that, in this group, GA_4 is least inhibitory, GA_7 is most inhibitory, and GA_3 and GA_{4+7} are intermediate in their ability to inhibit flowering (Tromp, 1982; McArtney and Li, 1998). GA_3 is not found in apple but will trigger responses such as parthenocarpic fruit (Luckwill, 1977; Dennis and Nitsch, 1966) and reduction of FBI (Tromp, 1982; McArtney; 1994; Prang et al., 1997). GA_3 inhibits FBI in other crops such as peach (Byers et al., 1990). Grochowska (1973) reported that GA_3 increased starch levels in apple spurs in the "off" year. Marino and Greene (1981) discovered that GA_3 and GA_{4+7} decreased FBI on 1-year-old wood as well as spurs, with GA_{4+7} being more effective. Though endogenous to apple, GA_4 did not decrease FBI and occasionally increased FBI (Looney et al., 1985). GA_7 reduced flowering more than $GA_{3,}$ but both were only effective on 1-year-old wood (McArtney and Li, 1998). A combination of GA_{4+7} is available commercially and is known to reduce FBI (McLaughlin and Greene, 1984; Meador and Taylor (1987). Dennis and Edgerton (1966) found GA_{4+7} to be more effective at reducing FBI than GA_3. A rate of 300 mg L^{-1} GA_{4+7} reduced FBI on fruit spurs and lateral flowers but was more effective on spurs (Marino and Greene, 1981). Meador and Taylor (1987) found that very low rates of GA_{4+7} will reduce FBI on apple. Applying GAs exogenously can cause negative side effects such as increased fruit set, fruit thinning, reduced seed number, and reduced postharvest life (Greene, 2000). High rates of some

gibberellins may result in production of "blind wood" (Greene, 1989).

There are other advantages to applying GA on apple other than for reduction of FBI. GA reduced russeting on some cultivars when applied shortly after bloom (Taylor, 1975; Edgerton and Veinbrandts, 1979; Eccher and Boffelli, 1981; Meador and Taylor, 1987). Apple fruit can be elongated by GA_{4+7} (McLaughlin and Greene, 1984; Looney et al., 1992; McArtney, 1994). GA combined with benzyladenine is used by tree fruit nurseries to increase "feathering" of young trees (Czarnecki and Mitrut, 1993; Jacyna, 1996). Unrath and Whitworth (1991) successfully defruited young apple trees with $GA_{4+7.}$

Since exogenous applications of GA can inhibit FBI, it has been used as a tool for inhibiting excessive return bloom in the "off " year. Spraying GA to inhibit flowering is complicated. The results will depend on the type of GA used, the rate, the timing and whether multiple applications are made.

The key to the correction of biennial bearing is the presence of many resting or non-bearing short shoots on the tree (Jonkers, 1979; Williams and Edgerton, 1974). To prevent biennial bearing, the balance between flower bud formation, fruit set, and shoot growth must be controlled (Tromp and Wertheim, 1980). Early recognition that individual trees or a block of trees will be going biennial is important to the implementation of any cultural practice that may be used to offset biennial bearing in either the "on" or "off" year (Byers et al., 1990).

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CHAPTER TWO

INHIBITING FLOWER BUD FORMATION IN APPLE BY PARTIAL AND WHOLE-TREE DEFOLIATION

Abstract

In 1997 and 1998, the effects of defoliation of apple (*Malus xdomestica* Borkh.) trees were determined on return bloom and fruit set following a light cropping year. 'Braeburn'/M.26 trees were hand-thinned to a crop density (CD) of three fruit/cm^2 trunk cross sectional area (TCSA) on 25 May 1997. Trees were either completely defoliated or half of the tree defoliated by hand, every four weeks, on one of five dates between June and September. Compared to a non-defoliated control, whole-tree defoliation reduced yield efficiency (kg/cm^2 TCSA). Both whole and half-tree defoliation affected fruit weight, firmness, starch, and soluble solids concentration in 1997. In 1998, return bloom and fruit set were reduced by most 1997 defoliation treatments. Compared to other dates, defoliation on 3 July caused the greatest reduction in return bloom in both whole and half-defoliated trees. In another study, 'Braeburn'/M.26 trees were hand-thinned to a CD of 4 on 22 May 1998. Complete defoliation by hand on 1, 15 or 29 July reduced return bloom and fruit set in 1999; the 1 July defoliation resulted in zero return bloom. 'Golden Delicious'/M.9 and 'Ramey York'/M.9 trees with a CD of less than 2 were hand-defoliated on 21 July or 12 August, 1998 by removing every other leaf or removing three of every four leaves over the entire tree. In 1999, return bloom and spur and lateral fruit set were reduced by all defoliation treatments. 'Ramey York'/Mark trees were sprayed with one of three chemical defoliants on 15

July or 5 August, 1998. Gramoxone suppressed spur flowering and fruit set the following year. Ammonium thiosulfate and endothall increased spur flowering but suppressed fruit set the following year. Chemical names used: 1, 1'-dimethyl-4,4'-bipyridinium dichloride (gramoxone); $(H_3N)_2H_2O_3S_2$ (ammonium thiosulfate); Mono N,N-dimethylalkylamine salt of endothall; (endothall).

Introduction

Removal of leaves or defoliation by insects, diseases, or caustic sprays can reduce flower-bud formation, especially if it occurs prior to the period of flower-bud differentiation (Childers et al., 1995). Roberts (1923) found that removal of leaves from non-bearing spurs prevented the development of flower parts in the bud. Defoliation has been used successfully in "off" years to suppress flowering in the following "on" years in apple (Harley et al., 1942; Fulford, 1960). The extent of suppression depends on the cultivar (Davies, 1959), the vigor of the trees (Sahulka, 1967), and the timing (Schumacher and Stadler, 1993). It seems reasonable to hypothesize that, if the leaf area of an apple tree is reduced beyond a certain point, the carbohydrate supply may be restricted to a level at which flower bud differentiation will be reduced (Singh, 1948).

Defoliation can be done by hand (Raven, 1968) or chemically (Fulford, 1970) and can be partial or complete. Hand-defoliation can remove only spur leaves, only extension shoot leaves, only bourse shoot leaves, or any combinations of these three. Harley et al. (1942) reported that removal of all but one leaf per spur on 'Yellow Newtown', 33 days after full bloom, reduced return bloom the following year. In another experiment with the same cultivar, Harley et al.

(1942) removed all but one, two, three, or four leaves per spur 33 days after full bloom. In response to increasing numbers of leaves left, more blossoms formed the following year. Singh (1948) reported that hand removal of two out of every three fully expanded leaves on 'Early Victoria' spurs between early May and mid June reduced the amount of shoot growth but did not reduce flower bud formation. In addition, he found that complete defoliation of young trees prevented flower bud differentiation. Chemical defoliants have included materials such as copper sulfate (Fulford, 1960), sodium chlorate, tar oil, and lime sulphur (Singh, 1948).

As the time of leaf removal is delayed after bloom, the suppression of flowering in the following year is decreased (Davis, 1957; Llewelyn, 1968). The more severe the defoliation, the greater will be the suppression of flowering the following year (Harley et al., 1942; Tustin et al., 1997). The degree and timing of defoliation appear to be important factors in determining the success of defoliation as a control measure against biennial bearing (Fulford, 1960).

Defoliation can also cause fruit abscission. Schumacher and Stadler (1993) removed zero, one-third, one-half, or all leaves on spurs at 0, 10, 20, or 30 days after full bloom (DAFB). With increasingly severe defoliation, at 0 DAFB, natural fruit drop increased. When the spurs were defoliated at 10, 20, or 30 DAFB, fruit drop increased only with complete removal of leaves. In another experiment, defoliation of individual fruit spurs just after full bloom resulted in severe fruit drop, whereas defoliation 30 days after full bloom resulted in no more drop than the control (Llewelyn, 1968).

In New Zealand where the growing season is long, natural leaf drop can occur up to 12 weeks after harvest (Tustin et al., 1997). Bud break and flowering of 'Royal Gala'/M.9 have been delayed by 4 to 6 days by defoliating trees just after harvest Also apple nursery stock has

successfully been defoliated with Dupont WK surfactant, ethephon, or combinations of both (Abusrewil and Larsen, 1981).

The objectives of these experiments were to determine 1) how defoliation timing and severity would affect refoliation, fruit drop, and fruit quality during the growing season; and 2) how defoliation timing and severity would affect flowering and fruiting on both spurs and laterals the following year.

Materials and Methods

All experiments were conducted on the Virginia Tech College of Agriculture and Life Sciences Kentland farm near Blacksburg, Virginia. The orchard is located at an elevation of 2,050 feet above sea level and the general soil type is a Shottower Cobbly loam.

Whole-tree and half-tree defoliation by hand, 1997. Six-year-old 'Braeburn'/M.26 trees spaced 3 x 6.5 m and trained as central leaders were in full bloom on 22 April and were hand-thinned on 25 May to three fruit/cm^2 trunk cross sectional area (TCSA). The trees carried a moderate crop the previous year. The experiment was a completely randomized design 2 x 5 factorial with three replications. The trees used for the half-tree defoliation were divided in half so that there were equal numbers of scaffold branches on both sides of the tree. All leaves were removed by cutting the leaf petiole either from one half of the tree or from the entire tree on one of five dates in 1997. The defoliation dates were approximately four weeks apart. The first defoliation date was 6 June and the last was 26 September. The fruit were harvested on 19 October and yield efficiency (kg fruit/cm^2 TCSA) was determined**.** The fruit were tested for

weight, firmness using a penetrometer, starch using Cornell University's starch-iodine index chart where 1=100% stained for starch and 8=0% stained for starch, and soluble solids concentration using a refractometer. TCSA was measured on 6 June and again the following March to determine the increase in TCSA. In 1998, spur and lateral fruit set/100 flowering clusters were measured.

Whole-tree defoliation by hand, 1998. Seven-year-old 'Braeburn'/M.26 trees spaced 3 x 6.5 m and trained as central leaders were in full bloom on 18 April and were hand-thinned on 22 May to 4 fruit/cm^2 TCSA. The trees carried a moderate crop the previous year. The experiment was a completely randomized design 2 x 3 factorial with three replications. Either no or all leaves were removed by cutting the petiole on 1, 15, or 29 July 1998. The fruit were harvested on 16 October and yield efficiency was determined. The increase in TCSA was measured the following spring. In 1999, spur and lateral flowering and fruit set/100 flowering clusters were measured.

Partial defoliation by hand, 1998. Seven-year-old 'Golden Delicious'/M.9 and 'Ramey York'/M.9 trees spaced 1.5 x 5 m with less than 2 fruit/cm^2 TCSA were selected. The trees carried a heavy crop the previous year. The experiment was a completely randomized design 2 x 2 x 3 factorial with three replications. Zero, 50 or 75 percent of the leaves were removed on either 21 July or 12 August, 1998. The increase in TCSA was determined the following spring. In 1999, two branches per tree were tagged and spur and lateral flowering and fruit set/cm^2 branch cross sectional area (BCSA) were measured. BCSA averaged 3.1 cm^2.

Partial defoliation by chemical, 1998. Twelve-year-old 'Ramey York'/Mark spaced 3.5 x 6.5 m with less than 1 fruit/cm^2 TCSA were selected. The trees carried a heavy crop the previous year. The experiment was a completely randomized design 2 x 3 factorial with three

replications. The trees were divided in half so that there were approximately equal numbers of scaffold branches on both sides of the tree. The trees were sprayed with ammonium thiosulfate (ATS), endothall, or gramoxone on either 15 July or 5 August, 1998. Half of the tree was sprayed and the other half was left unsprayed. Several weeks before the experiment, various rates of each chemical were tested to determine the lowest rate that would provide the desired level of defoliation. The selected rates were: ATS @ 40 $mL \cdot L^{-1}$, endothall @ 12 $mL \cdot L^{-1}$ and gramoxone @ 1 $mL \cdot L^{-1}$. In 1999, two branches on both halves of the tree were tagged and spur flowering and fruit set/cm^2 BCSA were measured. BCSA averaged 3.8 cm^2. The chemical formulations used were: ATS, 12% N, 26% S; endothall, 15.9% acid; and gramoxone, 37%.

Results and Discussion

Whole-tree and half-tree defoliation by hand, 1997. Trees that were completely defoliated on 6 June, 3 July, and 1 August refoliated from the terminal end of the shoot. Blind wood remained where the leaf petioles were cut and the petioles eventually abscised. Trees that were completely defoliated on 29 August and 26 September did not refoliate from the terminal end of the shoot. Severe sunburn of the fruit occurred following the 29 August defoliation.

Whole-trees defoliated on 6 June and 26 September had the lowest yield efficiency among the defoliated trees (Table 2.1). These two dates were also the only dates that had a significant reduction in yield efficiency compared to the control trees. These results are consistent with the findings of Llewelyn (1968) and Schumacher and Stadler (1993) who reported that the earlier the defoliation, the more severe the fruit abscission but defoliations as late as 26 September has not

been previously reported.

There was an interaction between date and treatment for fruit weight, starch and soluble solids concentration (Tables 2.2 to 2.4). Mean fruit weight on the defoliated trees was less than the control trees on all but the last defoliation date (Table 2.2). Defoliation this late was probably too late to affect fruit size, since harvest followed 23 days later. Firmness of fruit was not affected from defoliation (data omitted). Fruit starch levels were lower (higher rating) for trees defoliated at the first four dates than for the control (Table 2.3) and fruit soluble solids concentration levels were lower for the first four defoliation dates (Table 2.4). This is probably due to defoliations on the first four dates causing a reduction in carbohydrate production, which resulted in a higher starch rating and lower soluble solids. The fruit from trees defoliated on the last date had starch ratings and soluble solids similar to the control fruit.

There was no interaction between defoliation and timing on the increase in TCSA (Table 2.5). Whole tree defoliation resulted in 36% less of an increase in TCSA. Tustin et al. (1997) reported that trees which were completely defoliated early had a reduced rate of increase in TCSA compared to trees that were partially defoliated. The timing of defoliation had no effect on the increase in TCSA.

Compared to the control trees, the trees defoliated on the first four dates had less spur fruit set in 1998 (Table 2.6). Defoliation on 3 July, resulted in zero spur fruit set in 1998. Defoliation on 1 August, 29 August, and 26 September resulted in approximately one half as much spur fruit set as the control. Lateral fruit set on the trees defoliated on the 6 June and 26 September was the same as the control trees (Table 2.7). Trees defoliated on 3 July and 1 August had zero fruit set in 1998.

There was no difference in mean fruit weight between the defoliated half and the foliated half of the tree (Table 2.8), but there was a main effect of date on mean fruit weight. Defoliation on 6 June caused the lowest fruit weight. In the whole-tree defoliation experiment, mean fruit weight on defoliated trees was lower for the first four defoliation dates compared to the control (Table 2.2). The average weights were greater for fruit from the half defoliated trees (171 g) compared to fruit from the whole defoliated trees (160 g) (Tables 2.2 and 2.8). The average fruit weight for the control half of the trees (175 g) was 9 g less than the average fruit weight for the control trees (184 g) in the whole tree defoliation experiment. Firmness of fruit from the half defoliated trees was inconsistent (data omitted). Fruit starch was not affected by treatment, but was affected by an interaction of date and treatment (Table 2.9). The defoliated half trees had lower starch levels (higher ratings) than the control half-trees on two of the five defoliation dates. This was similar to the whole-tree defoliated trees. However, the defoliated half trees averaged a 0.5 lower starch rating than the whole-tree defoliated trees (Tables 2.3 and 2.9). The difference in starch rating between the control and the whole-tree defoliated trees was (0.6) (Table 2.3). The difference in starch rating between the control half of the tree and the defoliated half of the tree was (0.1) (Table 2.9). As was the case with fruit weight, only a main effect of date was significant for fruit soluble solids (Table 2.10). There was no difference among the two treatments for soluble solids at any date of defoliation.

Treatment was not significant on the half-tree defoliation for any of the fruit qualities. This suggests that the foliated half of the tree contributed some carbohydrates to fruit on the defoliated half of the trees. Additional support for this suggestion is that fruit from the defoliated half of the tree tended to be heavier, have more starch and more soluble solids than fruit on trees that were

completely defoliated (Tables 2.2 to 2.4, 2.8 to 2.10).

In general, the increase in TCSA was greater as the defoliations were delayed (Table 2.11). On average, the half defoliated trees had an increase in TCSA intermediate between the non defoliated trees and the completely defoliated trees (Tables 2.5 and 2.11).

Fruit set/100 flowering spurs and laterals was determined on both the defoliated half of the tree and the foliated half of the tree in 1998. Spur fruit set on the defoliated half was subtracted from the foliated half. Spur fruit set was greater on the defoliated half of the tree on the 6 June, 29 August, and 26 September defoliation dates (Table 2.12). Spur fruit set was greater on the foliated half of the tree on the 3 July and 1 August defoliation dates. Lateral fruit set was greater on the foliated half of the tree on the first three defoliation dates (Table 2.12). The greatest difference in fruit set was on the 3 July defoliation date for both spur and lateral fruit set which was the same date that resulted in zero fruit set on the whole-tree defoliated trees (Tables 2.6, 2.7, and 2.12). Though spur and lateral flowering was not measured, very few, if any, spurs flowered in 1998 following the 3 July defoliation and very few, if any, laterals flowered following the 3 July and 1 August defoliations. Obviously, if spurs and laterals don't flower fruit set won't occur. Defoliations at these times would not be recommended. However, since lateral fruit is often small and misshapen, (Volz et al., 1994) it may be desirable to defoliate on 1 August. According to these results, this defoliation date would result in approximately half as many spur fruit as the controls and zero lateral fruit. This would encourage the production of spur fruit only.

Whole-tree defoliation by hand, 1998. In 1999, flowering spur clusters on the defoliated trees was zero with the 1 July defoliation date and tended to increase as the defoliation dates were delayed (Table 2.13). The mean for flowering spur clusters also tended to increase as the

defoliation dates were delayed. The control trees averaged 3 times as many flowering spur clusters/cm^2 BCSA as the defoliated trees. Spur fruit set was zero on the 1 July defoliation date due to no flowering occurring. Spur fruit set increased as the defoliation dates were delayed.(Table 2.13). The control trees averaged approximately 4 more spur fruit/cm^2 BCSA than the defoliated trees.

Lateral flowering and subsequent fruit set were similar to spur flowering and fruit set. Defoliation on 1 July caused zero lateral flowering (Table 2.14). Lateral flowering tended to increase as the defoliation dates were delayed. The control trees averaged 3 times more flowering lateral clusters than the defoliated trees. Lateral fruit set was zero from the 1 July defoliation date since no flowering occurred. Fruit set tended to increase as the defoliation dates were delayed. For the control, spur fruit set was almost three times greater than lateral fruit set (Tables 2.13 and 2.14).

In the previous whole-tree defoliation experiment, 1997, July appeared to be a critical time for defoliation to get return bloom on spurs the following year. Defoliation on 3 July resulted in zero fruit set while defoliation on 1 August resulted in 67 fruit/100 flowering spur clusters (Table 2.6). In this whole-tree defoliation experiment, 1998, whole trees were defoliated in early, mid and late July to determine which timings would result in an ideal return bloom and fruit set/cm^2 BCSA which would be more than 0 and less than 67 fruit/100 flowering spur clusters.

Defoliation on 1 July resulted in zero flowering in 1998 which would be very undesirable. Perhaps it would be reasonable to defoliate at a particular time to get a return bloom the following year of approximately 50% which would leave approximately 50% of the spurs resting. Fulford (1960), applied a chemical defoliant that resulted in 62% of the spurs flowering the following

year. In the year after that, 49% of the spurs flowered. On the 15 July defoliation date, 1.4 spur clusters/cm^2 BCSA flowered which is approximately 25% of the mean for the control (Table 2.13). On the 29 July defoliation date, 4.1 spur clusters/cm^2 BCSA flowered which is approximately 67% of the mean for the control. For this experiment, getting 50% of the spurs to flower would fall somewhere between the 15 July and the 29 July timings (Table 2.13).

The suppression of flowering may not reduce fruit set proportionally. Spur fruit set was affected by treatment but not by date. The mean for the 15 and 29 July defoliation dates resulted in approximately four times fewer spur fruit set/cm^2 BCSA than the control (Table 2.13). All the crop loads, resulting from these defoliation dates, are too low. The number of flowering spurs clusters the following year would likely be very high with crop loads this low.

Lateral flowering and fruit set was very similar to spur flowering and fruit set (Table 2.14). Since lateral fruit is less desirable than spur fruit, I would choose a timing that gives the best results for spur flowering and fruit set.

Partial defoliation by hand, 1998. Only the main effect of treatment was significant for spur flowering and fruit set and lateral flowering and fruit set in 1999 (Tables 2.15 to 2.18). Spur flowering was greater for the control trees compared to the defoliated trees for both cultivars and both defoliation dates (Table 2.15). Spur fruit set was also greatest for the control trees in all cases (Table 2.16). There were no differences in spur flowering or spur fruit set between the two defoliation severities or dates of defoliation.

Lateral flowering was greatest for the control trees regardless of cultivar or defoliation date (Table 2.17). Lateral fruit set was also greatest for the control trees in all cases (Table 2.18). For the most part, there were no significant differences in lateral flowering and fruit set between

the two defoliation severities or dates, but there was a consistent trend towards lower flowering and fruit set with the more severe defoliation. Spur fruit set in this experiment was similar to spur fruit set in the preceding whole-tree defoliation experiment (Tables 2.13 and 2.16).

Though spur flowering and fruit set were not significantly different between the two defoliation severities, they tended to be lower when 3/4 of the leaves were removed. When 3/4 of the leaves were removed, spur flowering was always less than 1 flowering spur cluster/cm^2 BCSA (Table 2.15). This resulted in spur fruit sets of less than 1 fruit/cm^2 BCSA in three of the four date and cultivar combinations. When fruit set is this low, the crop is probably not valuable enough to take care of and a snowball bloom will likely occur the following year. In general, removing ½ of the leaves on either date reduced spur flowering and fruit set which resulted in a crop load that should result in adequate flowering the following year. Since lateral fruit is not as important as spur fruit, I would not recommend lateral fruit set as a measure of when and how severe to defoliate.

Partial defoliation by chemical, 1998. ATS resulted in almost 4 more flowering spur clusters/cm^2 BCSA than the control while gramoxone resulted in approximately 3 less flowering spur clusters/cm^2 BCSA than the control in 1999 (Table 2.19). The endothall treatment was similar to the control and not statistically different. Date had no effect on increasing or decreasing spur flowering. Spur fruit set was decreased by all 3 chemical defoliants (Table 2.20). However, the defoliants were not different from one another. Date had no effect on spur fruit set, and there was not a treatment x date interaction.

Of the three chemical defoliants used, leaf scorching was observed within two days on the gramoxone treated trees and within five days on the ATS and endothall treated trees. Singh

(1948) observed scorching after two days using sodium chlorate and tar oil. Fulford (1960) observed scorching and large necrotic areas on leaves after five days following treatments with copper sulfate. After two weeks, leaf drop was approximately 20% for ATS, 60% for endothall and 80% for the gramoxone treated half of the trees. ATS is a fertilizer and most of the treated leaves turned chlorotic and necrotic but remained on the tree. Gramoxone, which is a non-selective herbicide, caused more defoliation than the other two chemicals and also caused some shoot tips to die. Endothall is a desiccant which caused more defoliation than the ATS treatments.

Even though ATS and endothall increased spur flowering, they greatly decreased fruit set compared to the control. The average number of spur fruit set/cm^2 BCSA for the control half of the trees, for both dates, was 13.8. All three chemicals resulted in approximately one half as much fruit set/cm^2 BCSA as the control half of the tree. Fruit set for the defoliated half of the trees was approximately 6/cm^2 BCSA.

Defoliating apple trees at a particular time to get a spur fruit set of approximately 50-60 fruit/100 flowering spur clusters or 4-6 spur fruit/cm^2 BCSA is probably a realistic goal for assuring return bloom the following year. Williams and Edgerton (1974) concluded that a crop load of 50-60 fruit/100 flowering spur clusters would result in a moderate bloom the following year. It has been determined that spur-type 'Golden Delicious' trees in Washington state can adequately size about 60 fruits/100 growing points (E. Stahley and M. Williams, unpublished data). However, to maintain annual cropping, a crop of 40 fruits/100 growing points is about the practical limit. It would appear that the practical aim with 'Golden Delicious' is to crop individual spurs biennially. Williams and Edgerton (1974) recommended removing all the fruit from 50% of the spurs instead of thinning 100% of the spurs to just one fruit.

Defoliating trees by hand would be cost prohibitive. The ideal chemical defoliant would cause enough leaves to abscise to adequately suppress flowering and fruit set the following year without causing permanent damage to the tree. In 1997, completely defoliating trees on 1 and 29 August resulted in 67 and 54 spur fruit/100 flowering spur clusters the following year (Table 2.6). In 1998, completely defoliating trees on 29 July resulted in approximately 2 spur fruit/cm^2 BCSA the following year (Table 2.13). Also in 1998, removing ½ or 3/4 of the leaves resulted in approximately 1-2 spur fruit/cm^2 BCSA the following year (Table 2.16). This is probably too low a fruit set for a good crop and may cause a snowball bloom the following year. Perhaps removing fewer leaves would result in more fruit set but as mentioned earlier, defoliating by hand is cost prohibitive. The chemical defoliants resulted in spur fruit set between 4 and 9.2 fruit/cm^2 BCSA the following year (Table 2.20). Since these defoliants were sprayed on half trees, more work should be done using whole-trees and adjusting the rates and timing. Chemical sprays can cause damage to apple trees from being too caustic or being used at rates that are too high. Singh (1960), injured trees with sodium chlorate and miscible tar oil winter wash resulting in zero fruit buds flowering the following year. The companies that manufacture these chemicals would probably not support a label for their use as a defoliant because of the risk of defruiting trees or causing injury to the trees. Also, there would have to be enough usage to justify pursuing a label. Gibberellic acid may be a better approach to suppressing return bloom with chemical sprays (Chapter 3). They are naturally present in apple and don't cause injury to the trees even at very high rates.

It would be easier to choose rates and timings of defoliation or gibberellic acid if one knew how much return bloom was ideal. I haven't found anything in the literature where someone has

suggested an ideal percent of return bloom or an ideal flower number/cm^2 BCSA or TCSA. However, in two experiments, Fulford (1960) and McArtney (1994), it is interesting that whatever return bloom resulted from a particular treatment, the following year the percent return bloom added to the previous years percent return bloom added up to approximately 100-115. In Fulford's experiment, when a particular treatment resulted in a return bloom of 90%, the following year it would be around 25%. In another treatment, the result was a return bloom of 62%, the following year it was 49%. In McArtney's experiment, in three consecutive years, the control went from 93% to 10.5% to 92.3%. If the percent of any two successive crops adds up to approximately 100-115, than the ideal percent return bloom would be between 50% and 57.5%.

Table 2.1. Effect of whole-tree defoliation in 1997 on yield efficiency (kg/cm^2 TCSA) on 'Braeburn'/M.26 apple trees in October 1997.[Z]

Defoliation date - 1997	DAFB [Y]	Yield efficiency (kg fruit/cm^2 TCSA)[X]	
		Control	Defoliation
June 6	44	0.4 a A[W]	0.1 b B
July 3	72	0.5 a A	0.3 a A
Aug 1	100	0.5 a A	0.4 a A
Aug 29	128	0.5 a A	0.4 a A
Sept 26	156	0.5 a A	0.2 b B
Significance			
Date		0.001	
Treatment		< 0.001	
Date x treatment		0.01	

[Z] Values are means for three replications.
[Y] Days after full bloom.
[X] Fruit harvested on 19 October 1997.
[W] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.2. Effect of whole-tree defoliation in 1997 on mean fruit weight on 'Braeburn'/M.26 apple trees in 1997. [Z]

Defoliation Date - 1997	DAFB [Y]	Mean fruit weight (g)[X]	
		Control	Defoliation
June 6	44	189 a A[W]	148 b B
July 3	72	191 a A	170 a B
Aug 1	100	190 a A	166 a B
Aug 29	128	177 b A	145 b B
Sept 26	156	174 b A	170 a A
Mean		184	160
Significance			
Date		< 0.001	
Treatment		< 0.001	
Date x treatment		< 0.001	

[Z] Values are means for 20 fruit from each of three trees.
[Y] Days after full bloom.
[X] Fruit harvested on 19 October, 1997 and weighed on 26 October 1997.
[W] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.3. Effect of whole-tree defoliation in 1997 on fruit starch rating on 'Braeburn'/M.26 apple trees in 1997. [Z]

Defoliation Date - 1997	DAFB [Y]	Starch rating [X W]	
		Control	Defoliation
June 6	44	5.5 b B [V]	6.1 bc A
July 3	72	5.5 b B	6.0 c A
Aug 1	100	5.7 b B	6.4 b A
Aug 29	128	6.1 a B	6.8 a A
Sept 26	156	5.9 a A	6.0 c A
Mean		5.7	6.3
Significance			
Date		< 0.001	
Treatment		< 0.001	
Date x treatment		< 0.001	

[Z] Values are means for 20 fruit from each of three trees.
[Y] Days after full bloom.
[X] Cornell University's starch-iodine index chart where 1=100% stained for starch and 8=0% stained for starch.
[W] Fruit harvested on 19 October 1997 and tested on 28 October 1997.
[V] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.4. Effect of whole-tree defoliation in 1997 on fruit soluble solids concentration on 'Braeburn'/M.26 apple trees in 1997. [Z]

Defoliation Date - 1997	DAFB [Y]	Soluble solids concentration [X]	
		Control	Defoliation
June 6	44	15.7 ab A[W]	13.2 b B
July 3	72	16.7 a A	13.7 b B
Aug 1	100	15.0 b A	11.1 c B
Aug 29	128	14.5 b A	13.1 b B
Sept 26	156	16.3 a A	15.6 a A
Mean		15.6	13.3
Significance			
Date		< 0.001	
Treatment		< 0.001	
Date x treatment		< 0.001	

[Z] Values are means for three replications.
[Y] Days after full bloom.
[X] Fruit harvested on 19 October 1997 and tested on 28 October 1997.
[W] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.5. Effect of whole-tree defoliation in 1997 on the increase in trunk cross sectional area (TCSA) on 'Braeburn'/M.26 apple trees in 1997.[Z]

Defoliation date - 1997	DAFB [Y]	Increase in TCSA (cm^2)[X]	
		Control	Defoliation
June 6	44	8.5	4.6
July 3	72	7.0	4.5
Aug 1	100	9.3	5.6
Aug 29	128	7.7	5.8
Sept 26	156	7.7	4.9
Mean		8.0 A[W]	5.1 B
Significance			
Date		0.524	
Treatment		0.012	
Date x treatment		0.961	

[Z] Values are means for 20 fruit from each of three trees.
[Y] Days after full bloom.
[X] Increase in TCSA measured 30 cm above the orchard floor between 25 May 1997 and 28 March 1998.
[W] Mean separation between treatments (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.6. Effect of whole-tree defoliation in 1997 on fruit set/100 flowering spur clusters on 'Braeburn'/M.26 apple trees in 1998.[Z]

Defoliation date - 1997	DAFB[Y]	Fruit set/100 flowering spur clusters	
		Control	Defoliation
June 6	44	115 ab A[X]	21 ab B
July 3	72	109 ab A	0 b B
Aug 1	100	103 b A	67 a B
Aug 29	128	135 a A	54 ab B
Sept 26	156	108 ab A	79 a B
Significance			
Date		0.029	
Treatment		< 0.001	
Date x treatment		0.007	

[Z] Values are means for three replications.
[Y] Days after full bloom.
[X] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.7. Effect of whole-tree defoliation in 1997 on fruit set/100 flowering lateral clusters on 'Braeburn'/M.26 apple trees in 1998.[Z]

Defoliation date - 1997	DAFB[Y]	Fruit set/100 flowering lateral clusters	
		Control	Defoliation
June 6	44	24 b A[X]	42 a A
Jul 3	72	30 b A	0 b B
Aug 1	100	23 b A	0 b B
Aug 29	128	44 a A	4 b B
Sept 26	156	24 b A	18 ab A
Significance			
Date		0.176	
Treatment		0.015	
Date x treatment		0.009	

[Z] Values are means for 3 replications.
[Y] Days after full bloom.
[X] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.8. Effect of half-tree defoliation in 1997 on fruit weight (g) on 'Braeburn'/M26 apple trees in 1997.[Z]

Defoliation date - 1997	DAFB [Y]	Mean fruit weight (g)[X]		
		Foliated-half	Defoliated-half	Mean
June 6	44	167	154	161 c[W]
July 3	72	176	163	170 b
Aug 1	100	176	174	175 b
Aug 29	128	193	194	194 a
Sept 26	156	166	175	171 b
Mean		175 A	171 A	
Significance				
Date		< 0.001		
Treatment		0.158		
Date x treatment		0.075		

[Z] Values are means for 20 fruit from each side of three trees.
[Y] Days after full bloom.
[X] Fruit harvested on 16 October 1998 and weighed on 17 October 1998.
[W] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.9. Effect of half-tree defoliation in 1997 on fruit starch on 'Braeburn'/M.26 apple trees in 1997.[Z]

Defoliation date - 1997	DAFB	Starch rating [X W]	
		Foliated-half	Defoliated-half
June 6	44	5.8 b B[V]	6.1 ab A
July 3	72	5.4 c B	5.8 bc A
Aug 1	100	6.3 a A	5.6 cd B
Aug 29	128	6.0 ab A	6.2 a A
Sept 26	156	5.8 b A	5.5 d A
Mean		5.9	5.8
Significance			
Date		< 0.001	
Treatment		0.853	
Date x treatment		< 0.001	

[Z] Values are means for 20 fruit from each side of three trees.
[Y] Days after full bloom
[X] Fruit harvested on 16 October 1998 and tested on 20 October 1998.
[W] Cornell University's starch-iodine index chart where 1=100% stained for starch and 8=0% stained for starch.
[V] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.10. Effect of half-tree defoliation in 1997 on soluble solids concentration on 'Braeburn'/M.26 apple trees in 1997.[Z]

Defoliation date - 1997	DAFB [Y]	Soluble solids concentration[X]	
		Foliated-half	Defoliated-half
June 6	44	16.0 a A[W]	16.6 a A
July 3	72	14.2 b A	15.5 ab A
Aug 1	100	14.0 b A	12.7 c A
Aug 29	128	14.4 b A	13.5 c A
Sept 26	156	16.1 a A	15.2 b A
Mean		14.9	14.7
Significance			
Date		< 0.001	
Treatment		0.347	
Date x treatment		0.034	

[Z] Values are means for 20 fruit from each side of three trees.
[Y] Days after full bloom.
[X] Fruit harvested on 16 October 1998 and tested on 20 October 1998.
[W] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.11. Effect of half-tree defoliation in 1997 on the increase in trunk cross sectional area (TCSA) on 'Braeburn'/M.26 in 1997.[Z]

Defoliation date - 1997	TCSA (cm^2) [Y]
June 6	5.8 c [X]
July 3	5.8 c
Aug 1	7.1 b
Aug 29	6.8 b
Sept 26	8.1 a
Significance	
Date	0.03

[Z] Values are means for 3 replications.
[Y] TCSA measured 30 cm above the orchard floor on 28 March, 1998.
[X] Mean separation within columns (lowercase letters) by Tukey's test $P \leq 0.05$.

Table 2.12. Effect of half-tree defoliation on fruit set/100 flowering spur and lateral clusters on 'Braeburn'/M.26 apple trees in 1998.[Z]

Date of defoliation 1997	Fruit set/100 flowering clusters [Y]					
	Spur			Lateral		
	Foliated half	Defoliated half	Difference	Foliated half	Defoliated half	Difference
June 6	36	79	- 43 d [X]	53	8	45 b
July 3	123	0	123 a	63	0	63 a
Aug 1	52	25	27 b	37	0	37 b
Aug 29	28	45	- 17 c	12	39	- 27 c
Sept 26	29	47	- 18 c	7	28	- 21 c
Significance						
Date			< 0.001			0.018

[Z] Values are means for three replications.
[Y] The control half of the tree minus the defoliated half of the tree.
[X] Mean separation within columns by Tukey's test $P \leq 0.05$.

Table 2.13. Effect of whole-tree defoliation in 1998 on flowering spur clusters and fruit set/cm^2 BCSA on 'Braeburn'/M.26 apple trees in 1999.[Z]

Treatment - 1998	DAFB [Y]	Control	Defoliated	Mean
			Flowering spur clusters/cm^2 BCSA	
1 July	74	5.2	0.0	2.6 b [X]
15 July	88	6.7	1.4	5.3 a
29 July	102	6.3	4.1	4.1 ab
Mean		6.1 A	1.9 B	
Significance				
Date		< 0.001		
Treatment		0.032		
Date x treatment		0.134		
Treatment - 1998			*Fruit set/cm^2 BCSA*	
1 July		4.7	-	-
15 July		5.7	0.7	3.2 a
29 July		5.5	1.9	3.7 a
Mean		5.3 A	1.3 B	
Significance				
Date		0.348		
Treatment		< 0.001		
Date x treatment		0.740		

[Z] Values are means for three replications.
[Y] Days after full bloom.
[X] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.14. Effect of whole-tree defoliation in 1998 on lateral flowering clusters and fruit set/cm^2 BCSA on 'Braeburn'/M.26 apple trees in 1999.[Z]

Treatment - 1998	DAFB [Y]	Control	Defoliated	Mean
			Lateral flowering clusters/cm^2 BCSA	
1 July	74	5.3	0.0	2.6 a [X]
15 July	88	5.8	0.4	3.1 a
29 July	102	4.4	4.7	4.5 a
Mean		5.1 A	1.7 B	
Significance				
Date		0.255		
Treatment		0.002		
Date x treatment		0.076		
Treatment - 1998			*Fruit set/cm^2 BCSA*	
1 July		2.1	-	-
15 July		1.6	0.4	1.0 a
29 July		1.8	1.1	1.4 a
Mean		1.8 A	0.8 B	
Significance				
Date		0.338		
Treatment		< 0.001		
Date x treatment		0.086		

[Z] Values are means for three replications.
[Y] Days after full bloom.
[X] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.15. Effect of partial-tree defoliation in 1998 on flowering spur clusters/cm^2 BCSA on 'Golden Delicious'/M.9 and 'York'/M.9 apple trees in 1999.[Z]

	Defoliation date			
Treatment - 1998	July 21		August 12	
	Golden Del.	York	Golden Del.	York
	Flowering spur clusters/cm^2 BCSA			
Control	6.2 a [Y]	4.4 a	4.0 a	5.2 a
1 / 2 leaves removed	0.8 b	1.3 b	1.2 b	1.0 b
3 / 4 leaves removed	0.6 b	0.2 b	0.9 b	0.5 b
Significance				
Treatment	< 0.001			
Date	0.799			
Cultivar	0.975			
Treatment x date	0.716			
Treatment x cultivar	0.214			
Date x cultivar	0.819			
Trt x date x cultivar	0.307			

[Z] Values are means for three replications.
[Y] Mean separation within columns by Tukey's test $P \leq 0.05$.

Table 2.16. Effect of partial-tree defoliation in 1998 on spur fruit set/cm^2 BCSA on 'Golden Delicious'/M.9 and 'York'/M.9 apple trees in 1999.[Z]

	Defoliation date			
Treatment - 1998	July 21		August 12	
	Golden Del.	York	Golden Del.	York
	Spur fruit set/cm^2 BCSA			
Control	7.6 a [Y]	4.8 a	5.7 a	7.4 a
1 / 2 leaves removed	1.0 b	1.8 b	1.8 b	0.8 b
3 / 4 leaves removed	0.9 b	0.2 b	1.5 b	0.2 b
Significance				
Treatment	< 0.001			
Date	0.996			
Cultivar	0.481			
Treatment x date	0.726			
Treatment x cultivar	0.517			
Date x cultivar	0.852			
Trt x date x cultivar	0.093			

[Z] Values are means for three replications.
[Y] Mean separation within columns by Tukey's test $P \leq 0.05$.

Table 2.17. Effect of partial-tree defoliation in 1998 on flowering lateral clusters/cm^2 BCSA on 'Golden Delicious'/M.9 and 'York'/M.9 apple trees in 1999.[Z]

	Defoliation date			
Treatment - 1998	July 21		August 12	
	Golden Del.	York	Golden Del.	York
	Flowering lateral clusters/cm^2 BCSA			
Control	1.5 a [Y]	2.4 a	3.3 a	2.8 a
1 / 2 leaves removed	0.7 b	1.3 b	1.7 b	0.2 b
3 / 4 leaves removed	0.4 b	0.2 c	1.5 b	0.2 b
Significance				
Treatment	0.008			
Date	0.304			
Cultivar	0.463			
Treatment x date	0.383			
Treatment x cultivar	0.449			
Date x cultivar	0.093			
Trt x date x cultivar	0.965			

[Z] Values are means for three replications.
[Y] Mean separation within columns by Tukey's test $P \leq 0.05$.

Table 2.18. Effect of partial-tree defoliation in 1998 on lateral fruit set/cm^2 BCSA on 'Golden Delicious'/M.9 and 'York'/M.9 apple trees in 1999.[Z]

	Defoliation date			
Treatment - 1998	July 21		August 12	
	Golden Del.	York	Golden Del.	York
	Lateral fruit set/cm^2 BCSA			
Control	2.2 a [Y]	2.9 a	2.9 a	2.7 a
1 / 2 leaves removed	0.5 b	1.3 b	1.3 b	0.3 b
3 / 4 leaves removed	0.2 b	0.2 c	1.2 b	0.2 b
Significance				
Treatment	< 0.001			
Date	0.727			
Cultivar	0.697			
Treatment x date	0.948			
Treatment x cultivar	0.528			
Date x cultivar	0.109			
Trt x date x cultivar	0.759			

[Z] Values are means for three replications
[Y] Mean separation within columns by Tukey's test $P \leq 0.05$.

Table 2.19. The effect of three chemical defoliants in 1998 on the number of flowering spur clusters/cm^2 BCSA on 'Commander York'/Mark apple trees in 1999.[Z]

	Flowering spur clusters/cm^2 BCSA						
Treatment - 1998	Defoliation date						
	July 15			August 5			
	Control half	Def. half	Difference	Control half	Def. half	Difference	Mean
ATS	8.7	12.6	- 3.9 [Y]	11.1	14.8	- 3.7	- 3.8 a [X]
Endothal	9.0	10.3	- 1.3	13.2	13.4	- 0.2	- 0.7 ab
Gramoxone	12.4	8.5	3.9	11.0	8.8	2.2	3.1 b
Mean			0.4 A			0.5 A	
Significance							
Treatment			0.009				
Date			0.949				
Treatment x date			0.764				
ATS vs. control			0.010				
Endothal vs. control			0.603				
Gramoxone vs. control			0.044				

[Z] Values are means for three replications

[Y] The control half of the tree minus the defoliated half of the tree.

[X] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 2.20. The effect of three chemical defoliants in 1998 on spur fruit set/cm^2 BCSA on 'Commander York'/Mark apple trees in 1999.[Z]

Treatment - 1998	Spur fruit set/cm^2 BCSA						
	Defoliation date						
	July 15			August 5			
	Control half	Def. half	Difference	Control half	Def. half	Difference	Mean
ATS	17.4	5.9	11.5 [Y]	11.7	9.2	2.5	7.0 a [X]
Endothal	11.0	4.3	6.7	14.0	6.8	7.2	6.5 ab
Gramoxone	16.9	4.0	12.9	11.8	4.6	7.2	9.3 b
Mean			10.4 A			5.6 A	
Significance							
Treatment			0.528				
Date			0.087				
Treatment x date			0.167				
ATS vs. control			0.001				
Endothal vs. control			0.003				
Gramoxone vs. control			< 0.001				

[Z] Values are means for three replications

[Y] The control half of the tree minus the defoliated half of the tree.

[X] Mean separation within columns (lowercase letters) and rows (uppercase letters) by Tukey's test $P \leq 0.05$.

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CHAPTER THREE

INHIBITING FLOWER BUD INITIATION IN APPLE WITH GIBBERELLIC ACID

Abstract

Gibberellic acid treatments were evaluated to suppress flower bud formation in "off" or light crop years and thereby reduce biennial bearing in apple (*Malus* x*domestica* Borkh.). In 1999, 8-year-old 'Braeburn'/M.26 trees were rated as having a very light or heavy fruit load. The heavy fruit load trees were hand thinned on 9 June to four fruit/cm^2 trunk cross sectional area (TCSA). The light fruit load trees had a crop load of 0 to1 fruit/cm^2 TCSA. The trees were sprayed with one application of 400 $mg \cdot L^{-1}$ GA_3 or four applications of 100 $mg \cdot L^{-1}$ GA_3. GA_3 did not suppress flowering in 2000 of the very light crop load trees, and the heavy crop load trees had no return bloom, regardless of treatment. Also in 1999, 3-year-old 'Ramey York'/M.9 trees were defruited and sprayed with 100 $mg \cdot L^{-1}$ GA_3 ,100 $mg \cdot L^{-1}$ $GA_{4+7,}$ or left unsprayed as a control. The surfactant Regulaid was applied at 1.3 $mL \cdot L^{-1}$ in all treatments. Treatments were applied at 4, 6 and 8 weeks after full bloom (WAFB); 6, 8 and 10 WAFB; or 8, 10 and 12 WAFB. The GA_{4+7} treatments suppressed return bloom of both spur and lateral flowers more than the GA_3 treatments. The effectiveness of GA declined with delayed application. Both GA treatments reduced lateral flowering the most on the basal 1/3 of the shoot. In 2000, the 1999 GA experiment on 'Ramey York' was repeated. The rates and timing of GA sprays were the same with the exception that Tween 20 replaced Regulaid as the surfactant. GA_{4+7} effectively suppressed flowering more than did GA_3. However, spur fruit set was not affected by either GA treatment or timing. In another

experiment, 8-year-old 'Ramey York'/M.9 trees were defruited or thinned to approximately three fruit/cm^2 TCSA. Four branches per tree were girdled and sprayed with 100 mg·L^{-1} GA_{4+7} (every 2 weeks), 100 mg·L^{-1} GA_{4+7} + 50 g·L^{-1} D-Sorbitol (twice a week), 50 g·L^{-1} D-Sorbitol (twice a week) or left unsprayed as a control. Tween 20 @ 1.3 mL·L^{-1} was used in all treatments. Both GA_{4+7} and GA_{4+7} + sorbitol reduced spur flowering compared to sorbitol alone and the control on trees with both crop loads. Both GA_{4+7} treatments increased fruit set compared to the control for the defruited trees, but fruit set on the thinned trees was similar for all treatments. Both GA treatments reduced the percent of laterals flowering over sorbitol alone and the control on defruited trees but not thinned trees. Lateral fruit set was greater for the two GA treatments than the sorbitol only or control treatments on the defruited trees, but treatments did not differ on thinned trees. In another experiment, 8-year-old 'Braeburn'/M.26 trees were thinned by hand to three fruit/cm^2 TCSA and were sprayed every two weeks between 24 May and 21 June with 250 mg·L^{-1} GA_3 + 40 mg·L^{-1} Tween 20, 100 mg·L^{-1} GA_{4+7} + 40 mg·L^{-1} Tween 20, 40 mg·L^{-1} Tween 20 only or left unsprayed as a control. The percent flowering laterals and lateral fruit set were greatly reduced by both GA treatments on the proximal and middle thirds of the shoots. Lateral flowering was almost identical for both GA treatments.

Introduction

There are more than 80 known gibberellins (Fosket, 1994). GA stimulates stem elongation in many plants, causes bolting in rosette plants, reduces the juvenility time in some conifers, replaces the cold period needed for seed germination, breaks apical bud dormancy, and can cause

sexual differentiation in some monoecious plants (Taiz and Zeiger, 1998). GA also promotes flower bud initiation (FBI) and flowering in long-day plants even when kept in non inductive conditions (Taiz and Zeiger, 1998; Kamuro et al., 2001). Apple trees do not appear to be photoperiodic and some GAs inhibit flowering in apple (Dennis and Edgerton, 1966; Tromp,1973; Tromp, 1982; Meador and Taylor, 1987).

After the discovery of gibberellic acid (GA) in apple seeds and its effect on FBI, researchers began applying GAs exogenously at different rates and timings with various results. Of the known GAs, GA_3, GA_4, $GA_{7,}$ and GA_{4+7} are most often used in attempts to suppress flowering. It appears that, in this group, GA_4 is least inhibitory, GA_7 is most inhibitory, and GA_3 and GA_{4+7} are intermediate in their ability to inhibit flowering (Tromp, 1982; McArtney and Li, 1998). GA_3 is not naturally present in apple but will trigger responses such as reduction of FBI (Tromp, 1982; McArtney, 1994; Prang et al., 1997) and induction of parthenocarpic fruit (Luckwill, 1959; Dennis and Nitsch, 1966). GA_3 inhibits FBI in other fruit crops such as peach (Byers et al., 1990) and apricot (Southwick and Yeager, 1991). Marino and Greene (1981) discovered that GA_3 and GA_{4+7} decreased FBI on 1-year-old wood as well as spurs of apple. GA_4, though endogenous to apple, did not decrease FBI and occasionally increased FBI (Looney et al., 1985; Greene, 1993). GA_7 reduced FBI more than did GA_3 (McArtney and Li, 1998). A combination of GA_{4+7} is available commercially and has been shown to reduce FBI (McLaughlin and Greene, 1984; Meador and Taylor, 1987). Dennis and Edgerton (1966) and Tromp (1973) found GA_{4+7} to be more effective than GA_3 at suppressing FBI on ‘Baldwin’, ‘McIntosh’ and ‘Wealthy’.

The timing of GA application is very important for suppressing FBI. In general, one application made during the first 2 weeks after bloom is as effective as multiple applications made

several weeks after bloom on return bloom on spurs (Greene, 1989; Marino and Greene, 1981; Tromp, 1982). On 1-year-old wood, GA applied just after full bloom had no effect on reducing FBI (McArtney, 1994). However, when GA was applied between 6 and 12 weeks after full bloom, it did suppress FBI on 1-year-old wood (McArtney and Li, 1998).

Also, the effect of GA_{4+7} on FBI is inversely related to concentration (Meador and Taylor, 1987). GA_{4+7} at 300 mg· L^{-1} applied 10 days after full bloom reduced FBI on fruit spurs and lateral flowers but was more effective on spurs (Marino and Greene, 1981). GA_{4+7} at 250 mg·L^{-1} or 500mg·L^{-1} applied once a month beginning 1 month after petal fall eliminated 95% or 99% of return bloom, respectively on young trees (Unrath and Whitworth, 1991). Meador and Taylor (1987) found that rates as low as 20 mg·L^{-1} of GA_{4+7} reduced FBI on apple if the applications began shortly after full bloom.

Since exogenous applications of GA inhibit FBI, they can be used as a tool for inhibiting excessive FBI in the "off " year (Buban and Faust, 1982). The results from applying GA to inhibit flowering in the "off" year will depend on the crop load, the type of GA used, the rate, the timing, and whether or not multiple applications are made.

The objective of the following experiments was to evaluate various GA treatments applied in the "off" year to suppress flowering and reduce fruit set in the subsequent "on" year. The rates and timings of the applications were designed to result in moderate flowering and fruiting the following year instead of a snowball bloom and a heavy fruit set which typically occurs after the "off year".

Materials and Methods

All experiments were conducted on the Virginia Tech College of Agriculture and Life Sciences Kentland farm near Blacksburg, Virginia. The orchard is located at an elevation of 2,050 feet above sea level and the general soil type is a Shottower Cobbly loam.

'Braeburn', 1999. Eight-year-old 'Braeburn'/M.26 trees spaced 3 x 6.5 m and trained to a central leader system were rated in early May as having a very light or heavy crop load. The heavy crop load trees were hand-thinned on 9 June to four fruit/cm^2 trunk cross sectional area (TCSA). The very light crop load trees carried less than one fruit/cm^2 TCSA and were not thinned. Full bloom occurred on 27 April. The experiment was a randomized complete block design 2 x 2 x 2 factorial. Three trees from each of the two crop loads were assigned to each chemical treatment for a total of six trees per treatment. The trees were sprayed with one application of 400 $mg \cdot L^{-1}$ GA_3 (Release^R LC; Abbott Labs., North Chicago, Ill.) + 1.3 $mL \cdot L^{-1}$ Regulaid; (Kalo, Overland Park, Kans.), one application of 1.3 $mL \cdot L^{-1}$ Regulaid only, four applications of 100 $mg \cdot L^{-1}$ GA_3 + 1.3 $mL \cdot L^{-1}$ Regulaid, or four applications of 1.3 $mL \cdot L^{-1}$ Regulaid only. The trees that received one spray application were sprayed on 19 July. The trees that received four spray applications were sprayed approximately every 2 weeks from 28 June to 10 August. The trees were sprayed to runoff with a 57 L Solar sprayer. Ten actively growing shoots per tree were tagged on 13 July and terminal bud set was determined on 11 August. In the spring of 2000, lateral flowering and fruit set were determined.

'York', 1999. Three-year-old 'Ramey York'/M.9 trees spaced 1.5 x 5.0 m and trained to a vertical axis system were used. Full bloom occurred on 29 April, and the trees were defruited by

hand on 22 May. This was the first year the trees flowered. The trees were sprayed with 100 mg·L^{-1} GA_{4+7} (Provide^{R}; Abbott Labs., North Chicago, Ill.)+ 1.3 mL·L^{-1} Regulaid, 100 mg·L^{-1} GA_3 + 1.3 mL·L^{-1} Regulaid, or just 1.3 mL·L^{-1} Regulaid.

The trees were sprayed at approximately 4,6, and 8 weeks after full bloom (WAFB), 6,8, and 10 WAFB, or 8,10, and 12 WAFB. The trees were sprayed to runoff with a 6.0 L compressed air sprayer. The experiment was a completely randomized design 3 x 3 factorial plus an unsprayed control. There were nine replications per treatment. Ten shoots per tree were tagged on 2 May, and their length was measured approximately every two weeks from 2 May until 4 August. Nearly all terminal buds had set by 21 July. In the spring of 2000, flowering and non-flowering spurs were counted on a whole-tree basis. The percentage of spurs flowering and fruit set/100 flowering spurs were determined. Flowering and non-flowering lateral buds were counted on ten shoots per tree. The shoots were divided into equal thirds. The percentage of lateral buds flowering and fruit set/100 flowering lateral clusters were determined.

'York', 2000. This experiment repeated the 'York' 1999 experiment using the same trees (now 4 years old) which were re-randomized for this experiment. Full bloom occurred on 24 April, and all trees were defruited by hand on 15 and 16 May. The trees were sprayed with 100 mg·L^{-1} GA_{4+7} + 1.3 mL·L^{-1} Tween 20 (polyoxyethylene sorbitan monolaurate), 100 mg·L^{-1} GA_3 + 1.3 mL·L^{-1} Tween 20, or just 1.3 mL·L^{-1} Tween 20. The trees were sprayed at approximately 4,6, and 8 WAFB, 6,8, and 10 WAFB or 8,10, and 12 WAFB. The trees were sprayed to runoff with a 6-L compressed-air sprayer. The experiment was a completely randomized design 3 x 3 factorial plus an unsprayed control. There were nine replications per treatment. Eight shoots per tree were tagged, and their length was measured approximately every two weeks from 23 May to 18 July .

The only differences from the 'York' 1999 experiment were that Tween 20 was used as the surfactant instead of Regulaid, percentage spur flowering and fruit set were determined using three scaffold branches per tree instead of using the whole tree, and percent lateral flowering and fruit set were determined using eight branches per tree instead of ten.

'York' girdling, 2000. Eight-year-old 'Ramey York'/M.9 trees spaced 1.5 x 5.0 m and trained to a central leader system were in full bloom on 24 April. Trees were either defruited or hand thinned to approximately three fruit/cm^2 TCSA on 19 May, when average fruit diameter was 20 mm. Four branches averaging 1.8 cm in diameter were selected per tree and girdled on 23 May. Each girdle was approximately 2.5 cm in width and was left uncovered. At harvest, callus tissue had not closed the girdle. The four branches were sprayed with 100 $mg \cdot L^{-1}$ GA_{4+7} + 1.3 $mL \cdot L^{-1}$ Tween 20 (every 2 weeks), 100 $mg \cdot L^{-1}$ GA_{4+7} + 50 $g \cdot L^{-1}$ D-Sorbitol + 1.3 $ml \cdot L^{-1}$ Tween 20 (twice a week), 50 $g \cdot L^{-1}$ D-Sorbitol + 1.3 $mL \cdot L^{-1}$ Tween 20 (twice a week), or left unsprayed as a control. The treatments began on 24 May and ended on 21 June. The trees were sprayed to runoff with a 6-L compressed-air sprayer. The experiment was a 2 x 4 factorial, randomized complete block design with ten replications. The branches were supported to prevent them from breaking at the girdle. The percent of spur and lateral flowering and the percentage of spur and lateral fruit set was determined for each branch in 2001.

'Braeburn', 2000. On the basis of equalizing costs, GA_3 was used at 2.5 x the rate of GA_{4+7} to determine if they had the same effect on suppressing lateral flowering and fruit set. Eight-year-old 'Braeburn'/M.26 trees spaced 3.0 x 6.5 m and trained to a central leader system were used for this study. Full bloom occurred on 22 April. The trees were thinned by hand to three fruit/cm^2 TCSA on 22 May. Average fruit diameter was 27 mm at the time of thinning. The trees

were sprayed every 2 weeks between 24 May and 21 June with 250 $mg \cdot L^{-1}$ GA_3 + 1.3 $ml \cdot l^{-1}$ Tween 20, 100 $mg \cdot L^{-1}$ GA_{4+7} + 1.3 $mL \cdot L^{-1}$ Tween 20, 1.3 $mL \cdot L^{-1}$ Tween 20 only or left unsprayed as a control. The trees were sprayed to runoff with a 57 L Solar sprayer. The percent of lateral flowering and fruit set was determined in 2001.

Results

'Braeburn' 1999. Lateral flowering in 2000 was affected only by the main effect of crop load in 1999 (Table 3.1). The various treatments had little to no effect on the percent of laterals flowering in 2000. The heavy crop load trees had zero lateral flowering the following year. All of the light crop load trees had some lateral flowering, but none of the treatments was significantly different from the others (Table 3.1).

Only the main effect of treatment was significant in the setting of terminal buds (Table 3.2). Both GA_3 treatments delayed terminal bud set compared to the control treatments.

'York' 1999. Since there was no interaction between timing and chemical treatment at (0.05 level) for percent flowering spurs, main effects are presented in Table 3.3. Both timing and treatment were highly significant (Table 3.3). Treatments applied at the earliest timing, 4, 6, and 8 WAFB, suppressed spur flowering more than either of the later timings. Both GA treatments led to significantly lower flowering percentages than did the control treatment. GA_{4+7} suppressed spur flowering more than GA_3.

Fruit set/100 flowering spurs in 2000 tended to be higher in trees treated at the earliest timing in 1999 (Table 3.3). These trees had the lowest percentage of spurs flowering. Both GA's

suppressed spur flowering but fruit set was similar to the control treatment (Table 3.3).

The interaction for only two of six response variables involved with lateral flowering and fruit set were significant (0.05 level) so main effects are presented (Table 3.4). On the proximal third of the shoot (PTS), the effect of GA treatments in suppressing flowering declined as the treatments were delayed. Both GA treatments suppressed flowering percentages more on the PTS than did control; GA_{4+7} was more effective than GA_3. On the PTS, fruit set was lowest with the earliest timing and both GA treatments suppressed fruit set compared to the control treatment.

On the middle third of the shoot (MTS) the earliest and second timing suppressed flowering more than the latest timing (Table 3.4). Both GA treatments suppressed flowering percentages on the MTS compared to control trees. Again, GA_{4+7} suppressed lateral flowering more than did GA_3. Fruit set was similar for all three timings on the MTS; however, both GA treatments suppressed fruit set compared to the control.

On the distal third of the shoot (DTS), the trees treated at the earliest timing had the highest percentage of laterals flowering, though all three timings were high (Table 3.4). GA_{4+7} suppressed lateral flowering more than did GA_3, which did not differ from the control. Fruit set was lowest for the latest timing. GA_{4+7} treated branches had higher fruit set on the DTS than the Regulaid treated branches and those treated with GA_3. In general, the PTS had the least flowering and the least fruit set while the DTS had the most flowering and the highest fruit set (Table 3.4).

Shoot growth between 2 May and 4 August was increased by both GA treatments but timing and the treatment x timing interaction were not significant (Table 3.5).

'York' 2000. The interaction between timing and treatment was significant for percent flowering spurs and not significant for spur fruit set; only the main effects are presented in Table

3.6. Only the treatments applied at the earliest timing, 4, 6, and 8 WAFB, suppressed spur flowering (Table 3.6). Only GA_{4+7} suppressed flowering. Fruit set/100 flowering spurs was similar for all timings and treatments.

For lateral flowering and fruit set, five out of six interactions were significant (Tables 3.7 to 3.9. Lateral flowering on the proximal third of the shoot (PTS) was suppressed by both GA_{4+7} and GA_3 at the earliest timing (Table 3.7). Only GA_{4+7} suppressed flowering at the middle timing, and neither GA treatment suppressed flowering at the latest timing. Lateral flowering on the middle third of the shoot (MTS) was also suppressed by both GA_{4+7} and GA_3 at the earliest timing (Table 3.8). There was no significant flower suppression at the middle and latest timings. On the distal third of the shoots (DTS), lateral flowering was suppressed by the GA_{4+7} treatment on the earliest and latest timing. Both GA_{4+7} and GA_3 suppressed flowering at the middle timing (Table 3.9). On the DTS, GA-treated trees at the latest timing all had the least flowering, which was not the case for the PTS and MTS. Lateral flowering on the control only shoots was lowest on the PTS and greatest on the DTS (Tables 3.7 to 3.9).

Lateral fruit set was also affected by the interaction of treatment and timing. GA_{4+7} at the earliest and middle timing resulted in the least fruit set on the PTS (Table 3.7.). GA_3 treated limbs also had less fruit set than the surfactant only (Table 3.7). As the timing of the treatments was delayed, the GA_{4+7} treated limbs had increased fruit set, but the GA_3 treated limbs were less consistent. On the MTS, GA_{4+7}-treated limbs had less fruit set than the other treatments for the early and middle timings (Table 3.8). GA_3 was not significantly different than the control for any of the timings (Table 3.8). $GA_{4+7,}$ but not $GA_{3,}$ treatments resulted in increased fruit set on the MTS as the timing was delayed. GA_{4+7} had the least fruit set on the DTS only on the earliest timing

(Table 3.9). Fruit set was similar for all treatments on the second and third timings. Overall, fruit set was generally lowest at the first timing and higher on the third timing.

The main effect of treatment was significant for the increase in shoot length during the 2000 growing season (Table 3.10). Both GA treatments significantly increased shoot length over the control trees.

'York' girdling 2000. The interaction between treatment and crop load was significant for the percent of spurs flowering (Table 3.11). Both GA_{4+7} and GA_{4+7} + sorbitol reduced spur flowering compared to sorbitol alone and the control on trees with both crop loads. The defruited trees had significantly more spur flowering than the thinned trees among all treatments (Table 3.11). GA_{4+7} with or without sorbitol resulted in significantly more fruit set than the control for the defruited trees, but fruit set on the thinned trees was similar for all treatments. All the thinned trees had very low fruit set.

Both GA treatments reduced the percent of laterals flowering compared to sorbitol alone and the control on defruited trees but not thinned trees (Table 3.12). The defruited trees had much more flowering than the thinned trees. Like the spur flowering results, lateral fruit set was greater for the two GA treatments than the sorbitol only or control treatments on the defruited trees but treatments did not differ on thinned trees (Table 3.12). All the thinned trees had very low fruit set.

'Braeburn' 2000. Percent flowering laterals was greatly reduced by both GA treatments on the proximal and middle thirds of the shoots (Table 3.13). Both GA treatments increased flowering on the distal third of the shoots. Lateral flowering was almost identical for both GA treatments. There was a gradual increase in flowering, going from the proximal third to the distal third, on the control. (Table 3.13). Lateral fruit set was greatly reduced by both GA treatments on

the proximal and middle thirds of the shoots. On the distal third of the shoots, fruit set on the GA treated trees was similar to the control. Fruit set was similar for all sections of the shoots for the control.

Discussion

'Braeburn' 1999. As crop load increases, less GA should be required to inhibit FBI, since seeds are producing GA, which should inhibit FBI. Or, as crop load increases and the same rates of GA are applied, one would expect the least FBI on the trees with the heaviest crop load. These results show that a heavy crop load will entirely eliminate return bloom with or without a GA_3 treatment on Braeburn (Table 3.1). This is consistent with Guttridge (1962) and Greene (2000) who reported that GA was most effective in suppressing FBI on trees with the highest crop load. McArtney (1998), found that 55% of the nodes on 1-year-old wood flowered compared to only 19% in this experiment when using similar rates and timings of GA_3. McArtney explained that New Zealand's growing season is long and perhaps more applications are needed to reduce lateral flowering.

Of the two control-only treatments, an average of 17% of the 1-year-old wood flowered. Perhaps all the trees were thinned too late or 5 fruit/cm^2 TCSA may have been too much fruit to leave on the trees. In my observation, Braeburn is inconsistent in flowering on one-year-old wood.

'York' 1999. Both GA_3 and GA_{4+7} treatments suppressed flowering on spurs and laterals in the following year (Table 3.3). These results are consistent with the findings of Dennis and Edgerton (1966) Marino and Greene (1981), Tromp (1982) and McArtney (1994). However,

Fulford (1973) concluded that GA only reduced FBI on some cultivars. GA_{4+7} was more effective than GA_3 at suppressing spur and lateral flowering. Dennis and Edgerton (1966) and Marino and Greene (1981) found GA_{4+7} to be more effective at reducing FBI than GA_3. Jonkers (1979) reported that GA_3 was inconsistent in reducing FBI.

Although spur flowering was suppressed by both GA treatments, fruit set was not (Table 3.3). The earliest application of the GAs suppressed spur flowering the most. This is consistent with work by Marino and Greene (1981), Tromp (1982) and Greene (1989). GA is most effective at suppressing FBI on spurs when it is applied shortly after full bloom. However, suppressing spur flowering doesn't necessarily reduce fruit set. When a frost kills most of the flowers on a tree, the fruit set from the surviving flowers is often high on a percentage basis. Williams (1979), reported that generally lower bloom densities result in a larger percent of flowers that will set fruit. It seems that the fewer spurs that flower, the more fruit that sets per flowering spur. In this experiment, spur fruit set was not affected by type of GA or when the GAs were applied.

The earliest timing caused the greatest suppression of lateral flowering in the PTS (Table 3.4). However, it led to the highest percentage of flowering in the DTS. This is probably because the earliest treatments began about the time the PTS growth ended. The high percentage of flowering in the DTS is probably due to the earliest and middle treatments ending around the time the DTS began to grow. This is consistent with McArtney (1994) who reported that suppression of FBI by GA_3 and GA_{4+7} was restricted to tissues which existed at the time of treatment. Similarly, the latest timing wasn't as effective at suppressing flowering on the PTS and MTS because these sections of the shoot had grown before the latest timing of GA was applied.

GA_{4+7} suppressed flowering more than GA_3 in all three shoot sections. This is consistent

with the findings of Tromp (1982). McArtney (1998) found GA_7 to be more effective than GA_3 at suppressing flowering on 1-year-old shoots. Both GA treatments suppressed flowering compared to the control in the PTS and the MTS; but only GA_{4+7} was significantly different from the control in the DTS.

Lateral fruit set appears to behave differently than spur fruit set. With spurs, heavy sets often occur even when flowering is greatly reduced (Table 3.3). With laterals, the set appears to be more proportional to the flowering (Table 3.4).

Though spur fruit set was not significantly different than the control-only treatment (Table 3.3), having more spurs remaining vegetative may be beneficial for flowering the following year. The rate and timing of GA_{4+7} used in this experiment (Table 3.4) resulted in very little lateral flowering and fruit set on the PTS and the MTS. The rate and timing of GA_{4+7} resulted in more lateral fruit set on the DTS than the GA_3 or control treatments. Since lateral fruit is often small and misshapen (Volz et al., 1994), it may be desirable to apply GAs later than 12 WAFB to suppress lateral flowering and fruit set even more. Applying GAs earlier would most likely suppress spur flowering more. Applying GAs later would most likely suppress lateral flowering more on the DTS.

Both GA treatments increased shoot length (Table 3.5). This was consistent with results from (Hull and Lewis, 1959), who showed that gibberellin increased shoot length by lengthening internodes in apple, peach, and cherry.

'York' 2000. This experiment was deliberately designed to be similar to the *'York' 1999* experiment. The only difference was that the surfactant Tween 20 was used instead of Regulaid.

Only the earliest timing of the GA treatments suppressed spur flowering (Table 3.6). This is

consistent with the results from the 'York*' 1999* experiment. However, the percentage of spurs flowering was greater overall than in the 1999 experiment. Spur fruit set was similar for all timings and was less overall than in the 1999 experiment. In 1999, fruit set per 100 flowering spurs averaged 133, while in the 2000 experiment it only averaged 82 fruit per 100 flowering spurs.

The GA_{4+7} treatment suppressed spur flowering significantly more than the other treatments (Table 3.6) which is consistent with the 1999 experiment (Table 3.3). However, suppression was greater in the 1999 experiment. The GA_3 treatment suppressed spur flowering compared to the control treatment in 1999 but not in 2000. Spur fruit set was similar for all treatments in both the 1999 and 2000 experiments. However, again there was higher fruit set in the 1999 experiment (Table 3.3) than in 2000 (Table 3.6). The main difference between these two experiments is that in 1999 spur flowering was suppressed more than in 2000, but spur fruit set was greater in 1999 than in 2000.

For lateral flowering, the earliest timing had the greatest suppression in the PTS (Table 3.7) and the MTS (Table 3.8) with the highest percentage of flowering in the DTS (Table 3.9). The same results occurred in the 1999 experiment. This is consistent with the results of McArtney (1994). GA_{4+7} generally suppressed lateral flowering more than the GA_3 treatments regardless of timing or branch location (Tables 3.7 to 3.9). Lateral fruit set was consistently lower for the GA_{4+7} treated trees than the other treatments for the earliest and middle timing. Overall, lateral flowering and fruit set was similar to the 1999 experiment.

Both GA treatments increased shoot length (Table 3.10). This was consistent with the results from the 1999 experiment.

'York' girdling 2000. This experiment was designed to determine if applying sorbitol

would offset the effect of applying GA. Sorbitol is the primary sugar imported by apple fruit, although some sucrose and other sugars may also be translocated (Archibold, 1999). Though there were differences among treatments, crop load appears to have played a greater role in suppressing flowering and fruit set than did the treatments (Tables 3.11 and 3.12). This is consistent with Guttridge (1962) and Greene (2000) who determined that apple trees sprayed with GA developed the least FBI where the crop load was greatest. The thinned trees may have been thinned too late or perhaps 3 fruit/cm^2 TCSA was too many fruit for a good return bloom on these 'York' trees.

The percent of spurs flowering was always less where the trees had been thinned instead of defruited. This may have been due to GA being produced by the seeds and contributing to flower suppression. The sorbitol-only treatment and the control were significantly different from the GA_{4+7} treatments on spur flowering, suggesting that the applied GA had a slight effect on flowering but not as much as crop load. As shown in the 'York' 1999 experiment (Table 3.3), when GA suppresses flowering on spurs it often results in increased fruit set compared to the control. Both GA treatments resulted in about one half of the spurs flowering the following year. This is probably an ideal situation where half the spurs flower and the other half remain vegetative.

The percent of laterals flowering was always greater when the trees had been defruited. This is consistent with Greene (2000), who found that flowering is difficult to inhibit with GA when applied to vegetative trees in the "off" year. It is also consistent with previous work reporting that seeds produce relatively large amounts of GA that reduce flower initiation (Guttridge, 1962; Jonkers, 1979). Since lateral fruit is often of inferior quality (Volz et al. 1994), the low flowering and fruiting percentages for the thinned trees may be advantageous. However, spur fruit set was very low which was not advantageous. Sorbitol-only treatments were very

similar to the control in all cases, suggesting that the rate was too low, it wasn't applied frequently enough, or it wasn't taken up by the plant.

'Braeburn' 2000. In this experiment GA_3 was used at 2.5 times the rate of GA_{4+7} since GA_{4+7} is approximately 2 ½ times more expensive than GA_3. The results were very similar in that both GAs significantly reduced lateral flowering and fruit set. The treatments were terminated 9 weeks after full bloom and had they been applied farther into the growing season, perhaps flowering and fruit set would have been further reduced on the distal third of the shoots. McArtney (1994) applied GAs at full bloom on Braeburn and none of the treatments affected lateral flowering the following year. McArtney and Li (1998) applied GAs up to12 WAFB on Braeburn and got the most suppression of lateral flowering on the latest treatment. However, in both experiments, McArtney measured lateral flowering on the whole shoot not on thirds of the shoot.

GAs applied exogenously can inhibit FBI on apple trees. However, suppressed flowering does not always result in proportionally decreased fruit set. Many factors play a role in determining whether or not GAs will be effective at suppressing flowering for the following year such as: type of GA used and its concentration, the timing of the application(s) and whether or not multiple applications are made. Other factors include cultivar, crop load, tree vigor and climatic conditions.

The key to getting GAs to suppress FBI consistently when applied in the "off" year may be to apply them at the concentration and the time when buds are at a particular stage of development. This may require weekly applications over several weeks particularly to inhibit FBI in lateral buds which are formed over an extended period of time. Problems with this approach are that in the "off" year, growers don't typically spray the trees often, and the cost of multiple applications may be prohibitive. Recommendations for a GA application for suppressing flowering

in the “off” year may eventually be developed, but to date have been very elusive.

Table 3.1. Effect of GA_3 applied in 1999 to 'Braeburn'/M.26 apple trees with light or heavy crop loads on the percentage of laterals flowering in 2000.[Z]

Treatment in 1999 [Y]	Number of applications	Percent laterals flowering in 2000	
		Light crop load (< 1 fruit/cm^2 TCSA)	Heavy crop load (4 fruit/cm^2 TCSA)
GA_3 @ 400 mg·L^{-1}	1 [X]	23	0.0
GA_3 @ 100 mg·L^{-1}	4 [W]	14	0.0
Control	1	15	0.0
Control	4	20	0.0
Mean		18 A [V]	0.0 B
Significance			
Crop load	< 0.001		
Chemical	0.444		
Crop load x chemical	0.287		

[Z] Values are means for three trees with ten branches per tree.
[Y] Regulaid applied at 1.3 mL·L^{-1} in all treatments.
[X] Applied on 19 July.
[W] Applied on 28 June, 12 July, 26 July, and 10 Aug.
[V] Mean separation within lines (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 3.2. Effect of GA_3 applied in 1999 on percent terminal bud set by 11 August 1999 for two crop loads of 'Braeburn'/M.26 apple trees.[Z]

Treatment in 1999[Y]	Number of applications	Percent terminal bud set at following crop loads:		
		Light crop load (< 1 fruit/cm^2 TCSA)	Heavy crop load (4 fruit/cm^2 TCSA)	Mean
GA_3 @ 400 mg·L^{-1}	1[X]	0	0	0 b
GA_3 @ 100 mg·L^{-1}	4[W]	10	30	20 b
Control (surfactant)	1	70	90	80 a
Control (surfactant)	4	60	60	60 a
Mean		33 A[V]	45 A	
Significance				
Crop load	0.141			
Chemical	< 0.001			
Crop load x chemical	0.453			

[Z] Values are means for three trees with 10 branches per tree.
[Y] Regulaid applied at 1.3 mL·L^{-1} in all treatments.
[X] Applied on 19 July.
[W] Applied on 28 June, 12 July, 26 July, and 10 Aug.
[V] Mean separation within columns (lowercase letters) and lines (uppercase letters) by Tukey's test $P \leq 0.05$.

Table 3.3. Percent of spurs flowering and fruit set on 'Ramey York'/M.9 apple trees in 2000 as affected by timing and type of GA treatment in 1999.[Z]

Treatment	% of spurs flowering	Fruit set/100 flowering spurs
Timing (WAFB) [Y]		
4, 6, 8	63.1 b [X]	143.3 a
6, 8, 10	76.0 a	129.9 a
8, 10, 12	83.0 a	126.6 a
Chemical [W]		
GA_{4+7} @ 100 mg·L^{-1}	55.7 c	130.9 a
GA_3 @ 100 mg·L^{-1}	76.4 b	130.8 a
Control [V]	90.0 a	138.2 a
Significance		
Timing	0.001	0.390
Treatment	< 0.001	0.804
Timing x treatment	0.060	0.799

[Z] Values are means for nine replications.
[Y] Weeks after full bloom in 1999.
[X] Mean separation within columns (lowercase letters) by Tukey's test $p \leq 0.05$.
[W] Regulaid applied at 1.3 mL·L^{-1} in all treatments.
[V] The mean for the Regulaid only treatment was not significantly different from the control at the $P \leq 0.05$ so it was not included.

Table 3.4. Percent of laterals flowering (% fl lat) and fruit set per 100 lateral clusters (fruit set) on 'Ramey York'/M.9 apple trees in 2000 as affected by timing and type of GA treatment in 1999.[Z]

Treatment	% fl lat	Fruit set	% fl lat	Fruit set	% fl lat	Fruit set
	Proximal 1/3 of shoot		Middle 1/3 of shoot		Distal 1/3 of shoot	
Timing (WAFB)[Y]						
4, 6, 8	23.8 c[X]	8.1 b	54.1 b	34.5 a	95.6 a	50.6 ab
6, 8, 10	34.8 b	16.1 a	55.8 b	34.8 a	88.4 b	58.4 a
8, 10, 12	42.3 a	17.1 a	74.9 a	34.7 a	85.2 b	46.6 b
Treatment[W]						
GA_{4+7} @ 100 $mg \cdot L^{-1}$	13.4 c	8.5 b	39.4 c	29.8 b	80.4 b	64.5 a
GA_3 @ 100 $mg \cdot L^{-1}$	26.2 b	11.2 b	59.3 b	30.3 b	91.0 a	45.1 b
Control[V]	61.4 a	21.6 a	86.1 a	43.8 a	94.7 a	46.0 b
Significance						
Timing	< 0.001	0.007	< 0.001	0.998	0.003	0.008
Treatment	< 0.001	0.006	< 0.001	0.005	< 0.001	0.001
Timing x treatment	< 0.001	0.324	< 0.001	0.494	0.410	0.879

[Z] Values are means for nine trees with ten branches per tree.
[Y] Weeks after full bloom in 1999.
[X] Mean separation within columns by Tukey's test $p \leq 0.05$.
[W] Regulaid applied at 1.3 $mL \cdot L^{-1}$ in all treatments.
[V] The mean for the Regulaid only treatment was not significantly different from the control at the $P \leq 0.05$ so it was not included.

Table 3.5. Increase in shoot length (cm) from 2 May to 4 August 1999 on 'Ramey York'/M.9 apple trees as affected by type and timing of GA treatment. [Z]

Treatment [Y]	Shoot length (cm)
GA_{4+7} @ 100 mg·L^{-1}	48 a [X]
GA_3 @ 100 mg·L^{-1}	47 a
Control [V]	39 b
Significance	
Timing	0.729
Treatment	0.009
Timing x treatment	0.923

[Z] Values are means for nine trees with ten branches per tree.
[Y] Regulaid applied at 1.3 mL·L^{-1} in all treatments.
[X] Mean separation by Tukey's test $p \leq 0.05$.
[V] The mean for the Regulaid only treatment was not significantly different from the control at the $P \leq 0.05$ so it was not included.

Table 3.6. Percent of spurs flowering and fruit set on 'Ramey York'/M.9 apple trees in 2001 as affected by timing and type of GA treatment in 2000.[Z]

Treatment	% spurs flowering	Fruit set/100 flowering spurs
Timing (WAFB)[Y]		
4, 6, 8	86.9 b[X]	79.6 a
6, 8, 10	93.6 a	83.7 a
8, 10, 12	94.3 a	83.5 a
Treatment [W]		
GA_{4+7} @ 100 mg·L^{-1}	84.0 b	83.9 a
GA_3 @ 100 mg·L^{-1}	94.5 a	81.4 a
Control[V]	96.2 a	81.3 a
Significance		
Timing	< 0.001	0.415
Treatment	< 0.001	0.391
Timing x treatment	< 0.001	0.472

[Z] Values are means for nine trees with three branches per tree.
[Y] Weeks after full bloom in 2000.
[X] Mean separation within columns by Tukey's test $p \leq 0.05$.
[W] Tween 20 applied at 1.3 mL·L^{-1} in all treatments.
[V] The mean for the Tween 20 only treatment was not significantly different from the control at the $P \leq 0.05$ so it was not included.

Table 3.7. Effect of GA_{4+7}, GA_3 on the percent of laterals flowering and fruit set on the proximal third of branches in 2001 following treatments in 2000 of 'Ramey York'/M.9 apple trees.[Z]

Treatment - 2000 [Y]	Weeks after full bloom		
	4, 6, 8	6, 8, 10	8, 10, 12
		Percent laterals flowering	
GA_{4+7} @ 100 mg·L^{-1}	4 c B [X]	23 b A	27 a A
GA_3 @ 100 mg·L^{-1}	13 b B	31 ab A	26 a A
Control [W]	41 a A	39 a AB	30 a B
Significance			
Timing	< 0.001		
Treatment	< 0.001		
Timing x treatment	< 0.001		
		Fruit set per 100 flowering lateral clusters	
GA_{4+7} @ 100 mg·L^{-1}	3 c C	36 b B	52 ab A
GA_3 @ 100 mg·L^{-1}	30 b B	51 ab A	42 b AB
Control	71 a A	70 a A	67 a A
Significance			
Timing	0.001		
Treatment	< 0.001		
Timing x treatment	0.003		

[Z] Values are means for nine trees with eight branches per tree.
[Y] Tween 20 applied at 1.3 mL·L^{-1} in all treatments.
[X] Mean separation within columns (lowercase letters) and lines (uppercase letters) by Tukey's test $p \leq 0.05$.
[W] The mean for the Tween 20 only treatment was not significantly different from the control at the $P \leq 0.05$ so it was not included.

Table 3.8. Effect of GA_{4+7}, GA_3 on the percent of laterals flowering and fruit set on the middle third of branches in 2001 following treatments in 2000 of 'Ramey York'/M.9 apple trees.[Z]

Treatment-2000 [Y]	Weeks after full bloom		
	4, 6, 8	6, 8, 10	8, 10, 12
		Percent laterals flowering	
GA_{4+7} @ 100 mg·L^{-1}	37 c B [X]	67 a A	65 a A
GA_3 @ 100 mg·L^{-1}	51 b B	76 a A	71 a A
Control [W]	82 a A	77 a AB	70 a B
Significance			
Timing	< 0.001		
Treatment	< 0.001		
Timing x treatment	< 0.001		
		Fruit set per 100 flowering clusters	
GA_{4+7} @ 100 mg·L^{-1}	27 b C	46 b B	77 a A
GA_3 @ 100 mg·L^{-1}	59 a A	67 a A	61 a A
Control	69 a A	64 a A	64 a A
Significance			
Timing	0.001		
Treatment	< 0.001		
Timing x treatment	< 0.001		

[Z] Values are means for nine trees with eight branches per tree.
[Y] Tween 20 applied at 1.3 mL·L^{-1} in all treatments.
[X] Mean separation within columns (lowercase letters) and lines (uppercase letters) by Tukey's test $p \leq 0.05$.
[W] The mean for the Tween 20 only treatment was not significantly different from the control at the $P \leq 0.05$ so it was not included.

Table 3.9. Effect of GA_{4+7}, GA_3 on the percent of laterals flowering and fruit set on the distal third of branches in 2001 following treatments in 2000 of 'Ramey York'/M.9 apple trees.[Z]

Treatment - 2000 [Y]	Weeks after full bloom		
	4, 6, 8	6, 8, 10	8, 10, 12
	Percent laterals flowering		
GA_{4+7} @ 100 mg·L^{-1}	74 b A [X]	69 b A	51 b B
GA_3 @ 100 mg·L^{-1}	80 ab A	67 b B	66 a B
Control [W]	84 a A	83 a A	72 a B
Significance			
Timing	< 0.001		
Treatment	< 0.001		
Timing x treatment	0.029		
	Fruit set per 100 flowering lateral clusters		
GA_{4+7} 100 mg·L^{-1}	46 c B	72 a A	74 a A
GA_3 100 mg·L^{-1}	76 b A	75 a A	68 a A
Control	62 a B	64 a B	75 a A
Significance			
Timing	< 0.001		
Treatment	< 0.001		
Timing x treatment	< 0.043		

[Z] Values are means for nine trees with eight branches per tree.
[Y] Tween 20 applied at 1.3 mL·L^{-1} in all treatments.
[X] Mean separation within columns (lowercase letters) and lines (uppercase letters) by Tukey's test $p \leq 0.05$.
[W] The mean for the Tween 20 only treatment was not significantly different from the control at the $P \leq 0.05$ so it was not included.

Table 3.10. Increase in shoot length (cm) from 23 May to 18 July 2000 on 'Ramey York'/M.9 apple trees as affected by type of GA treatment.[Z]

Treatment [Y]	Shoot length in (cm)
GA_{4+7} @ 100 mg·L^{-1}	21.3 a [X]
GA_{3} @ 100 mg·L^{-1}	19.8 a
Control [W]	14.7 b
Significance	
Timing	0.494
Treatment	0.015
Timing x treatment	0.426

[Z] Values are means for nine trees with eight shoots per tree.
[Y] Tween 20 applied at 1.3 mL·L^{-1} in all treatments.
[X] Mean separation within columns by Tukey's test $p \leq 0.05$.
[W] The mean for the Tween 20 only treatment was not significantly different from the control at the $P \leq 0.05$ so it was not included.

Table 3.11. Percent of spurs flowering and fruit set/100 flowering spur clusters on girdled limbs of 'York'/M.9 apple trees in 2001 as affected by crop load adjustment on 19 May, GA_{4+7} and sorbitol treatments in 2000.[Z]

Treatment - 2000 [Y]	Defruited	Thinned to 3 fruit/cm^2 BCSA
	Percent spurs flowering	
GA_{4+7} [W]	51 b A [X]	1 b B
GA_{4+7} + sorbitol [V]	43 b A	1 b B
Sorbitol [U]	91 a A	25 a B
Control	91 a A	23 a B
Significance		
Crop load	< 0.001	
Treatment	< 0.001	
Crop load x treatment	0.031	
	Fruit set per 100 flowering spur clusters	
GA_{4+7}	145 ab A	3 a B
GA_{4+7} + sorbitol	169 a A	1 a B
Sorbitol	96 bc A	2 a B
Control	75 c A	16 a B
Significance		
Crop load	< 0.001	
Treatment	0.003	
Crop load x treatment	< 0.001	

[Z] Values are means for 10 replications.
[Y] Tween 20 applied at 1.3 mL·L^{-1} in all treatments.
[X] Mean separation within columns (lowercase letters) and lines (uppercase letters) by Tukey's test $P \leq 0.05$.
[W] GA_{4+7} @ 100 mg·L^{-1} applied every 2 weeks between 24 May and 21 June.
[V] GA_{4+7} @ 100 mg·L^{-1} + Sorbitol @ 50 g·L^{-1} applied twice a week between 24 May and 21 June.
[U] Sorbitol @ 50 g·L^{-1} applied twice a week between 24 May and 21 June.

Table 3.12. Percent of laterals flowering and fruit set/100 flowering lateral clusters on girdled limbs of 'York'/M.9 apple trees in 2001 as affected by cropload adjustment on 19 May, GA_{4+7} and sorbitol treatments in 2000.[Z]

Treatment [Y]	Defruited	Thinned to 3 fruit/cm^2 BCSA
	Percent laterals flowering	
GA_{4+7} [W]	13 b A[X]	1 a B
GA_{4+7} + sorbitol [V]	10 b A	1 a B
Sorbitol [U]	39 a A	2 a B
Control	46 a A	15 a B
Significance		
Crop load	< 0.001	
Treatment	< 0.001	
Crop load x treatment	0.002	
	Fruit set per 100 flowering lateral clusters	
GA_{4+7}	104 ab A	3 a B
GA_{4+7} + sorbitol	162 a A	0 a B
Sorbitol	58 b A	0 a B
Control	71 b A	12 a B
Significance		
Crop load	< 0.001	
Treatment	0.022	
Crop load x treatment	0.021	

[Z] Values are means for 10 replications.
[Y] Tween 20 applied at 1.3 mL·L^{-1} in all treatments
[X] Mean separation within columns (lowercase letters) and groups (uppercase letters) by Tukey's test $P \leq 0.05$.
[W] GA_{4+7} @ 100 mg·L^{-1} applied every 2 weeks between 24 May and 21 June.
[V] GA_{4+7} @ 100 mg·L^{-1} + Sorbitol @ 50 g·L^{-1} applied twice a week between 24 May and 21 June.
[U] Sorbitol @ 50 g·L^{-1} applied twice a week between 24 May and 21 June.

Table 3.13. Effect of G_{4+7} and GA_3 on the percent of laterals flowering and fruit set on the proximal, middle and distal thirds of shoots on 'Braeburn'/M.26 apple trees in 2001.[Z]

Treatment - 2000 [Y]	Shoot section		
	Proximal	Middle	Distal
	Percent laterals flowering		
GA_{4+7} 100 mg·L^{-1}	6 c B [X W]	6 c B	88 a A
GA_3 250 mg·L^{-1}	6 c B	8 b B	88 a A
Control	44 b B	63 a A	70 b A
Significance			
Treatment	< 0.001		
Branch position	< 0.001		
Treatment x branch position	< 0.001		
	Fruit set per 100 flowering lateral clusters		
GA_{4+7} @ 100 mg·L^{-1}	8 b B	16 b B	72 ab A
GA_3 @ 250 mg·L^{-1}	15 b B	21 b B	73 a A
Control	65 a A	66 a A	67 ab A
Significance			
Treatment	< 0.001		
Branch position	< 0.001		
Treatment x branch position	< 0.001		

[Z] Values are means for nine trees with eight branches per tree.
[Y] Tween 20 applied at 1.3 mL·L^{-1} in all treatments
[X] Mean separation within columns (lowercase letters) and groups (uppercase letters) by Tukey's test $P \leq 0.05$.
[W] Applied on 24 May, 7 June, and 21 June.

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CHAPTER FOUR

THE EFFECTS OF CROP LOAD ON SHOOT GROWTH, FLOWERING AND FRUIT SET OF 'FUJI' APPLE TREES

Abstract

Six-year-old 'Fuji'/M.9 apple trees were thinned to one fruit per flowering cluster every year from 1997 to 2000. Other trees were thinned to zero fruit or two fruit per flowering cluster in alternate years from 1997 to 2000. Trees thinned to two fruit per flowering cluster had very little to no flowering the following year. Trees thinned to zero fruit per flowering cluster had a snowball bloom the following year. Trees thinned to one fruit per flowering cluster produced a moderate return bloom each year and the best fruit quality of all the thinning treatments. There was no effect of crop load on fruit set per 100 flowering clusters. Flowering on one-year-old wood was similar for all thinning treatments. From 1998 through 2000, the greatest shoot growth occurred on trees that carried the heaviest crop load (two fruit per flowering cluster). In contrast to shoot growth, TCSA increased more on trees thinned to zero fruit, the "off" year, than trees carrying one or two fruit per flowering cluster.

Introduction

The annual vegetative growth of an apple tree is distributed in a definite pattern between leaves, shoots and roots (Maggs, 1963). There are three kinds of apple shoots: terminal, lateral and bourse (Avery, 1969; Barlow, 1964; Forshey, 1982). Terminal shoots develop from apical buds, lateral shoots develop from axillary buds on the previous season's shoots and bourse shoots

develop from axillary buds at the base of a flower cluster (Forshey, 1985). When a crop is borne, there becomes an additional sink for growth materials (Maggs, 1963).

The reduction in vegetative growth resulting from cropping in apple has been noted many times (Singh, 1948). It is generally accepted that heavy fruiting reduces vegetative growth, whereas a sparse crop leads to increased vegetative vigor (Maggs, 1963). Maggs reported that deblossomed or defruited 'Worcester Pearmain' trees on M.7 rootstock produced about twice as much vegetative dry matter as did fruiting trees.

However, several investigators have found that there is a significant negative correlation between yield and the following year's shoot growth (Avery, 1969; Barlow, 1964; Curry and Looney; 1986; Forshey, 1982; Jackson, 1984). In a 25 year study, Rogers and Booth (1964) discovered a negative correlation between yield and the following year's shoot growth for trees on five different rootstocks. In another long-term experiment, Barlow (1964) found very light crops to have no effect on shoot growth, but at higher levels of cropping there was a negative linear relationship between yield and shoot growth. Several researchers have suggested that this negative correlation between yield and shoot growth the following year is a result of less reserves being stored in roots or branches in years with a heavy crop (Jackson, 1984; Looney et al., 1978; Proebsting, 1925; Roberts, 1923). Linear growth of the terminal is made largely at the expense of stored foods, and may therefore be affected by the growth and fruiting conditions of the previous year (Wilcox, 1937). Finch (1927) reported that there is a greater production of xylem tissue and a greater storage of carbohydrates during the "off" year than during the "on" year. The negative correlation between yield and shoot growth the following year is greater as the rootstocks become more dwarfing (Avery, 1969; Rogers and Booth, 1964). When the tree is growing very vigorously,

as in the case of M.XVI, the crop has a smaller influence (Rogers and Booth, 1964). High tree vigor might mask the effect of the previous year on shoot growth (Forshey, 1982).

Singh (1948) evaluated shoot development in both "on" year and "off" year situations. He reported that shoot growth began about April 28th. In the first 3 weeks, there was not much difference but the "on" year trees grew slightly faster. During the next 6 weeks, late May through the middle of July, shoots on the "on" year trees grew nearly twice as fast as those on "off" year trees. In the third stage, from mid July to mid August, the shoots on "off" year trees grew faster than shoots on the "on" year trees. In the final stage, from mid August onward, the rate of growth slowed down and finally ceased, with the shoots on "off" year trees being longer than those on "on" year trees at the end of the season. The critical period for flower bud initiation (FBI) is generally accepted to be in May and June. During this period, shoot growth on the "on" year trees is rapid, whereas that of "off" year trees is relatively slow (Singh, 1948). Perhaps rapid shoot growth of "on" year trees puts a heavy demand on the food supply of the tree throughout the critical period of fruit bud initiation resulting in few or no flower buds being formed. Crop load also has an effect on the increase in trunk cross sectional area (TCSA). Trees bearing biennially increase in TCSA more in the "off" year than in the "on" year (Barlow 1964; Maggs 1963; Partridge 1919; Singh 1948; Wilcox 1937).

Adjusting the crop load, or fruit thinning, has been practiced for centuries and serves a number of theoretical purposes including: reducing the number of seeds producing gibberellins, reducing competition for photosynthates and nutrients and improving growth and ultimate size of the remaining fruit (Williams and Edgerton, 1974). However, the most important reason for adjusting the crop load is to ensure flower bud initiation. A satisfactory thinning program will

remove enough fruit to assure an adequate return bloom the following season (Williams and Edgerton, 1981). Fruit set from less than 5% of the blossoms on a snowball bloom tree is enough for a full crop (Williams and Edgerton, 1981). Flowering puts a heavy demand on the tree for photosynthate and stored reserves (Greene, 2000). Heavy flowering 'York' and 'Golden Delicious' trees thinned at bloom did not produce an adequate return bloom the following year (Byers and Carbaugh, 2002). Trees more moderate in flowering (even if not thinned) were more likely to give an adequate return bloom than if trees had nearly 100% of the spurs flowering.

The objective of this experiment was to determine how crop load affects shoot length, the increase in TCSA, and flowering and fruit set the following year.

Materials and Methods

This experiment was conducted on the Virginia Tech College of Agriculture and Life Sciences Kentland farm near Blacksburg, Virginia. The orchard is located at an elevation of 2,050 feet above sea level and the general soil type is a Shottower Cobbly loam.

Six-year-old 'Fuji'/M.9 trees spaced 3 x 6.5 m and trained as central leaders were in full bloom on 22 April 1997. The trees carried a moderate crop the previous year. The trees were hand thinned on 25 May to zero, one or two fruit per flower cluster over the entire tree. Three scaffold branches per tree were tagged at the base of the 1995 shoot segment. Trees thinned to one fruit per flower cluster were again thinned to a maximum of one fruit per flower cluster in each succeeding year through 2000. Trees thinned to 0 fruit per flower cluster in 1997 were thinned to a maximum of 2 fruit per flower cluster in 1998, thinned to 0 fruit per flower cluster in 1999 and

thinned to a maximum of 2 fruit per flower cluster in 2000. Trees thinned to a maximum of 2 fruit per flower cluster in 1997 were thinned to 0 fruit per flower cluster in 1998, thinned to a maximum of 2 fruit per flower cluster in 1999, and thinned to 0 fruit per flower cluster in 2000. In 1998, full bloom occurred on 18 April and the trees were thinned on 24 May. In 1999, full bloom occurred on 30 April and the trees were thinned on 30 May. In 2000, full bloom occurred on 26 April and the trees were thinned on 27 May. Fruit set was determined during the last 10 days of May each year, followed by thinning to the assigned crop load. Shoot length on the three branches was measured at the end of each growing season. Shoot length was also determined for 1995 and 1996 on the three branches The trees were pruned each winter except for the three tagged branches per tree. The experimental design was completely randomized with ten replications. Percentage of flowering and fruit set per 100 flowering clusters was determined each season. The increase in trunk cross sectional area (TCSA) was determined each spring.

Results and Discussion

The original intent of this experiment was to adjust the crop load so that certain trees would carry 0, 1 or 2 fruit per flowering cluster for several years. The trees that had been thinned to 2 fruit per flowering cluster in 1997 had very little to no return bloom in 1998. The trees that had been thinned to 0 fruit had a snowball bloom in 1998. Both of these sets of trees had in essence become biennial in flowering. The trees thinned to 1 fruit per flowering cluster had a moderate bloom in 1998. Because of this, it was decided to alternate the crop load from 0 to 2 fruit per flowering cluster for two treatments. The trees thinned to1 fruit were suitable to be thinned to1 fruit each year.

Crop load adjustments began in May of 1997. However, shoot growth was determined for wood that grew in 1995 and 1996. There was no difference in shoot growth in 1995 and 1997 and a slight difference in 1996 (Figure 4.1). There was no difference in 1997 in response to the thinning treatments. In 1998 through 2000, there were significant differences in shoot growth among the treatments (Figure 4.1). From 1998 through 2000, the greatest shoot growth occurred on trees that carried the heaviest crop load which was two fruit per flowering cluster. These trees averaged approximately twice as much shoot growth as trees in the "off" year.

This is consistent with the findings of Curry and Looney (1986); Forshey (1982) and Rogers and Booth (1964). Curry and Looney (1986) reported that "on" year tree shoots were approximately one and a half times longer than "off" year tree shoots, and Forshey (1982) reported that "on" year tree shoots grew slightly less than one and a half times the "off" year tree shoots. Rogers and Booth (1964) discovered that "on" year tree shoots on M.9 rootstock grew 53% longer than "off" year tree shoots but only 9% longer than "off" year tree shoots on the vigorous M.16 rootstock. Their experiments included several cultivars and pruning regimes. This is inconsistent with the findings of Maggs (1963), who artificially created "off" year trees by deblossoming or defruiting trees in the spring. He reported that deblossomed 'Worcester Pearmain' trees on M.7 rootstock produced about twice as much vegetative dry matter as did cropping trees. Root growth was reduced the most, to about a quarter, by the presence of a crop. These 'Worcester Pearmain' trees probably didn't have a heavy enough crop load the previous year to deplete the tree's reserves. The general conclusion from these researchers is that, when a tree carries a heavy crop load, there are less reserves being stored in the roots, trunk and branches. This lack of reserves results in less shoot growth in the following "off" year. The lack of a

difference in shoot growth in 1997 is probably due to the trees having equal carbohydrate reserves from the previous year.

In contrast to shoot growth, TCSA increased more on trees in the "off" year than trees carrying one or two fruit per flowering cluster (Figure 4.2). Treatments 2 and 3 alternated having the greatest increase in TCSA, depending on which carried two fruit per flowering cluster. The difference in the increase in TCSA was more than two-fold between the trees carrying two fruit per flowering cluster and those trees carrying zero fruit per flowering cluster except for 1997. The increase in TCSA for treatment one was unusually small in1999 compared to the other years. This lack of increase in TCSA may have been caused by a drought in 1999. These results are consistent with reports by Barlow (1964), Maggs (1963), Partridge (1919), and Wilcox (1937) who reported a negative correlation between crop load and the increase in trunk girth. In a six year study on biennial bearing, Wilcox, (1937) reported that trees in the "off" year increased in circumference an average of 3.6 cm while "on" year trees increased an average of 1.5 cm per year. Maggs (1963) found that "off" year trees of several cultivars on M.9 rootstock increased in TCSA approximately three times more than "on" year trees and "off" year tree cultivars on M.16 rootstock increased in TCSA approximately two times more than "on" year trees.

Table 4.1 shows the percentage of spurs and lateral buds flowering on wood grown between 1995 and 2000. Table 4.1 also includes the number of spurs or lateral buds that developed on each section of wood. The interaction between thinning treatment and year of wood was highly significant in all years as well as the main effects (Table 4.1). The percentage of flowering for treatment one fluctuated some with years and also with the year that the wood grew. The percent flowering on Treatments 2 and 3 only fluctuated with year, not counting 1-year-old wood, but the

fluctuations were much greater compared to Treatment 1. Treatments 2 and 3 had greater fluctuations in shoot growth compared to Treatment 1 (Figure 4.1). The percent flowering was recorded on the sections of wood between 1997 and 2001. There was a significant interaction between treatment and the year in which the wood grew in all years. Much of the interaction may be due to the low percentages of 1-year-old wood flowering for all treatments. Treatment 1 flowered the most consistently. The percentage of 1-year-old wood that flowered was approximately 20% and was consistent from 1997 to 2001. Two-year-old and older wood flowered between 73% and 30% in all years (Table 4.1). Treatment 1 flowered moderately, and thus annually, every year. The percentage of flowering for Treatment 1 fluctuated some between year of wood and the year it flowered excluding 1-year-old wood. For example, in 2001 the wood that grew in odd years had a flowering percentage in the range of 60 to 69% whereas wood that grew in even years had a flowering percentage in the range of 34 to 37%. Thus in 2001, the wood that grew in odd years would have had approximately one-third of the spurs resting while the wood that grew in even years would have had approximately two-thirds of the spurs resting. Wood that grew in odd years had a higher flowering percentage in odd years. For example, the percentage of spurs flowering on 1995 wood was greater in 1997, 1999 and 2001. The percentage of spurs flowering on1996 wood was greater in 1998 and 2000.

The percentage of spurs and 1-year-old wood flowering for Treatments 2 and 3 was very similar. When one treatment was in the "on" year, the other was in the "off" year. When either treatment was in the "on" year, the flowering percentage was in the range of 78 to 91% excluding the 1-year-old wood (Table 4.1). When these two treatments were in the "off" year, the percentage of flowering averaged less than 10%, excluding the 1-year-old wood. The percentage of flowering

for Treatments 2 and 3 did not fluctuate much between year of wood as was the case with Treatment 1. For example, when either Treatment 2 or 3 was in the "on" year, all the sections of wood had similar flowering percentages. The mean number of spurs and 1-year-old wood flowering is listed in Table 4.2.

Fruit set was determined for each section of wood each year expressed as fruit set per 100 flowering clusters (Table 4.3). Only in 2001 was the interaction between treatment and year of wood significant. The main effect of year of wood was significant in all the years that flowering was measured and was probably due to the lower fruit set on the 1-year-old wood. Fruit set per 100 flowering clusters was similar for all treatments, with most set being above 200 (Table 4.3). Fruit set per 100 flowering spur clusters can be misleading when there are big differences in the percentages of spurs or 1-year-old wood flowering. Therefore, actual fruit numbers per section of wood are included in Table 4.3. The most spur fruit that set on any section of wood from either Treatment 2 or 3 after being thinned to two fruit per spur the previous year was 6 (Table 4.3). This is due to very few spurs flowering following an "on" year. Fruit set on 1-year-old wood was similar for all three treatments and was never greater than 5. Shortly after the fruit data were collected, the trees were thinned to the assigned crop load.

The fruit from Treatments 2 and 3 in the "off' year tended to be very large and matured earlier than fruit from Treatment 1 or fruit from Treatments 2 and 3 in the "on" year (data not shown). Fruit from Treatments 2 and 3 in the "on" year tended to be very small, poorly colored and delayed in maturity. Fruit from Treatment 1 was typical in size, color and maturity for "Fuji".

Thinning the trees to one apple per flowering cluster (Treatment 1) resulted in consistent annual flowering and fruit set. This is consistent with the results of Forshey (1982) who, in a four-

year study, found that thinning to one fruit per spur resulted in the greatest overall yield. Leaving two fruit per flowering cluster resulted in biennial flowering and fruit set with the fruit being of poor quality (data not shown). Williams and Edgerton (1974) recommended removing all the fruit from half of the spurs so they would rest and flower the following year. However, in this study, thinning to one fruit per spur resulted in adequate return bloom the following year. Never did more than 73% of the spurs flower, so there were some resting spurs on each section of wood each year. Also some flowering spurs do not set any fruit; thus they would be resting and potentially could flower again the following year.

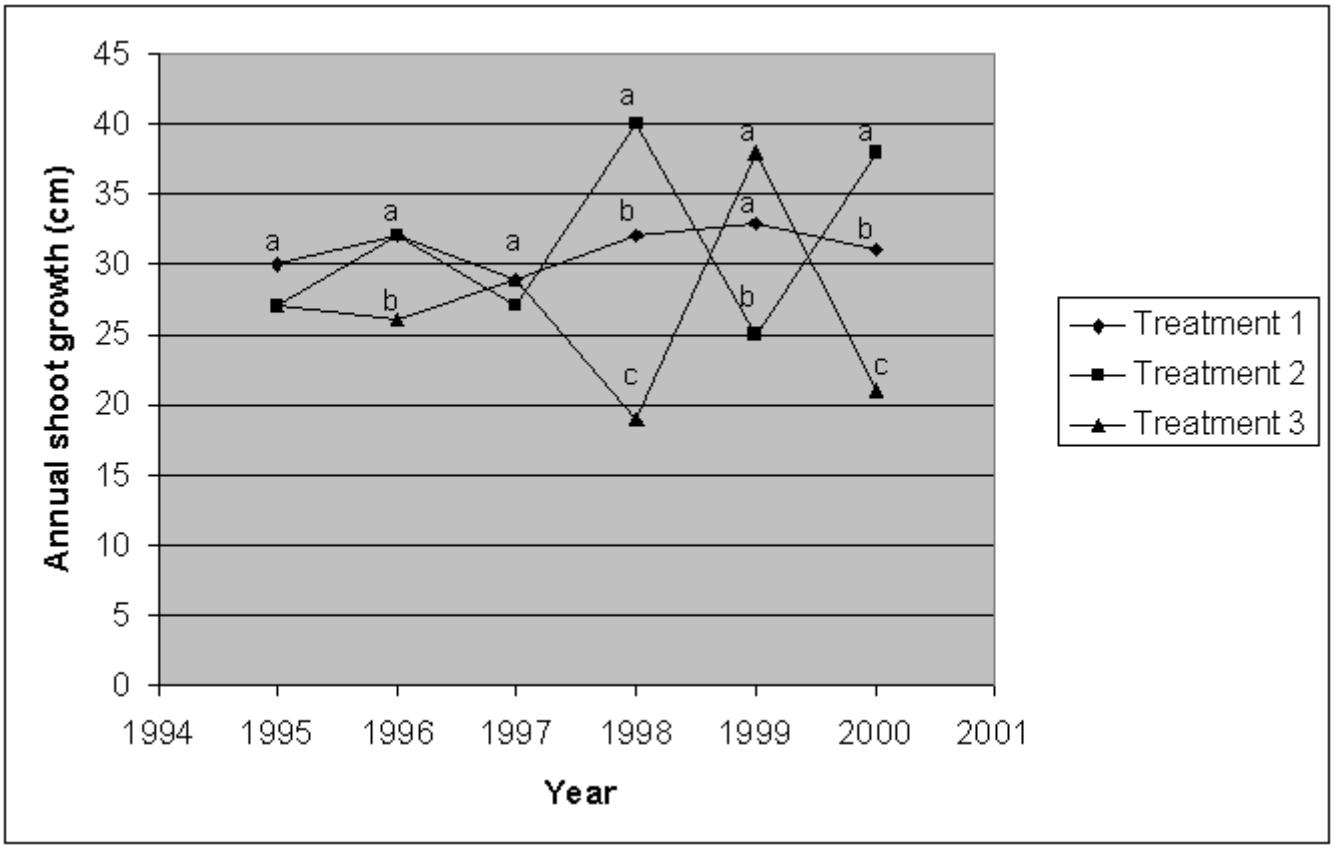

Figure 4.1. Terminal shoot growth on "Fuji"/M.9 apple trees as affected by fruit thinning treatments. Treatment 1 was thinned to 1 fruit per flowering cluster each year beginning in 1997. Treatment 2 was thinned to 0 fruit in odd years and 2 fruit per flowering cluster in even years beginning in 1997. Treatment 3 was thinned to 2 fruit in odd years and 0 fruit per flowering cluster in even years beginning in 1997. Mean separation within years by Tukey's test $p \leq 0.05$.

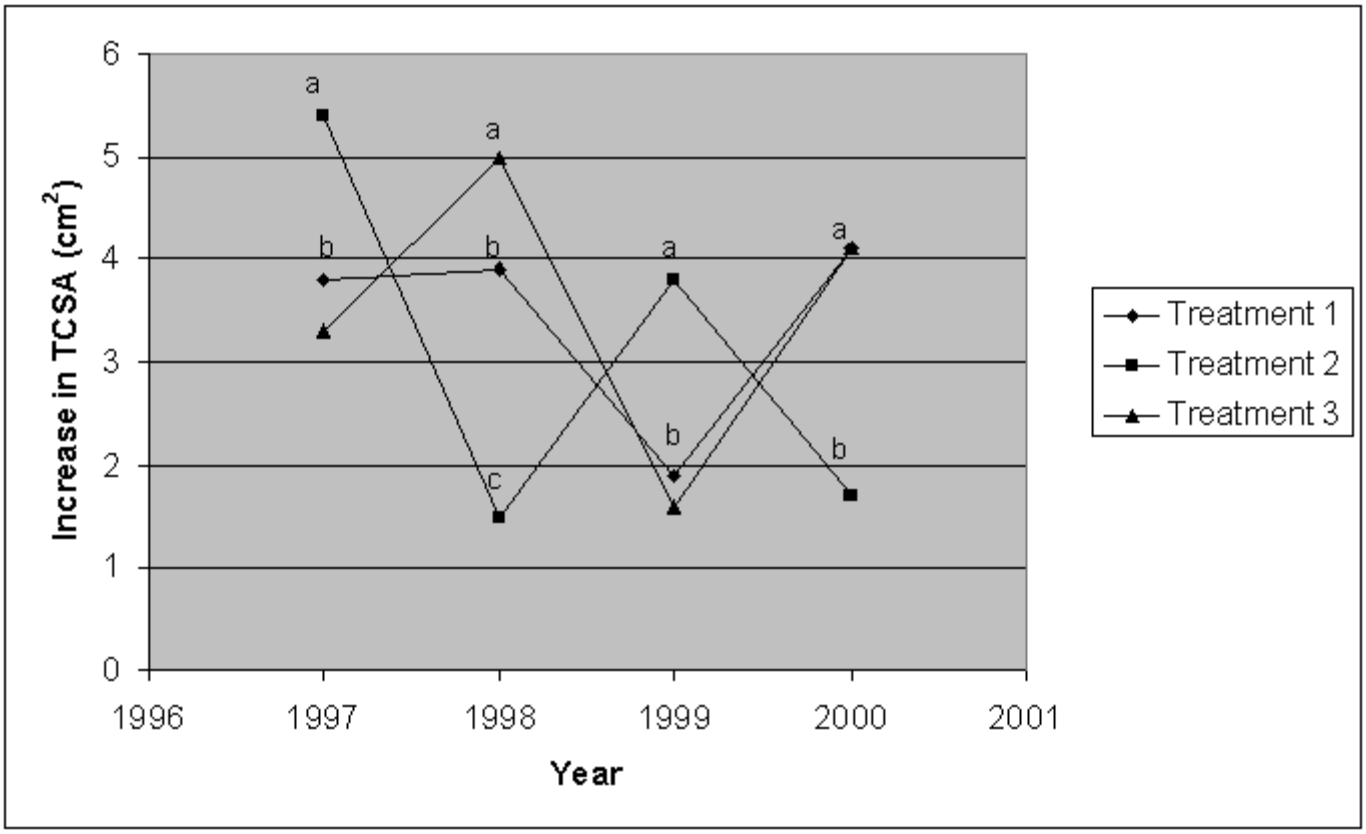

Figure 4.2. Annual increase in trunk cross sectional area (TCSA) on "Fuji" apple trees as affected by fruit load. Treatment 1 was thinned to 1 fruit per flowering cluster each year beginning in 1997. Treatment 2 was thinned to 0 fruit in odd years and 2 fruit in even years per flowering cluster beginning in 1997. Treatment 3 was thinned to 2 fruit in odd years and 0 fruit in even years per flowering cluster beginning in 1997. Mean separation within years by Tukey's test $p \leq 0.05$.

Table 4.1. Percentage of spurs and one-year-old nodes flowering on various sections of wood over five years on 'Fuji'/M.9 apple trees as affected by thinning treatments.[Z]

Year of wood[Y]	Spurs or nodes[X]	Percent nodes flowering				
		Treatment 1				
		1997 (1)[W]	1998 (1)	1999 (1)	2000 (1)	2001 (1)
1995	22.4	61	37	64	38	61
1996	24.0	20[V]	70	32	66	37
1997	23.0	-	19	73	30	67
1998	23.2	-	-	20	69	34
1999	24.6	-	-	-	23	69
2000	23.5	-	-	-	-	21
		Treatment 2				
		1997 (0)	1998 (2)	1999 (0)	2000 (2)	2001 (0)
1995	18.1	75	80	1	81	1
1996	20.1	23	80	3	80	2
1997	16.0	-	21	8	83	1
1998	25.7	-	-	12	78	7
1999	17.5	-	-	-	21	8
2000	25.5	-	-	-	-	13
		Treatment 3				
		1997 (2)	1998 (0)	1999 (2)	2000 (0)	2001 (2)
1995	23.4	62	3	86	1	86
1996	24.3	19	9	87	2	83
1997	27.2	-	11	86	3	86
1998	15.1	-	-	12	14	91
1999	30.9	-	-	-	8	82
2000	18.7	-	-	-	-	11
Significance						
Treatment		< 0.001[U]	< 0.001	< 0.001	< 0.001	< 0.001
Year of wood		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Trt* year of wood		0.022	< 0.001	< 0.001	< 0.001	< 0.001

[Z] Values are lsmeans for 10 trees with three branches per tree.
[Y] The year in which a particular section of wood grew.
[X] The mean number of spurs or nodes on a particular section of wood.
[W] ( ) number of fruit per spur or node to which the trees were thinned in a particular year.
[V] The bottom number in each column for each treatment represents 1-year-old wood.
[U] Mean separation within columns by PDIFF $P \leq 0.05$

Table 4.2. The number of spurs and one-year-old nodes flowering on various sections of wood over five years on 'Fuji'/M.9 apple trees as affected by thinning treatments.[Z]

Year of wood[Y]	Spurs or nodes[X]	Number of spurs or nodes flowering				
		Treatment 1				
		1997 (1)[W]	1998 (1)	1999 (1)	2000 (1)	2001 (1)
1995	22.4	13.4[V]	8.1	14.1	8.4	13.4
1996	24.0	4.8[U]	16.8	7.7	15.8	8.9
1997	23.0	-	4.4	16.8	6.9	15.4
1998	23.2	-	-	4.6	15.9	7.8
1999	24.6	-	-	-	5.8	17.3
2000	23.5	-	-	-	-	5.0
		Treatment 2				
		1997 (0)	1998 (2)	1999 (0)	2000 (2)	2001 (0)
1995	18.1	13.5	14.4	0.2	14.6	0.2
1996	20.1	4.6	16	0.6	16	0.4
1997	16.0	-	3	1.3	13.3	0.2
1998	25.7	-	-	3.1	20.3	1.8
1999	17.5	-	-	-	3.8	1.4
2000	25.5	-	-	-	-	3.4
		Treatment 3				
		1997 (2)	1998 (0)	1999 (2)	2000 (0)	2001 (2)
1995	23.4	14.3	0.7	19.8	0.2	19.8
1996	24.3	4.6	2.2	20.9	0.5	19.9
1997	27.2	-	3.0	23.2	0.8	23.2
1998	15.1	-	-	1.8	2.1	13.7
1999	30.9	-	-	-	2.5	25.4
2000	18.7	-	-	-	-	2.1
Significance						
Treatment		< 0.001[T]	< 0.001	< 0.001	< 0.001	< 0.001
Year of wood		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Trt* year of wood		0.022	< 0.001	< 0.001	< 0.001	< 0.001

[Z] Values are lsmeans for 10 trees with three branches per tree.
[Y] The year in which a particular section of wood grew.
[X] The mean number of spurs or nodes on a particular section of wood.
[W] ( ) number of fruit per spur or node to which the trees were thinned in a particular year.
[V] The mean number of spurs and one-year-old nodes flowering.
[U] The bottom number in each column for each treatment represents one-year-old wood.
[T] Mean separation within columns by PDIFF $P \leq 0.05$

Table 4.3. Fruit set per 100 flower clusters on various sections of wood over five years on 'Fuji'/M.9 apple trees as affected by thinning treatments.[Z]

Year of wood[Y]	Spurs or nodes[X]	Fruit set/100 flower clusters				
		Treatment 1				
		1997 (1)[W]	1998 (1)	1999 (1)	2000 (1)	2001 (1)
1995	22.4	196[V] [27][U]	219 [18]	202 [28]	210 [18]	188 [25]
1996	24.0	75[T] [4]	197 [33]	221 [17]	200 [3]	213 [19]
1997	23.0	-	57 [3]	186 [31]	233 [16]	202 [31]
1998	23.2	-	-	77 [4]	202 [32]	225 [18]
1999	24.6	-	-	-	73 [4]	195 [34]
2000	23.5	-	-	-	-	93 [5]
		Treatment 2				
		1997 (0)	1998 (2)	1999 (0)	2000 (2)	2001 (0)
1995	18.1	210 [28]	210 [30]	202 [1]	211 [31]	246 [1]
1996	20.1	71 [3]	211 [4]	238 [1]	213 [4]	273 [1]
1997	16	-	76 [2]	199 [3]	213 [28]	134 [1]
1998	25.7	-	-	77 [2]	203 [41]	196 [4]
1999	17.5	-	-	-	56 [2]	234 [3]
2000	25.5	-	-	-	-	91 [3]
		Treatment 3				
		1997 (2)	1998 (0)	1999 (2)	2000 (0)	2001 (2)
1995	23.4	192 [27]	219 [2]	185 [37]	189 [4]	193 [38]
1996	24.3	82 [4]	251 [6]	200 [42]	223 [1]	195 [39]
1997	27.2	-	106 [3]	198 [46]	272 [2]	194 [45]
1998	15.1	-	-	74 [1]	253 [5]	213 [29]
1999	30.9	-	-	-	119 [3]	178 [45]
2000	18.7	-	-	-	-	56 [1]
Significance						
Treatment		0.897[S]	0.432	0.008	0.016	0.191
Year of wood		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Trt* year of wood		0.337	0.213	0.496	0.330	< 0.001

[Z] Values are lsmeans for 10 trees with three branches per tree.
[Y] The year in which a particular section of wood grew.
[X] The mean number of spurs or nodes on a particular section of wood.
[W] ( ) number of fruit per spur or node to which the trees were thinned in a particular year.
[V] Fruit set per 100 flowering clusters.
[U] [ ]The mean number of fruit per year of wood.
[T] The bottom number in each column and treatment represents one-year-old wood.
[S] Mean separation within columns by PDIFF $P \leq 0.05$.

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SUMMARY

The purpose of this dissertation was to evaluate some cultural practices to prevent or disrupt biennial bearing in the "off" year and to hand thin trees in the "on" year to determine at what crop load would the trees become annual bearers.

Whole-tree and partial-tree defoliation were evaluated as ways to suppress flower bud initiation (FBI) and fruit set on both spurs and laterals. Whole-tree defoliation resulted in less flowering and fruit set the following year than did partial-tree defoliation. Compared to other timings, defoliation in early to mid July suppressed flowering the following year the most. Whole-tree defoliation in early August resulted in approximately one half as many fruit/100 flowering spur clusters and little to no fruit/100 flowering lateral clusters compared to a control. With increasing severity of defoliation, flowering and fruit set declined the following year regardless of timing. Partial defoliation with ammonium thiosulfate and endothal increased flowering but decreased spur fruit set while Gramoxone suppressed both spur flowering and fruit set compared to a control. Whole-tree or severe partial-tree defoliation in August was the best treatment with approximately one half as much spur fruit set as the control and very little to no lateral fruit set the following year.

Gibberellic acid (GA) treatments were evaluated to suppress FBI and fruit set on both spurs and laterals. GA_3 did not suppress flowering on 'Braeburn'/M.26 in 2000 on very light crop load trees, and heavy crop load trees had no return bloom, regardless of treatment. GA_{4+7} treatments suppressed return bloom of spurs and laterals more than the GA_3 treatments on 'Ramey York'/M.9. However, spur fruit set was no different than the control. The effectiveness of GA declined with delayed application. Both GA_{4+7} and GA_3 treatments suppressed lateral flowering and fruit set on the proximal and middle third of 1-year-old shoots.

In another experiment, both GA_{4+7} and GA_{4+7} + sorbitol reduced spur flowering compared to sorbitol alone and the control on trees with no crop or a light crop. On the basis of equalizing costs, GA_3 was used at 2.5 x the rate of GA_{4+7}. The GA treatments equally suppressed lateral flowering and fruit set.

GA treatments will suppress spur and lateral flowering depending on the timing and concentration. However, GA treatments do not always result in decreased fruit set. When only one half of the spurs flower, fruit set per spur tends to be greater than if near 100 % of the spurs flower.

'Fuji'/M.9 trees were hand thinned to one of three crop loads from 1997 to 2000. Trees thinned to one fruit per flowering cluster, produced in a moderate return bloom each year. Trees thinned to two fruit per flowering cluster did not produce many flowers the following year and were thinned to zero fruit per flowering cluster. Trees thinned to zero fruit per flowering cluster produced a 'snowball' bloom the following year and were thinned to two fruit per flowering cluster. The trees that alternated between two and zero fruit per flowering cluster were in a biennial bearing situation. Two fruit per flowering cluster was too heavy a crop load for an adequate return bloom the following year. The greatest shoot growth occurred on trees that carried the heaviest crop load (two fruit per flowering cluster). In contrast to shoot growth, TCSA increased more on trees thinned to zero fruit, the "off" year, than trees carrying one or two fruit per flowering cluster.

In 1997, L. C. Luckwill suggested three techniques for decreasing flower induction in the "off" year. These included: reducing leaf area, applying GA, and applying other flower inhibitors such as meta-tolylphthalamic acid and xanthine. Twenty five years later, there are not any new

strategies for decreasing flower induction in apple in the "off" year. In this study, both defoliation and GA applications suppressed spur and lateral flowering the following year. Defoliation by hand was effective but very time consuming. It would be cost prohibitive for commercial apple growers to defoliate by hand. There are no chemicals registered for defoliating apple trees in the "off" year with the intent of suppressing flowering the following year. Chemical companies would probably not support a label for their use as a defoliant because of the risk of defruiting trees or causing injury to the trees. Also, there would likely be insufficient usage to justify pursuing a label.

Gibberellic acid may be a better approach to suppressing flowering with chemical sprays. GAs are naturally present in apple and don't cause injury to the trees even at very high rates. Since a lot of the literature about the effect of GAs on flowering is on atypical cultivars, more work is needed on today's cultivars. Also more work needs to be done on the timing, the concentration and making multiple applications. Perhaps in the future there will be recommendations for using either defoliation or GA sprays to suppress flowering on apple trees that are in the "off" year.

VITA

David Evan Davis was born on 23 September 1956, in New York, NY. He is the son of Lloyd and Mary Davis of Morgantown, WV. He graduated from Morgantown High school in 1974. He earned a Bachelor of Science degree in Plant and Soil Science from West Virginia University in 1980. He earned a Master of Science degree in Horticulture from West Virginia University in 1986.He managed apple and peach orchards in Mt. Jackson, VA and Summit Point, WV from 1985 to 1996. He enrolled in the doctoral program in Horticulture at Virginia Polytechnic Institute and State University in the fall of 1996, and was granted a Doctor of Philosophy degree in September 2002.