

EFFECTS OF APPLE BRANCH GIRDLING ON RETENTION AND QUALITY OF
FRUIT AND VEGETATIVE GROWTH

by


Carl Eugene Mitchell

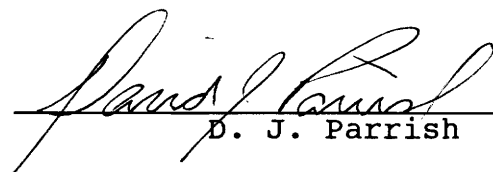
Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Horticulture

APPROVED:


J. A. Barden


R. P. Marini


D. M. Orcutt


D. J. Parrish

September, 1994
Blacksburg, Virginia

G.2

LD
5655
V855
1994
M583
C.2

EFFECTS OF APPLE BRANCH GIRDLING ON RETENTION AND QUALITY OF
FRUIT AND VEGETATIVE GROWTH

by

Carl E. Mitchell

Committee Chairman: Dr. John A. Barden

Horticulture

(ABSTRACT)

In 1992, branches on 'Triple Red Delicious'/M.7 were girdled. A factorial arrangement of girdling treatments (control, 9-mm girdle + uncovered, 9-mm girdle + electric tape, 9-mm girdle + TreeKote), and timings (0, 15, 30, 60, 90 days after full bloom (DAFB)) was used. With 'Golden Delicious'/M.7, branch treatments were control, scored, and 6-mm, 9-mm, 12-mm electric-tape-covered girdles, each applied at 0, 15, 30, and 60 DAFB. In 1993, treatments on both cultivars were control, 9-mm uncovered girdle, and pruning saw wound. Each was applied at 0, 7, 14, and 21 DAFB. Each girdle was a complete ring of bark; pruning saw wound was removal of bark using a pruning saw; scoring was a knife cut through the bark.

In 1992, the two cultivars responded similarly to girdling. Effects were greatest with treatments at 0 to 30 DAFB and included increased fruit set or retention, temporary suppression of vegetative growth (except

watersprouts), and increased levels of soluble solids in the fruit. Treatments affected starch levels in the fruit and flesh firmness, but these effects were variable.

In 1993, the two cultivars responded similarly to the main effects of girdling, which caused increased crop density and yield efficiency. Girdling increased mean apple diameter, weight, and soluble solids on 'Triple Red Delicious'/M.7 branches. Fruit diameter was reduced on 'Golden Delicious'/M.7 branches. Girdling affected flesh firmness in both cultivars, but these results were variable.

DEDICATION

This work is foremost dedicated to Lori, my wife, for without her loyal faith and support this would never have come to pass. To Andrew, my son, may you achieve more than I hope to ever achieve. To everyone in my family that may have silently and/or vocally supported my total graduate experience, I offer this work.

In addition, I dedicate this work to those who laid the ground work for basic and applied research in the fields of pomology and the tree fruit sciences.

ACKNOWLEDGEMENTS

I would like to thank all of those individuals who assisted me during the course of this study. A tremendous amount of thanks go to Dr. John A. Barden for all of his advice, counsel, editing, and most of all his understanding throughout the past few years. I would also like to express my gratitude to Drs. Richard Marini, David Orcutt, and David Parrish for their advice, instruction, and service as my committee.

I thank Donnie, Marilyn, Donna, and Connie for sharing in all of the times both good and challenging, for their assistance in " helping getting the job done," and for "keeping me in line" so that I could finish my degree.

Finally, over the past few years, I have met many people who were and are a wonderful source of help and support. I have gained so very much from them, and hope I have been able to offer some insight in return. For their friendship, support and laughter, I especially thank Melinda Shiflett, Amey Schweizer, Richard Harkess, Wangechi Muthui, Michelle Infante, Dave Wuosmaa, and Drs. Bob Lyons and Kevin Grueber.

TABLE OF CONTENTS

ABSTRACT	ii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
LIST OF TABLES	vii
INTRODUCTION	1
LITERATURE REVIEW	3
MATERIALS AND METHODS	28
RESULTS	35
DISCUSSION	64
LITERATURE CITED	72
APPENDIX I	79
VITA	87

LIST OF TABLES

Table 1 : Crop density (CD) ^z on 'Delicious' apple branches before hand thinning as affected by time (DAFB) ^y of girdling and wound treatment	36
Table 2 : Effects of timing and wound treatments on crop density (CD) ^z on 'Delicious' apple branches at harvest	37
Table 3 : Effects of timing(DAFB) ^z and wound treatments on yield efficiency (YE) ^y of 'Delicious' apple branches	38
Table 4 : Effects of timing (DAFB) ^z and wound treatments on soluble solids concentration (SSC) of 'Delicious' apples	40
Table 5 : Seed number in 'Delicious' apples as affected by time (DAFB) ^z of girdling and wound treatments . . .	41
Table 6 : Effect of time (DAFB) ^z of treatment on 'Delicious' shoot length (cm) on 7 July 1992 and 18 January, 1993	42
Table 7 : Number of watersprouts on 'Delicious' branches as affected by time (DAFB) ^z of girdling and wound treatments	43
Table 8 : Healing percent (HP) ^z of 'Delicious' apple branches as affected by time (DAFB) ^y of girdling and wound treatments	44

Table 9 : Crop density (CD) ^z of 'Golden Delicious' apple branches as influenced by girdling treatments at several days after full bloom (DAFB)	46
Table 10: Effects of time (DAFB) ^z and type of girdling on crop density (CD) ^y at harvest	47
Table 11 : Effects of time (DAFB) ^z and type of girdling on yield efficiency (YE) ^y of 'Golden Delicious' apple branches	48
Table 12: Ground color (GC) ^z of 'Golden Delicious' apples as affected by time (DAFB) ^y and type of girdling . . .	50
Table 13: Percent blush on 'Golden Delicious' apples as affected by the interaction of time (DAFB) ^z and type of girdling	51
Table 14 : Effect of time (DAFB) ^z and type of girdling on soluble solids concentration (SSC) in 'Golden Delicious' apples	52
Table 15 : Seed number per 'Golden Delicious' apple as affected by the interaction of time (DAFB) ^z and type of girdling	53
Table 16 : Effect of type of girdling on number of water sprouts (WS) on 'Golden Delicious' branches	55
Table 17: Effect of girdling and wound treatments on several factors of 'Delicious' apple	56

Table 18: Flesh firmness^z of 'Delicious' apples as affected
by time (DAFB)^y and girdling and wound treatments . 57

Table 19: Starch rating (SR)^z of 'Delicious' apples as
affected by time (DAFB)^y and girdling and wound
treatments 58

Table 20: Main effects of girdling and wound treatments on
several factors on 'Golden Delicious' apple 60

Table 21 : Flesh firmness^z of 'Golden Delicious' apples as
affected by time (DAFB)^y and type of girdling and wound
treatments 61

Table 22 : Starch rating (SR)^z of 'Golden Delicious' apples
as affected by time (DAFB)^y and type of girdling
treatments 62

Table 23 : Seed number per 'Golden Delicious' apple as
affected by time (DAFB)^z and type of girdling
treatments 63

INTRODUCTION

Girdling is a practice used over a number of years to induce changes in apple trees. It has been reported to alter tree size, flower bud formation, fruit set, fruit size, fruit maturation, fruit quality, and yield. Girdling also is an accepted research practice for avocado, citrus, grapes, nectarine, olive, peach, and pear. Girdling can, however, cause damage and even permanent injury to trees if healing across the girdles does not occur (Fernandez-Escobar et al. 1987).

Among tree fruits and related fruiting plants, much work has been done dealing with citrus and drupe fruits and grapes. Earlier apple researchers reported that girdling apple branches increased flower bud formation, flowering, fruit set, and yield while, in some cases, suppressing vegetative growth (Batjer and Westwood 1963; Burkholder and McCown 1941; Dennis 1968; Dennis and Edgerton 1965; Drinkard 1915, 1917; Fagan 1929; Howlett 1941; Murneek 1938, 1939, 1940, 1941). Early results were encouraging enough to lead to the proclamation by Murneek (1939) that girdling should be accepted as a commercial practice for apple orchards.

Presently, the increasing costs involved with apple production have forced commercial growers to plant trees

more intensively in attempts to increase production per area and per worker hour. Where rootstock and tree spacing are mismatched, tree crowding with a loss of productivity has occurred. Cultural techniques and plant growth regulators were used successfully to restrict apple tree growth and influence flower bud formation. Because the availability of chemicals for plant growth regulation is uncertain, other methods to alter tree size, flower bud formation, and fruit set in orchards will need to be developed. The use of girdling alone or in combination with the utilization of dwarfing rootstocks in commercial orchards is a potential option. These methods may allow smaller closer planted trees while promoting early production of fruit.

LITERATURE REVIEW

General. This review deals with effects of girdling and scoring of apple trees, as well as related research on other fruit tree species such as apricot, avocado, cherry, citrus, grape, olive, peach, and pear. The following effects of girdling and scoring will be addressed: flowering, fruit set, fruit growth, fruit yield, fruit maturity, fruit quality, and vegetative growth.

Research to determine the effects of girdling on plant materials has been performed since the early 1900s. Some of the initial findings were reported as early as 1914 by Drinkard. However, the non-specificity of the methods, materials, and results make the data difficult to interpret. For this reason, selected early reports will be omitted.

Wounding procedures described in the literature include the scoring of trunks or individual branches, a procedure requiring a single knife cut through the bark. More drastic procedures are ring and guillotine trunk girdling. The ring girdling technique involves cutting two horizontal half-circles into opposite sides of the trunk with a 4 to 6 cm overlap of each half-circle. The guillotine method uses a chainsaw to partially disrupt the continuity of the trunk by making two deep horizontal cuts one-third the radius of the trunk on opposite sides of the trunk and vertically spaced

20 cm apart (Hoying and Robinson 1992). Girdling requires the removal of a band of bark exposing the wood. Widths of wounds range from 0.5 mm in scoring to girdling widths of 1 mm to 12 mm. Scores or girdle treatments of varying widths appear most frequently in the literature; however, Cohen (1984a) reported that the width of the girdle did not seem to have consistent effects. In most cases, double girdling had a much greater effect than a single girdle even at widths of 1.25 mm, 2.5 mm, and 4.0 mm. Girdling instruments included pocket knives, razor blades, pruning saws, the California Grape Girdling Knife, and other patented U-shaped girdling tools.

Coverings applied to the girdling wounds vary with the researcher, plant, and timing. Wounds may be left uncovered or covered by grafting waxes (Griggs and Schrader 1941), grafting tape (Fagan 1929, Magness and Overley 1930; Murneek 1938), PVC tape (Lavee et al. 1983), electrician's tape (Howlett 1941), muslin tape impregnated with wax (Howlett 1941), or asphalt pastes (Cohen 1977). Lavee et al. (1983) used a mixture of CaCO_3 , mineral oil and wax (COW) containing 2% IBA, 2% ZnO , and 75 mg/l adenine. Howlett (1941) stated that care was taken to prevent the tape from touching the exposed cambium, which could prevent uniform healing.

Timing of treatment has also varied from researcher to researcher and includes: "when the sap began to flow..., at the time the foliage was well developed..., when the fruit buds began to form..." (Drinkard 1915), just before the blossoms opened (Heinicke 1932), "about the time length of terminals ceased to be rapid in nature...or at approximately 6-8 years of age" (Fagan 1929), 28 April, 1 May, and 18 May, 1931 (Greene 1937), at full bloom (Murneek 1938, 1939, 1940; Howlett 1941; Goren and Monselise 1971; Hoying and Robinson 1992), full bloom plus 14 days (Murneek 1939; Hoying and Robinson 1992), full bloom plus 19 days (Green and Lord 1983), full bloom plus 70 days (Murneek 1939), as flowers were opening or 16 days later (Murneek 1941), pink stage (Griggs and Schrader 1941; Howlett 1941), immediately after petal fall (Griggs and Schrader 1941, Goren and Monselise 1971), 2 June, 1940 (Griggs and Schrader 1941), early anthesis (Goren and Monselise 1971), mid-bloom, summer and autumn (Cohen 1984b), early September, 18 October, 22 November, 5 January (Lahav et al. 1986), and late March dormancy (Hoying and Robinson 1992).

Influences of girdling on flowering and flower bud initiation and development. Most research data indicate that girdling and scoring have positive effects on flower bud formation and development. Murneek (1943) found that, when fruit set is prevented by destruction of the blossoms,

bark girdling becomes an effective procedure for induction of flower buds during the "on" year. Scored branches of 'York' and 'Golden Delicious', that were in an alternate-year bearing pattern, invariably had a heavy to very heavy bloom and yield in the following "off" year. Batjer and Westwood (1963) stated that scoring of apple trees increased the amount of bloom in the following year. Additionally, scoring trees consecutively for two years increased bloom in the third year. However, bloom was light in the fourth year, after scoring was discontinued. Dennis (1968) reported that scoring in 1965 increased flowering appreciably in 1966 in four out of seven cases compared to Alar applied in 1965, which had no effect upon flowering of apple seedlings in 1966. Trunk scoring effectively promoted flowering only in apple progenies which had already begun to flower. Hennerty and Forshey (1971) reported that defruiting and scoring of apple in 1967 increased flowering in 1968, while shading and defoliation markedly reduced flowering. In Australia, Veinbrandts (1972) found that scoring in late October or in November was slightly more effective than the use of Alar in promoting flower bud initiation on 'Granny Smith' and 'Gravenstein' apple trees. Greene and Lord (1978, 1983) reported that scoring, limb spreading, and growth regulators predictably reduced terminal growth but that only scoring consistently increased

bloom. Autio and Greene (1992) reported that scoring just below the top tier of branches in 'Pioneer Mac'/Mark apple trees induced flower buds in the region above the scoring.

Evidence with other crops supports the results obtained with apple on the effects of scoring and girdling on flower bud initiation. Hartmann (1950) noted that girdling vigorous olive trees during December, January, or February increased the percentage of perfect flowers, fruit set and yields. Crane and Campbell (1957) reported that girdled apricot branches formed plentiful fruit buds but that excessive bud drop occurred during the early spring. Furr and Armstrong (1956) and Erner (1988) found that autumn girdling enhanced differentiation of flower buds in grapefruit. Lahav et al. (1986) reported that girdling of avocado increased flowering intensity, the percentage of seedlings that set fruit, and the number of fruits harvested per seedling as compared with the ungirdled control. Iwahori et al. (1990) showed that scoring in September or October increased bud sprouting the following spring and also the proportion of flowering nodes in 'Satsuma' mandarin.

Influence of girdling on fruit set and retention.

Burkholder and McCown (1941) reported that scoring only slightly increased the number of bloom clusters setting fruit on 14-year-old 'Starking Delicious' apple trees.

Fagan (1929) pointed out that scoring caused a desirable fruit set when the same tree was scored annually. Greene (1937) noted that scoring 'Grimes Golden' branches just before the flowers opened, more than doubled the fruit number per spur. Murneek (1938, 1939) noted that set was enhanced strikingly on scored branches. Griggs and Schrader (1941) described how branches scored on 3 May, at the pink stage, set higher percentages of fruit than the check. Branches scored later (1 June) did not set more fruit than the check, while scoring on 16 May (petal fall) resulted in a consistently higher set (13%) than girdling with a pruning saw on 3 May (11%) or on 2 June (8%). Batjer and Westwood (1963) noted that trees scored for two years had greater fruit set in the second year. In the third year, scored trees had a smaller crop than nonscored trees. In most instances, scoring increased fruit set the year following scoring. They stated, "One of the most interesting aspects of this experiment was the failure of previously scored trees to produce as much fruit as unscored trees after scoring was discontinued." Dennis and Edgerton (1966) reported on the effects of girdling and gibberellin (GA_3) sprays upon the retention of seedless apple fruits. They noted that most blossoms fell from nongirdled, non- GA_3 -treated limbs during the June drop, but that 46% of the blossoms developed into mature seedless fruit on girdled

limbs. Ferree and Palmer (1982) found that removing a 3-mm ring of bark from fully foliated 'Golden Delicious' spurs increased fruit set, determined 1 week after petal fall , compared to nongirdled spurs. A complete loss of fruit occurred when girdling was combined with the removal of all spur leaves. Fruit set determined 9 days after a thinning spray of carbaryl and after June drop was complete indicated that any treatment involving spur girdling induced more drop than on the control spurs. Hoying and Robinson (1992) reported that fruit numbers were increased on ring girdled trees, whereas guillotine girdling was intermediate between control and ring girdling.

There are several reports of related studies with other crops. Murneek (1940) found a 9 to 278% increase in fruit set in some cherry cultivars due to girdling and scoring. Yield of 'Ortanique', an orange-tangerine cross, was increased by girdling (DeLange et al. 1974). Monselise et al. (1972) found that girdling at the beginning of bloom increased yield of orange trees by increasing fruit numbers but not fruit size. Girdling caused abortion of some flowers which were in the early differentiation stages at girdling time and decreased the drop of ovaries during the first portion of the shedding season. Thus, fewer flowers produced more fruits. Cohen (1984a) noted that in the year after girdling, girdled grapefruit branches tended to bear

more and somewhat smaller fruits than did untreated branches. Schaffer et al. (1985), using pre-bloom girdling, increased fruit set in 'Shamouti' but noted a smaller effect in 'Murcott' oranges. Trochoulias and O'Neill (1976) noted that avocado trees girdled for three consecutive years retained an increased percentage of smaller fruit, but in the fourth year, girdled limbs produced the same weight and number of fruits as the controls.

Although in some instances the increased set was significant, in general, girdling did not produce either outstanding or dependable results in some relatively light-setting varieties, e.g. 'Stayman Winesap', 'Delicious', and 'Grimes Golden' (Howlett, 1941). He concluded that the results were variable for branches, trees, seasons, and cultivars. Finally, he reported, "up to 1941, it has not been possible to correlate the response in terms of time if ringing (girdling), age of tree, location, or vigor of the branches involved." Limb girdling three weeks after bloom did not effectively increase set but when used in combination with cluster thinning, increased 'Anjou' pear set beyond either treatment alone (Westwood and Bjornstad 1974). Greene and Lord (1978) found that scoring increased flower bud initiation but not fruit set in apple.

Influence of girdling on fruit size and growth.

Murneek (1939) found that in addition to enhanced fruit set, girdling increased fruit size in 'Ingram', 'Rome', 'King David', and 'Ralls' apples by 5 to 18%. Batjer and Westwood (1963) reported that scoring reduced fruit size in 1960 after trees were scored in 1959 and 1960. Dennis and Edgerton (1965) reported that girdling 'Wealthy' apple branches increased the initial growth rate of the seedless fruits. There was no appreciable difference in fruit diameter at harvest because smaller fruits on nongirdled branches had abscised. The only fruit characteristic affected by girdling was the length to diameter ratio, which was increased by 1%. Webster and Crowe (1969) reported that girdling increased fruit elongation. Greene and Lord (1983) noted that trunk scoring 19 days after full bloom reduced 'Cortland' fruit size in 1978 and 1979; but fruits were larger in 1980. They also reported reduced fruit size in 'Delicious' apples in 1979 and 1980. Schumacher et al. (1986) reported that girdling negatively influenced average fruit weight in all apple cultivars tested. Elfving et al. (1991) reported that trees scored at full bloom produced smaller apples than those scored in August. Autio and Greene (1992) noted that apple size was unaffected by girdling and scoring. Hoying and Robinson (1992) found that fruit size was not affected by either ring or guillotine

girdling compared to the control. Schechter et al. (1994) reported that at similar fruit loads, fruit on girdled limbs had 20 to 25% greater dry weight than those on non-girdled limbs. Diameter differences between fruit on nongirdled and girdled limbs were larger as fruit load increased.

Studies from other crops include Murneek (1940), who showed an increase of 0.4% to 23% in fruit size in girdled apple, cherry, peach, pear, and grape. Weinberger and Cullinan (1932) noted that girdling increased fruit size of peaches. Andrews et al. (1978) noted that fruit size was increased by girdling in all cultivars of peaches and nectarines tested with size increases ranging from 8 to 36%. Powell and Howell (1981) reported that girdling induced precocity of peaches and increased fruit size. Fruit size increased by 3 to 20 %; yields increased by 3 to 35% depending on season and cultivar. Dann et al. (1984) stated that, although girdling reduced total peach leaf area, there was no effect on either number or total weight of fruit harvested. Fruit growth was stimulated, however, in the last two weeks before harvest; thus, the growth rate of fruit on girdled limbs was increased over the control. As a consequence, final fruit size was unaffected, but in the second season fruit size was reduced by 80% compared to the first year. Powell and Howell (1985) reported that girdling of peach trees was the only treatment that consistently

advanced harvest and increased fruit size and yields with all varieties. Yield increased from 10 to 55 fruits per tree. Fruit size increased 10 to 25%, and harvest was advanced 3 to 10 days. Fernandez-Escobar et al. (1987) showed that girdling increased peach and nectarine fruit size and maturity. Girdling 'Springtime' peach trees increased the average fruit size and therefore increased the number of fruits included in the larger commercial sizes. In general, the larger the girdle width, the greater the response. DeVilliers et al. (1990) found that girdling in peach trees at the beginning of fruit growth stage II increased fruit size due to a 29% increase in growth rate during that stage. Day and DeJong (1990) reported that girdling nectarines before stage II of fruit growth increased fruit weight by 22.5% and more than doubled the percentage of fruit in the three largest size categories. Girdling on 31 March most effectively increased fruit size and maturity. Crane and Campbell (1957) and Lilleland and Brown (1936) reported that girdling slightly increased apricot fruit size. Cohen (1977, 1984a) observed that summer girdling caused grapefruit enlargement. Hochberg et al. (1977) found that girdling of grapefruit caused a clear decrease in the number of small and medium size fruit and an increase in large fruit. Fishler et al. (1983) reported that grapefruit on girdled branches weighed 44 to 119% more

than fruit on ungirdled branches. Erner (1988) stated that autumn girdling decreased citrus fruit size probably due to a two to four fold increase in fruit numbers, whereas spring girdling caused a significant increase in fruit size.

Jacob (1928) stated that girdling increased grape berry size. Dhillon and Singh (1949a, 1949b) reported that vines girdled with different methods all had increased yield and size of berries, and sugar and acid contents were similar for all treatments.

Influence of girdling on fruit drop. Murneek (1938, 1939, 1940) stated that the number of fruits per tree was increased by girdling which reduced early fruit drop on 'Minkler' and 'Arkansas' cultivars in Missouri. Dennis and Edgerton (1966) reported that interaction between GA₃ sprays and girdling on 'Wealthy' showed that girdling markedly reduced the severity of the June drop, resulting in many more fruits at harvest. Elfving et al. (1991) reported that scoring in July decreased preharvest drop compared to the control. Autio and Greene (1992) reported that girdling advanced fruit drop on 'Golden Delicious'/MM.106 by approximately one week. Hoying and Robinson (1992) noted that fruit drop was reduced by ring and guillotine girdling.

Influence of girdling on fruit maturity and ripening. Murneek (1939, 1940) indicated that apples, pears, and peaches from girdled branches were invariably more mature

and less firm. Ripening was also hastened with cherries, grapes and pears. Autio and Greene (1992) reported that girdling advanced maturity by approximately one week on 'Gardiner Delicious'/MM.106.

Several researchers reported that girdling of peach and nectarine cultivars resulted in advanced fruit ripening and maturity (Andrews et al. 1978; Powell and Howell 1981; Dann et al. 1984; Fernandez-Escobar et al. 1987; Day and DeJong 1990). DeVilliers et al. (1990) attributed earlier maturity of peaches from girdled trees to a 4 - day reduction in the duration of growth stage II. Fruit from girdled branches matured approximately 5 days earlier and were larger than those from control branches.

Crane and Campbell (1957) and Lilleland and Brown (1936) noted that girdling hastened maturity and ripening of apricots in the first season. Jacob (1928) and Dhillon and Singh (1949b) noted that girdling hastened the ripening of grapes. Cane plus trunk girdling proved more effective in hastening grape maturity than cane or trunk girdling alone (Dhillon and Singh 1949a).

Influence of girdling on fruit yield. Drinkard (1917) reported that a decrease in apple yield occurred over time upon discontinuing girdling treatments. Batjer and Westwood (1963) reported that, in most instances, scoring increased yields by increasing bloom and set. Utilizing a factorial

arrangement of pruning and scoring, they found an interaction between pruning and scoring. Scoring for three years significantly reduced cumulative yield in unpruned trees, but had little effect on the yields of pruned trees. Veinbrandts (1972) found that increased bloom due to scoring was resulted in higher yields on 'Gravenstein' apples. Ferree and Palmer (1982) reported that scoring spurs reduced the total weight of fruit at harvest, largely through the reduction of fruit numbers rather than fruit size. Greene and Lord (1983) noted that scoring 'Red Prince Delicious' apple trees for 3 consecutive years increased yield the second and third years. Hoying and Robinson (1992) reported that girdling increased yields in 'Mutsu' apple trees due to greater numbers of fruit per tree while fruit size was not affected.

In agreement with the effects of scoring on apple, many researchers have found that girdling is an effective means of increasing productivity in other fruits. Shamel and Pomeroy (1943) reported that trunk girdling of orange trees immediately increased yields compared to nongirdled trees. However, eight successive girdlings significantly reduced yield which was correlated with a smaller trunk size due to continuous girdling. Krezdorn and Brown (1970) reported increased yields on 'Minneola', 'Robinson,' and 'Osceola' orange due to girdling. Their evidence indicated that 5 to

20-year-old viral-free trees were most responsive to girdling. Erner (1988) reported that girdling of light- and heavy-bearing 'Shamouti' orange trees increased fruit yield when performed either before flower induction (autumn girdling) or at full bloom (spring girdling). Increased yield was due to a larger number of fruit with small differences in fruit size.

Lahav et al. (1971) noted that girdled branches of six avocado cultivars usually bore an increased subsequent crop. Reduced productivity of girdled compared with ungirdled control branches was recorded for all cultivars in the second and third years after treatment. Increased yield could be maintained by repeated girdling. Girdling sometimes induced a second "on" year in the alternate bearing cultivars. Trochoulis and O'Neill (1976) reported that girdled limbs of 'Fuerte' avocado had increased yields of fruit and total number of fruit for three consecutive years.

Dhillon and Singh (1949b) found that increased grape yield due to girdling can be accounted for by increases in berry size. Girdling clearly increased grape bunch weight and the number of seedless berries (Brown et al. 1988). Since no difference in bunch numbers occurred, crop weight was increased by girdling.

Lavee et al. (1983) reported that girdling olive trees increased yield when done in mid-winter (December to February) and to a lesser extent in April.

Influence of girdling on fruit quality. Ferree and Palmer (1982) showed that spur girdling reduced fruit calcium but increased magnesium. Greene and Lord (1983) noted trunk scoring at 19 DAFB reduced fruit firmness in 'Delicious' and increased soluble solids concentration in 'Cortland' and 'Delicious'. Schumacher et al. (1986) reported increased bitterpit in 'Gravenstein' fruits from girdled trees. Of all cultivars examined, scoring mainly intensified ground color on 'Cox Orange,' 'Boskoop,' and 'Glockenapfle'. Elfving et al. (1991) noted that trunk scoring or girdling increased soluble solids concentration and retarded loss of flesh firmness before harvest. Trunk girdling treatments increased soluble solids concentrations relative to the control. July trunk scoring retarded starch hydrolysis and ethylene evolution compared to control.

Girdling had little effect on citrus fruit quality (Goren and Monselise, 1971; Cohen 1984a). Girdling increased fruit soluble solids concentrations for 'Springcrest' peach (Andrews et al. 1978) and 'Mayfire' nectarine (Day and DeJong, 1990). Following girdling, grapes had higher acidity (Hochberg et al. 1977), higher sugars and lower pH (Brown et al. 1988).

Influence of girdling on storage behavior. Following storage, 'Cortland' apples from scored trees had more bitter-pit, and 'Delicious' fruit had more breakdown (Greene and Lord 1983). Elfving et al. (1991) reported that trunk scoring increased soluble solids concentrations and retarded loss of flesh firmness following storage, but scoring had little effect on starch hydrolysis. Scoring decreased the incidence of some disorders such as stem-cavity browning, storage scald, and brown-core and reduced post-storage ethylene evolution, flesh calcium, and magnesium based on the timing of scoring. Trunk scoring as late as three weeks before harvest increased fruit firmness and soluble solids concentrations.

Influence of girdling on tree/vegetative control. Fagan (1929) noted that yearly girdling would not kill but would retard growth to some extent; therefore, girdling should be practiced only on trees making at least 30 cm of terminal growth. He indicated that once started, girdling should be continued annually, or alternate bearing habits will be intensified. Batjer and Westwood (1963) noted that scoring of apple trees reduced trunk circumference and shoot length. Nonpruned scored trees made less trunk growth than pruned scored trees. As expected, pruning increased terminal shoots growth. Trunk circumference of non-scored trees was similar for both pruning treatments. Shoot growth

was increased in 'McIntosh' and reduced in 'Wealthy' trees following girdling (Dennis and Edgerton, 1966). Dennis (1968) noted that scoring reduced shoot growth by approximately 20% on apple seedlings. Webster and Crowe (1969) noted that 'McIntosh' fruit stems were thicker after ringing. Priestley (1970) stated that, when performed at an early stage of growth, ringing reduced average shoot length by 13% to 34% compared to control branches. It was unclear when shoot growth began to occur. Hennerty and Forshey (1971) reported that a scored trunk treatment made more growth than the other treatments before bloom but much less after bloom. In Australia, Veinbrandts (1972) found that scoring reduced extension growth, internode length, and number of leaves produced on 'Granny Smith'. Scoring 'Gravenstein' trees on 9 November, however, increased shoot length, shoot diameter, internode length and number of leaves compared to control trees. Later treatments did not influence these measurements. Greene and Lord (1978) reported that trunk scoring, limb spreading, and growth regulator predictably reduced terminal growth with non-spur 'Richared Delicious'/MM.106 trees. Both limb spreading and trunk scoring reduced terminal growth, but only scoring reduced lateral growth on previous season's wood. With spur-type 'Starkrimson Delicious'/MM.106, scoring and growth regulators reduced terminal growth the year of treatment.

Greene and Lord (1983) noted that terminal growth of 'Cortland' trees was reduced the year of scoring and the following year. Scoring 'Red Prince Delicious' for three consecutive years consistently reduced terminal growth. Scoring 'Cortland' once in 1978 reduced trunk circumference increases for three years. Embree and Crowe (1985) stated that scoring cuts which healed poorly, combined with initial light cropping, reduced lower trunk hardness. The incidence of winter injury was greatest below the score but always above the graft union. Winter injury was more severe and healing ratings were lowest on those trees with the widest scores and greatest crop load. Autio and Greene (1992) reported that girdling and scoring caused a similar level of growth reduction in 'Gardiner Delicious'/MM.106, resulting in approximately one-half of the trunk growth exhibited by the controls. Scoring in the top region of McIntosh/M.9 trees was a potential means of controlling top vigor and height. Scoring reduced shoot growth of 'Cortland'/M.7 and reduced the number of shoots arising in the top of the tree. Scoring of 'Pioneer'/Mark produced a desirable reduction in growth in the top of the tree. Hoying and Robinson (1992) reported that compared to control trees, ringing and guillotine girdling reduced trunk cross-sectional area, vegetative growth removed during summer pruning, shoot length and number of shoots per tree.

In agreement with the apple results, Crane and Campbell (1957) found that girdled apricot branches made little or no shoot growth during the season subsequent to treatment. Growth in the second season after girdling was less vigorous, and the leaves were considerably smaller than on non-girdled branches. In the season of girdling as well as the one following, leaves assumed a slight yellow/green as the season progressed and began to abscise in August, 6 to 8 weeks before leaves on non-girdled branches. Leaves on girdled branches were consistently lower in total nitrogen content. Trochoulis and O'Neill (1976) observed that avocado leaves on girdled limbs in the first season were lighter green than those on the control limbs. For the first three years, all girdles healed within three months. However in the fourth year; after 18 months, 85% of the fourth year consecutive girdles had healed.

Wallerstein et al. (1974) reported that girdling triggered starch accumulation in sour orange roots independent of carbohydrate transport from the leaves. Girdling also caused an increase in fresh weight in all parts of the seedling and a decrease in percentage dry weights of rootlets. Wallerstein et al. (1978) noted that girdling one-year-old sour orange seedlings decreased the starch level and respiration in the roots. One month after girdling healing had occurred and starch level and

respiration rates returned to comparable ratings of non-girdled seedlings. Iwahori et al. (1990) found that girdling suppressed the formation of vegetative shoots and increased formation of floral shoots of 'Satsuma' mandarin. Flowering was enhanced by more than 50% due to the increased formation of leafless inflorescences. Girdling increased the weight and accumulation of proteins in the buds during November and December.

Hartmann (1950) noted that alternate bearing in olive was not prevented by girdling trees during the winter months preceding the "off" year. Girdling young olive trees for two consecutive years reduced shoot growth, presumably due to increased fruit production. The degree of healing depended on the width of the girdle and the treatment given after girdling. Untreated girdles healed slowly; a COW dressing enhanced healing; and PVC covered girdle healed rapidly and completely (Lavee et al. 1983).

Andrews et al. (1978) reported no adverse effects of girdling on peach tree vigor in central Florida, but differences in tree vigor ratings were recorded elsewhere in Florida. Decreased tree vigor and severe leaf necrosis occurred on 'Springbrite' peach, while, girdling had no harmful effects on 'Springcrest' or 'Camden' peach and 'ArmKing' nectarine. Dann et al. (1984) observed that girdling reduced total peach leaf area by reducing the

number and average size of leaves. Limb girdling advanced leaf yellowing, senescence, and abscission on limbs which supported normal fruit loads but had only one-half the leaf area. Lateral shoot growth was reduced by 50% in the first and second year after girdling. 'Mayfire' nectarine shoot extension was reduced only by girdling at the end of fruit growth stage I (Day and DeJong, 1990). Shoot growth and callus formation depended on girdle width and peach and nectarine cultivar (Fernandez-Escobar et al., 1987).

Evert and Smittle (1990) noted that girdling decreased the percentage of peach cuttings that rooted. Girdling increased total sugar concentration independent of cultivar and increased nonstructural carbohydrates in girdled cuttings. Cutting survival depended more on the trees selected than on cultivar or girdling.

Influence of girdling on carbohydrate, nitrogen level, and growth regulator changes in vegetative growth. Greene (1937) measured higher sugar and starch content, and somewhat larger amounts of nitrogen in the spurs of girdled apple branches. Murneek (1938) suggested that girdling had some influence on nitrogen metabolism of apple branches, thereby affecting first drop. Batjer and Westwood (1963) reported that scoring reduced the nitrogen content of foliage, probably by interfering with the upward transport of this element. Hennerty and Forshey (1971) noted that

scoring had little effect on the content of carbohydrates and nitrogen in apple leaves. Consequently growth, flowering, and fruit set could not be associated with differences in carbohydrates, nitrogen, or carbohydrate/nitrogen relationship. Priestly (1970) reported that scoring did not increase carbohydrates in apple trees. Schechter et al. (1994) reported that nutrient levels in apple leaves on girdled, nonfruiting limbs were generally lower than for the control. Girdled limbs had more nitrogen, copper, and iron on a leaf area basis than nongirdled limbs.

In related research, Crane and Campbell (1957) observed that girdling apricot branches consistently lowered total nitrogen content of the leaves. Carlson and Yu (1969) noted that scoring increased cherry stem circumference, due mainly to an increase in bark thickness. However, starch content near loci of grafting, banding, and scoring did not increase in young cherry trees.

Furr et al. (1945) reported that girdling reduced nitrogen absorption by orange trees compared to the control. Goldschmidt et al. (1985) noted that the separation of a citrus branch from the rest of the tree by a girdle in autumn resulted in a high rate of starch accumulation and a corresponding nearly three-fold increase in flower number per branch. Goren et al. (1971) stated that girdling

'Shamouti' orange tree trunks in March promoted the accumulation of growth regulators in the bark near the girdle. During the first three weeks after girdling, gibberellin-like activity accumulated above the girdle, but after four weeks, all native regulators above and below the girdle were equal. Schaffer and Goldschmidt (1985) showed that girdling increased the nonstructural carbohydrate balance of 'Murcott' and 'Shamouti'. Girdling trees generally had a higher starch content in both the fruiting twigs and mature source leaves. This increase was observed in 'Murcott' two weeks after girdling but only 4 and 8 weeks after girdling in 'Shamouti' leaves and twigs, respectively.

Dann et al. (1986) showed that for 2 to 3 days after all but one of the secondary limbs of a peach tree were girdled, all limbs shrank. Shrinkage and subsequent growth were greatest in the zone immediately above the girdle, whereas growth was least immediately below. The concentration of IAA extracted from the bark immediately above the girdle first increased sharply but then decreased to the level in nongirdled limbs. On the other hand, beneath the girdle, the IAA concentration decreased by 75% and remained low. Thus, immediately above the girdle, IAA concentration in the bark increased, while the limb shrank and declined before the cambial growth rate increased.

Beneath the girdle, however, the concentration of IAA was severely depleted while growth of the limb was inhibited.

MATERIALS AND METHODS

Experiment #1 'Triple Red Delicious' / M.7 - 1992-93

'Triple Red Delicious' / M.7 apple trees planted in 1982 at the Virginia Tech Horticulture Farm in Blacksburg, Virginia were rated for bloom on 20 April 1992. On each of 25 trees with moderate bloom, four branches about 3.8 cm in diameter were selected. The experimental design was completely randomized with a factorial arrangement of four treatments and five timings. Trees were randomly assigned a timing of 0, 15, 30, 60, or 90 days after full bloom (DAFB), which was 29 April 1992. Branches on each tree received treatments of a nongirdled control, girdle + no cover, girdle + black plastic electrical tape, or girdle + TreeKote covering. All girdles were 9 mm wide, and a complete ring of bark was removed. Girdle coverings were applied immediately after treatment. On 20 May 1992, all trees were sprayed with carbaryl (Sevin) at 1.2 g/l to thin the crop.

In June, after the 'June drop', fruit counts were made on all experimental branches. Fruit loads were adjusted by hand on 24 June to a maximum of seven fruit per cm² branch cross sectional area (BCSA).

Lengths of ten randomly selected shoots per treatment branch were measured on 7 July and on 18 January 1993.

On 18 September 1992, apples were harvested, counted, weighed, and placed in cold storage at 0 ± 1 C. On 11 November 1992, apples were graded on a chain sizer. Counts and weights were taken for each of five size categories (1= < 62 mm, 2= 62 to 69 mm, 3= 70 to 76 mm, 4= 77 to 82 mm, 5= > 82 mm). Four apples per size were randomly sub-sampled at this time for a total sample size of twenty apples per experimental branch. On 25 November, fruit quality testing was started. Flesh firmness was measured on two peeled sides with an Effigi penetrometer. Using a hand-held Atago refractometer, soluble solids were determined on a composite juice sample collected during pressure testing. Starch ratings were made after dipping cross sections of fruit in an iodine-potassium iodide (I-KI) solution. Seeds were counted.

The same treatment limbs were used in 1993, but no new girdling was done. Healing varied from none to complete. In May 1993, basal and distal circumferences at the girdle were recorded from the previous seasons' control and treated branches.

On 14 May 1993, trees were sprayed with carbaryl (Sevin) at 1.8 g/l + naphthalene acetic acid (NAA) at 2.5 mg/liter + 70 second spray oil at 2.4 ml/l for fruit

thinning. Fruit loads were adjusted to a maximum of seven fruit per cm² BCSA on 17 and 18 June 1993. Total harvest counts, weights, and a random twenty fruit sample were taken on 8 September 1993 and placed in 0 ± 1 C storage.

On October 4, basal and distal circumference at the girdle were recorded. On October 22, all treatment branches were sacrificed for healing evaluation. Callus tissue growth was determined using an average of two caliper readings and compared to the original girdle width. Healing ratings were determined by measuring the amount of fusion of callus across the girdle around the circumference of the branch. A percentage was calculated by dividing the total amount of fusion by the total branch circumference. Healing ratings were made as follows: 1= <25%, 2= 26 to 50%, 3= 51 to 75%, 4= 76 to 100%.

Experiment #2 'Golden Delicious' / M.7 - 1992-93

'Golden Delicious' / M.7 apple trees planted in 1982 at the Virginia Tech Horticulture Farm in Blacksburg, Virginia were rated for bloom on 20 April 1992. Bloom ratings of light to heavy were made on all trees. Trees with medium bloom were selected.

On each of twenty trees, five branches of uniform size (about 3.8 cm diameter) were selected. The experimental

design was completely randomized with a factorial of four timings and five treatments. Trees were randomly assigned a timing of 0, 15, 30, or 60 DAFB. Branch treatments consisted of an untreated control, scoring, or a girdle of 6 mm, 9 mm, or 12 mm. The score treatment consisted of a single knife cut through the bark and cambium to the wood. Each girdle treatment involved the complete removal of the bark exposing the branch wood. All girdles were covered immediately with black plastic electrical tape.

For thinning in 1992, trees were sprayed with naphthalene acetic acid (NAA) at 8 mg/l plus Tween 20 at 1.2 ml/l on May 19 and with carbaryl (Sevin) at 1.2 g/l on May 20. In June, after the 'June drop', fruit counts were made on all experimental branches. Where necessary, fruit loads were adjusted on 24 June to a maximum of seven fruit per cm² BCSA; because of severe over-thinning, however, little hand-thinning was required.

Lengths of ten randomly selected shoots per treatment branch were measured on 7 July and on 18 January 1993. Water sprouts were counted on all branches on 18 January 1993.

On 18 September 1992, apples were harvested, counted, weighed, and placed in polyethylene lined boxes, which were placed in cold storage at 0 ± 1 C.

On 18 November 1992, fruit quality testing began. Individual apples were rated for ground color (1= dark green, 2= light green, 3= yellow/green, 4= yellow), and percent blush, diameter, weight, and flesh firmness were recorded. Composite samples were tested for soluble solids concentrations.

On 17 May 1993, the same trees were sprayed with NAA at 12 mg/l plus Regulaid at 1.2 ml/l for fruit thinning. Treatment limbs were not re-treated in 1993. However, fruit loads were adjusted to a maximum of seven fruit per cm² BCSA on 17 and 18 June 1993. Total harvest counts, weights, and a random twenty fruit sample were taken on 8 September 1993.

Fruit quality testing on apples from the sub-sample began on 25 October 1993. Diameter, weight, firmness starch ratings, and seed counts were recorded for each fruit (1993 data included in Appendix).

Experiment #3 'Triple Red Delicious' / M.7

& Experiment #4 'Golden Delicious' / M.7 1993

As previously described, sixteen 'Triple Red Delicious' / M.7 and sixteen 'Golden Delicious' / M.7 apple trees were selected on 20 April 1993. Three branches of uniform size (about 3.8 cm diameter) were selected per tree. The experimental design was completely randomized with a

factorial of timings and treatments. Trees were randomly assigned a timing of 0, 7, 14, or 21 DAFB which was 1 May 1993. Branches received treatments of nontreated control, pruning saw cut, or 9-mm girdle + black plastic electrical tape.

On 3 May 1993, approximately 100 blossom clusters were counted on each treatment branch, starting at the distal end. For fruit thinning, 'Triple Red Delicious' trees were sprayed with carbaryl (Sevin) at 1.8 g/l + NAA at 2.5 mg/l + 70 second spray oil at 2.4 ml/l on 14 May, 1993. 'Golden Delicious' were sprayed with 12 mg/l NAA + 1.2 ml/l Regulaid on 17 May 1993. On 26 and 27 May 1993, branch circumferences were measured. On 28 May 1993, fruit counts were made and fruit set was determined. Fruit loads were adjusted by hand to a maximum of seven fruit per cm² BCSA on 17 and 18 June 1993. Total harvest counts, weight and a random twenty fruit sample were taken on 8 September 1993 and placed in 0 ± 1 C storage.

Fruit quality testing on apples from the sub-sample began 15 November 1993. Fruit diameter, weight, firmness, starch ratings, water core, and seed counts were recorded for each fruit.

Statistical analysis. Analysis of variance (ANOVA) was run on each variable. Treatment means were compared with Duncan's multiple range test ($P = 0.05$). When interactions were significant for each treatment, linear, quadratic, and

exponential regression analysis were performed using DAFB as the regressor variable. The model, P-value, n, and R^2 values are presented for the most appropriate model. When main effects, but not interactions, were significant, data, excluding the non-girdled control, were pooled over girdling treatments and regression analysis was performed using DAFB as a regressor variable.

RESULTS

Experiment # 1 'Delicious' 1992 Branch girdling at 0 or 15 DAFB markedly increased crop density (CD); girdling at 30, 60, or 90 DAFB had no effect on CD (Table 1). The regression of treatment versus time was linear for all treatments, but the relationship between CD and DAFB was positive for the control and negative for all three girdle treatments.

On 24 June hand-thinning was used to reduce the maximum CD to 7.0; the regression was changed only slightly (data omitted). At harvest, CD and yield efficiency (YE) data were significantly affected by only the main effects of girdling and timing (Tables 2 & 3). Control branches had lower CD and YE than any of the three girdling treatments which did not differ. The significant regressions with DAFB indicate a linear decline in CD and YE as treatments were delayed. However, since the R^2 values are low, the relationship between CD and YE with DAFB is very poor.

DAFB and girdling treatments did not significantly affect fruit diameter, fruit weight, flesh firmness, starch or water core ratings (data not shown). Soluble solid concentration (SSC) increased quadratically with

Table 1 : Crop density (CD)^z on 'Delicious' apple branches before hand thinning as affected by time (DAFB)^y of girdling and wound treatment. ^x (Expt. #1, 1992)

Treatment	DAFB						Regression ^v			Model
	0	15	30	60	90	L	Q	n	R ²	
Control	2.8b ^v	2.8b ^v	3.3a	4.5a	4.1a	0.018	*	25	0.22	Y = 2.74 + 0.02DAFB
Girdle + no cover	10.0a	10.0a	4.2a	5.6a	4.3a	0.002	*	25	0.36	Y = 9.08 - 0.06DAFB
Girdle + tape	10.0a	10.0a	5.3a	4.0a	5.0a	0.004	*	25	0.30	Y = 9.40 - 0.07DAFB
Girdle + TreeKote	11.0a	9.2a	5.0a	4.4a	4.0a	0.0003	*	25	0.45	Y = 9.63 - 0.08DAFB

^z Crop density = fruit/cm² branch cross sectional area.

^y DAFB = days after full bloom which was 29 April 1992.

^x Interaction of time x girdle cover was significant by F-test ($P \leq 0.05$).

^v Linear and quadratic models were fit to data for each treatment. The model, P-value, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$).

^w Mean separation within columns by Duncan's multiple range test ($P \leq 0.05$).

Table 2 : Effects of timing and wound treatments on crop density (CD)^z on 'Delicious' apple branches at harvest. (Expt #1, 1992)

Timing (DAFB) ^y	CD	Treatment	CD
0	5.3	Control	3.6b ^x
15	5.5	Girdle + no cover	5.1a
30	4.4	Girdle + tape	5.2a
60	4.4	Girdle + TreeKote	5.0a
90	4.0		
Regression ^v	n	P-value	Model
L	80	0.01	Y = 5.29 - 0.015DAFB
Q		*	
R ²		0.07	

^z Crop density = fruit/cm² branch cross sectional area.

^y DAFB = days after full bloom which was April 29, 1992.

^x Mean separation within column by Duncan's multiple range test ($P \leq 0.05$).

^v Linear and quadratic regression models were fit to data pooled over all girdling treatments, excluding the control. The model, P-value, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$).

Table 3 : Effects of timing (DAFB)^z and wound treatments on yield efficiency (YE)^y of 'Delicious' apple branches. (Expt #1, 1992)

Timing (DAFB)	YE	Treatment	YE
0	0.75	Control	0.51b ^x
15	0.74	Girdle + no cover	0.72a
30	0.62	Girdle + tape	0.72a
60	0.62	Girdle + TreeKote	0.72a
90	0.59		
Regression ^v	n	P-value	Model
L	80	0.03	Y = 0.73 - 0.002DAFB
Q		*	
R ²		0.05	

^z DAFB = days after full bloom which was April 29, 1992.

^y Yield efficiency = kg/cm² branch cross sectional area.

^x Mean separation within columns by Duncan's multiple range test ($P \leq 0.05$).

^v Linear and quadratic regression models were fit to data pooled over all girdling treatments, excluding the control. The model, P-value, n and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$).

DAFB for girdling treatments (Table 4). The girdle without covering treatment increased SSC compared to the nongirdled control; covered girdle treatments were intermediate. Compared to the control, average seed number per fruit was larger for all girdle treatments applied at 0 and 15 DAFB (Table 5). For girdling applied at 60 and 90 DAFB, there was a trend towards fewer seeds per fruit for girdled branches compared to the nongirdled control.

As girdle treatments were delayed, shoot length in July increased linearly (Table 6). Girdling treatments applied at 0, 15, 30, and 60 DAFB induced water sprouts when compared to the control (Table 7). The significant linear regression of treatment versus time was negative for girdle + no cover and girdle + TreeKote treatments. Branches receiving girdle treatments had less than 100% healing over all application times (Table 8). Compared to no covering, covering the girdle with tape induced healing at all dates. Covering the girdle with TreeKote promoted healing as effectively as tape at 15, 30, and 60 DAFB, but was less effective at 0 and 90 DAFB. The regression model for treatment versus time was quadratic for girdle + tape and girdle + TreeKote.

Table 4 : Effects of timing (DAFB)^z and wound treatments on soluble solids concentration (SSC) of 'Delicious' apples. (Expt #1, 1992)

Timing (DAFB)	SSC	Treatment	SSC
0	13.6	Control	13.7b ^y
15	13.6	Girdle + no cover	14.4a
30	14.2	Girdle + tape	14.0ab
60	14.6	Girdle + TreeKote	14.1ab
90	14.2		
Regression ^x	n	P-value	Model
L		*	
Q	80	0.002	$Y = 13.41 + 0.03DAFB - 0.0003DAFB^2$
R ²		0.12	

^z DAFB = days after full bloom which was 29 April 1992.

^y Mean separation within column by Duncan's multiple range test ($P < 0.05$).

^x Linear and quadratic regression models were fit to data pooled over all girdling treatments, excluding the control. The model, P-value, n and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$).

Table 5 : Seed number in 'Delicious' apples as affected by time (DAFB)^z of girdling and wound treatments.^y
(Expt #1, 1992)

Treatment	DAFB					Regression ^x					Model
	0	15	30	60	90	L	Q	n	R ²		
Control	3.0c ^v	3.4b	2.9a	3.8a	3.8a	0.0294	*	72	0.01	Y = 13.89 - 0.004DAFB	
Girdle + no cover	3.9b	5.4a	3.5a	3.8a	2.8b	0.0001	*	100	0.04	Y = 13.84 + 0.013DAFB	
Girdle + tape	4.4ab	5.2a	3.5a	3.6a	3.3b	0.0001	*	100	0.03	Y = 4.65 - 0.016DAFB	
Girdle + TreeKote	4.9a	5.1a	3.5a	2.4b	2.9ab	*	0.0001	100	0.11	Y = 13.09 + 0.05DAFB - 0.0004DAFB ²	

^z DAFB = days after full bloom which was 29 April 1992.

^y Interaction of time x girdle cover significant by F-test ($P \leq 0.05$).

^x Linear and quadratic regression models were fit to data for each treatment. The model, P-value, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$).

^v Mean separation within columns by Duncan's multiple range test ($P \leq 0.05$).

Table 6 : Effect of time (DAFB)^z of treatment on 'Delicious' shoot length (cm) on 7 July 1992 and 18 January, 1993.^y (Expt #1, 1992)

DAFB	7 July 1992		18 January 1993	
	S1		S2	
0	26		24	
15	27		23	
30	28		26	
60	29		28	
90	35		29	
Regression ^y	n	P-value	Model	
L S1	80	0.0009	Y = 25.4 +	
S2	80	0.0054	0.09cm	
Q		NS	Y = 23.8 +	
		NS	0.06cm	
R ²		0.14		
		0.10		

^z DAFB = days after full bloom which was 29 April 1992.

^y Linear and quadratic models were fit to data pooled over all girdling treatments, excluding the control. The model, P-values, n, and R² are presented for the most appropriate model. NS = not significant.

Table 7 : Number of watersprouts on 'Delicious' branches as affected by time (DAFB)^z of girdling and wound treatments.^y (Expt #1, 1992)

Treatment	DAFB					Regression ^x			
	0	15	30	60	90	L	Q	n	R ² Model
Control	0.0b ^v	0.0b	0.0b	0.0b	0.0a	-	-	-	0 -
Girdle + no cover	2.8a	1.8a	1.0ab	1.4a	0.4a	0.004	*	25	0.31 Y = 2.31 - 0.02DAFB
Girdle + tape	1.8a	1.2ab	0.4b	0.0b	0.4a	*	0.007	25	0.36 Y = 1.86 - 0.06DAFB + 0.0005DAFB ²
Girdle + TreeKote	2.8a	0.6a	2.0a	1.6a	0.0a	0.028	*	25	0.19 Y = 2.21 - 0.02DAFB

^z DAFB = days after full bloom which was 29 April 1992.

^y Interaction of girdling time x girdle cover significant by F-test ($P \leq 0.05$).

^x Linear and quadratic models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$).

^v Mean separation within columns by Duncan's multiple range test ($P \leq 0.05$).

Table 8 : Healing percent (HP)^z of 'Delicious' apple branches as affected by time (DAFB)^y of girdling and wound treatments.^x (Expt #1, 1992)

Treatment	DAFB						Regression ^v			Model
	0	15	30	60	90	L	Q	n	R ²	
Control	- ^v	-	-	-	-	0	-	-	0.01	-
Girdle + no cover	4c	26b	12b	31b	7c	NS	NS	25	NS	NS
Girdle + tape	100a	100a	100a	100a	75b	*	0.0001	25	0.67	Y = 0.98 + 0.004DAFB - 0.00007DAFB ²
Girdle + TreeKote	49b	100a	91a	96a	60b	NS	0.01	25	0.34	Y = 0.58 + 0.02DAFB - 0.0002DAFB ²

^z HP = Percent of circumference in which girdle was bridged.

^y DAFB = days after full bloom which was 29 April 1992.

^x Interaction of time x girdle cover significant by F-test ($P \leq 0.05$).

^v Linear and quadratic model were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$), NS = not significant.

^v Mean separation within columns by Duncan's multiple range test ($P \leq 0.05$).

Experiment #2 'Golden Delicious' 1992 All girdling treatments increased CD when applied at 0 or 15 DAFB (Table 9). CD on scored branches did not differ from the control. CD declined linearly with increasing DAFB for all girdling treatments; but for the control CD increased linearly with DAFB. At harvest, only the main effects of treatment and time significantly affected CD and YE (Tables 10 and 11). Control branches had lower CD than any of the girdled branches, which did not differ; scored branches were intermediate. Control branches had lower YE than 6 mm girdle branches; all other treatments were intermediate. The significant linear regressions with DAFB indicate a reduction in CD and YE with a delay in treatments, but DAFB explained less than 10% of the variation in CD and YE.

There were no significant effects of DAFB or girdling treatments on fruit diameter, weight, flesh firmness, or starch ratings (data not shown). Differences in ground

Table 9 : Crop density (CD)^z of 'Golden Delicious' apple branches as influenced by girdling treatments at several days after full bloom (DAFB).^y (Expt #2, 1992)

Treatment	DAFB				Regression ^v				Model
	0	15	30	60	L	Q	n	R ²	
Control	0.3b ^v	0.2b	0.5a	0.7a	0.036	*	20	0.02	$Y = 0.199 + 0.009\text{DAFB}$
Score	0.6b	2.9ab	0.4a	0.9a	NS	NS	20	NS	
Girdle 6mm	2.7a	5.2a	0.7a	0.5a	0.025	*	20	0.25	$Y = 3.73 - 0.056\text{DAFB}$
Girdle 9mm	3.0a	3.9a	1.0a	0.5a	0.002	*	20	0.43	$Y = 3.429 - 0.052\text{DAFB}$
Girdle 12mm	4.2a	4.0a	0.7a	0.9a	0.006	*	20	0.35	$Y = 4.03 - 0.061$

^z Crop density = fruit/cm² branch cross sectional area.

^y Days after full bloom which was 29 April 1992.

^x Interaction of time x girdle width significant by F-test ($P \leq 0.05$).

^v Linear and quadratic models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$), NS = not significant.

^w Mean separation within columns by Duncan's multiple range test ($P \leq 0.05$).

Table 10: Effects of time (DAFB)^z and type of girdling on crop density (CD)^y at harvest. (Expt #2, 1992)

DAFB	CD	Treatment	CD
0	1.7	Control	0.5b ^x
15	2.8	Score	1.1ab
30	0.7	Girdle 6mm	1.8a
60	0.7	Girdle 9mm	1.7a
		Girdle 12mm	2.0a
Regression ^v	n	P-value	Model
L	80	0.002	Y = 2.13 - 0.026DAFB
Q		*	
R ²		0.09	

^z DAFB = days after full bloom which was 29 April 1992.

^y Crop density = fruit/cm² branch cross sectional area.

^x Mean separation within columns by Duncan's multiple range test ($P \leq 0.05$).

^v Linear and quadratic regression models were fit to data pooled over all girdling treatments, excluding the control. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$).

Table 11 : Effects of time (DAFB)^z and type of girdling on yield efficiency (YE)^y of 'Golden Delicious' apple branches. (Expt #2, 1992)

DAFB	YE	Treatment	YE
0	0.30	Control	0.21b ^x
15	0.52	Score	0.25ab
30	0.16	Girdle 6mm	0.40a
60	0.14	Girdle 9mm	0.33ab
		Girdle 12mm	0.33ab
Regression ^v			
L	n	P-value	Model
	80	0.008	$Y = 0.39 - 0.004\text{DAFB}$
Q		*	
R ²		0.08	

^z DAFB = days after full bloom which was 29 April 1992.

^y YE = yield efficiency (kg/cm² branch cross sectional area).

^x Mean separation within column by Duncan's multiple range test ($P \leq 0.05$).

^v Linear and quadratic regression models were fit to data pooled over all girdling treatments, excluding the control. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$).

color ratings were slight and inconsistent (Table 12). Branches girdled at 0 and 15 DAFB tended to bear fruit with greener ground color, while girdling at 60 DAFB tended to make fruit more yellow. The less severe girdling treatment of 6-mm showed a decreasing trend of ground color with a delay of treatments. For girdling treatments of 9 and 12 mm ground color increased as treatments were delayed. Blush was inconsistently affected by treatment (Table 13). There was a significant interaction between treatment and timing of treatment. Branches girdled at 0 and 15 DAFB tended to have less blush than the scored or controls. At 30 and 60 DAFB, the responses varied. Although individually significant, the regression models for blush versus time were variable, and the R^2 values were low. There was a significant linear relationship between DAFB and SSC, but treatment effects were not significant (Table 14).

Fruit on branches girdled at 0 and 15 DAFB had fewer seeds than the control and scored branches (Table 15). Regressions for seed number versus time varied among girdling treatments and clear trends were not apparent.

Table 12: Ground color (GC)^z of 'Golden Delicious' apples as affected by time (DAFB)^y and type of girdling.^x (Expt #2, 1992)

Treatment	DAFB					Regression ^v			
	0	15	30	60	L	Q	n	R ²	Model
Control	2.1a ^v	2.0a	2.1a	1.4b	*	0.0001	119	0.28	$Y = 2.04 + 0.01\text{DAFB} - 0.0004\text{DAFB}^2$
Score	1.7b	1.3b	1.6b	1.4b	NS	NS	183	NS	NS
Girdle 6mm	1.4c	1.1c	1.9ab	1.5b	*	0.032	379	0.02	$Y = 1.34 - 0.006\text{DAFB} + 0.0002\text{DAFB}^2$
Girdle 9mm	1.3c	1.3bc	1.7ab	2.5a	*	0.0001	384	0.27	$Y = 1.23 + 0.004\text{DAFB} + 0.0003\text{DAFB}^2$
Girdle 12mm	1.2c	1.4a	2.0ab	2.5a	0.0001	*	339	0.35	$Y = 1.17 + 0.023\text{DAFB}$

^z Ground color rated on a scale of 1 (green) to 4 (yellow).

^y DAFB = days after full bloom which was 29 April 1992.

^x Interaction of time x girdle width significant by F-test ($P \leq 0.05$).

^v Linear and quadratic models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$), NS = not significant.

^w Mean separation within column by Duncan's multiple range test ($P \leq 0.05$).

Table 13: Percent blush on 'Golden Delicious' apples as affected by the interaction of time (DAFB)^z and type of girdling.^y (Expt #2, 1992)

Treatment	DAFB				Regression ^x				
	0	15	30	60	L	Q	n	R ²	Model
Control	18b ^v	22a	22a	14bc	*	0.005	119	0.09	Y = 17.74 + 0.36DAFB - 0.007DAFB ²
Score	24a	13b	23a	20b	*	0.002	182	0.07	Y = 20.75 - 0.48DAFB + 0.008DAFB ²
Girdle 6mm	13c	8c	19ab	20b	*	0.0001	381	0.09	Y = 11.75 - 0.18DAFB + 0.006DAFB ²
Girdle 9mm	13c	13b	14b	9c	0.151	*	386	0.01	Y = 13.57 - 0.05DAFB
Girdle 12mm	12c	11bc	23a	29a	0.0001	*	340	0.22	Y = 10.22 + 0.3DAFB

^z DAFB = days after full bloom which was 26 April 1992.

^y Interaction of time x girdle width significant by F-test (P ≤ 0.05).

^x Linear and quadratic regression models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant (P ≤ 0.05).

^v Mean separation within columns by Duncan's multiple range test (P ≤ 0.05).

Table 14 : Effect of time (DAFB)^z and type of girdling on soluble solids concentration (SSC) in 'Golden Delicious' apples. (Expt #2, 1992)

DAFB	SSC	Treatment	SSC
0	15.8	Control	16.8
15	14.7	Score	16.4
30	17.6	Girdle 6mm	16.5
60	17.9	Girdle 9mm	15.7
		Girdle 12mm	16.9
			NS
Regression ^y n P-value Model			
L	68	0.0003	$Y = 15.16 + 0.046\text{DAFB}$
Q		NS	
R ²		0.18	

^z DAFB = days after full bloom which was 29 April 1992.

^y Linear and quadratic models were fit to data pooled over all girdling treatments, excluding the control. The model, P-values, n, and R² are presented for the most appropriate model. NS = not significant.

Table 15 : Seed number per 'Golden Delicious' apple as affected by the interaction of time (DAFB)^z and type of girdling.^y (Expt #2, 1992)

Treatment	DAFB				Regression ^x				Model
	0	15	30	60	L	Q	n	R ²	
Control	4b ^v	6a	5a	5	NS	NS	-	NS	NS
Score	7a	3b	5a	6	*	0.0001	173	0.14	$Y = 6.23 - 0.20\text{DAFB} + 0.003\text{DAFB}^2$
Girdle 6mm	3bc	3b	5a	6	0.0001	*	253	0.08	$Y = 2.39 + 0.06\text{DAFB}$
Girdle 9mm	2c	2b	3b	6	*	0.0001	257	0.15	$Y = 1.99 + 0.008\text{DAFB} + 0.001\text{DAFB}^2$
Girdle 12mm	4b	2b	5a	6	0.0002	*	244	0.06	$Y = 2.8 + 0.04\text{DAFB}$
NS									

^z DAFB = days after full bloom which was 29 April 1992.

^y Interaction of time x girdle width significant by F-test ($P \leq 0.05$).

^x Linear and quadratic models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$), NS = not significant.

^v Mean separation within column by Duncan's multiple range test ($P \leq 0.05$).

Water sprouts were induced by girdle treatments but not by scoring (Table 16). There was no significant relationship between number of water sprouts and DAFB.

Experiment #3 'Delicious' 1993 Girdling increased CD, YE, fruit diameter, fruit weight, SSC, and water sprouts compared to the control and the pruning saw cut treatment (Table 17). Healing percentage across the girdle was less for the girdle than for the control and pruning saw cut treatments.

Girdling increased flesh firmness of apples when applied at 14 DAFB compared to control and pruning saw cut treatments; at other application times treatments did not differ. (Table 18).

Starch ratings were higher on girdled branches compared to pruning saw cut treatments on 0 and 21 DAFB (Table 19). The control treatment was intermediate at these treatment times.

Table 16 : Effect of type of girdling on number of water sprouts (WS) on 'Golden Delicious' branches. (Expt #2, 1992)

Treatment		WS
Control		0.0b ^z
Score		0.0b
Girdle	6mm	0.6a
Girdle	9mm	0.6a
Girdle	12mm	0.8a
Girdle	12mm	0.8a

^z Mean separation within column by Duncan's multiple range test ($P \leq 0.05$).

Table 17: Effect of girdling and wound treatments on several factors of 'Delicious' apple.^z (Expt. #3, 1993)

Treatment	CD	YE	DIA	WT	SSC	WS	HP
Control	5.7b ^y	0.69b	64.5b	122b	13.6b	0.0b	-
Girdle	6.9a	0.88a	67.3a	139a	14.4a	1.8a	33b
Pruning saw cut	5.4b	0.62b	64.6b	123b	13.5b	0.0b	100a

^z Data are means for branches girdled at 0, 7, 14, and 21 days after full bloom which was 1 May 1993.
CD = Crop density (fruit/cm² branch cross sectional area).
YE = Yield efficiency (kg/cm² branch cross sectional area).

DIA = Mean apple diameter (mm).

WT = Mean apple weight (gm).

SSC = Soluble solids concentration.

WS = Mean water sprout number per branch.

HP = Percent of healing across girdle.

^y Mean separation within column by Duncan's multiple range test ($P \leq 0.05$).

Table 18: Flesh firmness^z of 'Delicious' apples as affected by time (DAFB)^y and girdling and wound treatments.^x (Expt. #3, 1993)

Treatment	DAFB					Regression ^v			Model
	0	7	14	21	L	Q	n	R ²	
Control	76.0 ^v	78.2	78.0b	76.5	NS	NS	158	NS	NS
Girdle	78.3	79.7	83.1a	75.2	NS	0.0009	160	0.09	$Y = 77.6 + 0.91\text{DAFB} - 0.05\text{DAFB}^2$
Pruning saw cut	76.6	79.2	78.4b	77.1	NS	NS	160	NS	NS
					NS NS NS NS NS				

^z Firmness (newtons) tested using an Effigi penetrometer on two peeled sides.

^y DAFB = days after full bloom which was 1 May 1993.

^x Interaction of DAFB x girdle significant by F-test ($P \leq 0.05$).

^v Linear and quadratic models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. NS = not significant.

^v Mean separation within columns by Duncan's multiple range test, ($P = 0.06$).

Table 19: Starch rating (SR)^z of 'Delicious' apples as affected by time (DAFB)^y and girdling and wound treatments.^x (Expt #3, 1993)

Treatment	DAFB					Regression ^v			
	0	7	14	21	L	Q	n	R ²	Model
Control	4.4ab ^v	4.3	4.7	4.6ab	NS	NS	319	NS	NS
Girdle	4.5a	4.4	4.4	4.8a	0.034	*	320	0.01	Y = 4.44 + 0.013DAFB
Pruning saw cut	4.3b	4.5	4.6	4.3b	NS	0.0004	320	0.03	Y = 4.29 + 0.06 - 0.003DAFB
		NS	NS						

^z Starch rating = rating scale 1 (full starch) - 9 (no starch).

^y DAFB = days after full bloom which was 1 May 1993.

^x Interaction of time x girdle significant by F-test (P ≤ 0.05).

^v Linear and quadratic models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant (P ≤ 0.05), NS = not significant.

^v Mean separation within columns by Duncan's multiple range test, (P = 0.06).

Experiment #4 'Golden Delicious' 1993 Girdling treatment increased CD, YE, and water sprouts compared to the control and pruning saw cut treatments (Table 20). Girdling decreased apple diameter compared to the control. Girdling suppressed healing across the wound compared to the pruning saw cut.

Apple flesh firmness was greater on branches receiving girdle treatment on 7 and 21 DAFB compared to control and pruning saw cut treatments (Table 21). Starch rating was higher for the girdle treatment at 0 and 14 DAFB than for control and pruning saw cut treatments (Table 22). Seed number per fruit on girdled branches was highest at 0 DAFB and lowest at 21 DAFB compared to control and pruning saw cut treatments (Table 23).

Table 20: Main effects of girdling and wound treatments on several factors on 'Golden Delicious' apple.^z (Expt #4, 1993)

Treatment	CD	YE	DIA	WS	HP
Control	4.6b ^y	0.69b	67.5a	0.00b	-
Girdle	6.7a	0.99a	66.4b	0.94a	77b
Pruning saw cut	4.9b	0.73b	66.9ab	0.00b	100a

^z Data are means for branches girdled at 0, 7, 14, and 21 days after full bloom which was 1 May 1993.

CD = Crop density after hand thinning to a maximum of 7 fruit/cm² branch cross sectional area.

YE = Yield efficiency (kg/cm² branch cross sectional area).

DIA = Mean apple diameter (mm).

WS = Number of water sprouts per branch.

HP = Percent healing across girdle or wound treatment.

^y Mean separation within columns by Duncan's multiple range test, ($P \leq 0.05$).

Table 22 : Starch rating (SR)^z of 'Golden Delicious' apples as affected by time (DAFB)^y and type of girdling treatments.^x (Expt #4, 1993)

Treatment	DAFB					Regression ^v			Model
	0	7	14	21	L	Q	n	R ²	
Control	5.3b ^y	5.6b	5.3b	5.4	NS	NS	320	NS	
Girdle	5.9a	5.8ab	6.2a	5.2	*	0.0002	320	0.05	$Y = 5.73 + 0.06\text{DAFB} - 0.004\text{DAFB}^2$
Pruning saw cut	5.3b	5.9a	5.3b	5.3	*	0.004	320	0.03	$Y = 5.37 + 0.06\text{DAFB} - 0.003\text{DAFB}^2$
NS									

^z SR = Starch rating on a scale of 1 (full starch) - 9 (no starch).

^y DAFB = Days after full bloom which was 1 May 1993.

^x Interaction of time x girdle significant by F-test ($P \leq 0.05$).

^v Linear and quadratic models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$), NS = not significant.

^w Mean separation within columns by Duncan's multiple range test, ($P = 0.06$).

Table 23 : Seed number per 'Golden Delicious' apple as affected by time (DAFB)^z and type of girdling treatments.^y (Expt #4, 1993)

Treatment	DAFB					Regression ^x				Model
	0	7	14	21		L	Q	n	R ²	
Control	4.4b ^v	5.3	4.4	4.4ab		NS	NS	320	NS	NS
Girdle	5.6a	5.1	4.5	4.1b		0.0002	*	320	0.04	Y= 5.58 - 0.07DAFB
Pruning saw cut	5.0ab	4.6	4.6	5.3a		NS	NS	320	NS	NS
		NS	NS	NS						

^z DAFB = days after full bloom which was 1 May 1993.

^y Interaction of time x girdle significant by F-test ($P \leq 0.05$).

^x Linear and quadratic models were fit to data for each treatment. The model, P-values, n, and R² are presented for the most appropriate model. (*) = significant ($P \leq 0.05$), NS = not significant.

^v Mean separation within columns by Duncan's multiple range test, ($P = 0.06$).

DISCUSSION

This study consisted of four experiments designed to evaluate the effect of girdling and other wounding treatments on the retention and quality of fruit and vegetative growth of 'Triple Red Delicious' and 'Golden Delicious' apple trees. Girdling between FB and FB + 3 weeks increased fruit retention and subsequently yield efficiency; however, fruit quality effects were inconsistent and vegetative growth was only slightly suppressed.

Murneek (1941) stated that it should be reasonable that girdling would result in holding carbohydrates above the girdle, for a certain period of time and would benefit the crop. Batjer and Westwood (1963) stated that scoring at full bloom increased the supply of carbohydrates during the fruit setting period by serving as a temporary interruption of the downward flow of carbohydrates. In the present study, crop density was increased by girdling, suggesting an interruption of assimilate transport out of treated branches. Assimilates may be maintained in the isolated terminal portion of the branch for use by the developing fruit.

Polomski et al. (1988) shaded limbs and whole trees for 5 to 10 days between 15 and 35 DAFB and reported that shading whole trees resulted in total fruit drop, while shading limbs caused incomplete fruit loss. These investigators suggested

that the greater fruit retention on shaded branches was due to translocation of assimilates from unshaded branches. Byers et al. (1990a) used shading, and Terbacil at 17 to 21 DAFB, to successfully thin spur 'Delicious' apple trees. These investigators suggested that the combined effects of environmental shading and photosynthetic inhibitor applications could limit photosynthesis and thereby cause fruit abscission in the period soon after bloom. Byers et al. (1990b) suggested that fruits are sensitive to photosynthetic inhibitors or limitation of light by shading for a brief period after bloom. Polomski et al. (1988) indicated that decreased levels of nonstructural carbohydrates in fruit prior to abscission affected growth-related processes that were involved in fruit retention.

In Experiment #2, trees were dramatically over-thinned by the combination of NAA + Sevin sprays followed by cloudy days. Girdling between 0 and 15 DAFB increased fruit retention and overcame this effect to a large degree (Table 9). These data suggest that the overthinning by NAA + Sevin + environmental shading was related to carbohydrate levels. They also suggest that girdling may be a possible reversal mechanism to overcome the negative effects of excessive environmental shading or overuse of certain chemical thinners.

Early season scoring enhances fruit set on apple branches (Murneek 1938, 1939; Green 1937; Batjer and Westwood 1963).

Scoring branches resulted in a consistently higher overall fruit set of 13% compared to the control (Griggs and Schrader, 1941). Girdling with a pruning saw on May 3, May 16 and June 2 showed increased fruit set by 10%, 13% and 8% respectively. These researchers, however, did not relate fruit set to CD or fruit retention. In my studies all girdle treatments between 0 and 21 DAFB increased fruit retention compared to control branches (Tables 1, 9, 17, 20 & Appendix I Table 1). Fruit retention was unaffected by treatment after 21 DAFB. These higher CDs indicate that fruit, which may have dropped during the 'June drop,' were retained due to the girdling treatment.

Barden (1992) evaluated the effect of CD on girdled versus nongirdled apple branches. On girdled branches there was a negative relationship between fruit quality and CD whereas on nongirdled control, CD had little effect. My results indicate that effects of girdling on fruit quality were inconsistent. There were no significant effects of DAFB or girdling treatments on fruit diameter, fruit weight, flesh firmness, starch or water core ratings in Experiments 1 and 2, yet, in Experiments 3 and 4 conflicting results occurred between cultivars (Tables 17, 18, 19, 20, 21, & 22). The lack of consistent effects of girdling on fruit quality in my studies is likely the result of low to moderate CD as compared to those of Barden (1992) in which CD were as high as 12 fruit/ cm² BCSA. Howlett, (1941) stated that fruit quality

effects seemed dependent on cultivars and location. Polomski et al. (1988) also suggested that cultivar effects may be involved in fruit effects.

In apples (Murneek 1939, 1940; Autio and Greene 1992), apricots (Crane and Campbell 1957), and grapes (Jacob 1928, Dhillon and Singh 1949b), fruit from girdled branches exhibited advanced fruit ripening and maturity. Fruit firmness was reduced (Greene and Lord 1983), while soluble solids concentrations were consistently increased in apples (Greene and Lord 1983; Elfving et al. 1991), peaches (Andrews 1978) and nectarines (Day and DeJong, 1990) following girdling. Soluble solids concentrations were inconsistently increased by girdling in both 'Delicious' and 'Golden Delicious' (Tables 4, 14, & 17), which may also relate to the low to moderate CDs in my studies.

Strong evidence, however, has been presented to support the use of girdling to increase size in peach, nectarine, apricot, grapefruit, and grapes (Weinberger and Cullinan 1932; Andrews 1978; Powell and Howell 1981; Fernandez-Escobar et al. 1987; DeVilliers et al. 1990; Day and DeJong 1990). Murneek 1939 reported an increase of 5-18% in apple size. Batjer and Westwood (1963) and Elfving et al. (1991) reported that girdling and or scoring reduced fruit size. Dennis and Edgerton (1965), Schumacher (1986), Autio and Greene (1992), and Hoying and Robinson (1992) found no adverse effects on

apple size or weight. These results are consistent with those of my experiments. Apple diameter and weight were not significantly affected by timing or treatment.

Using top scoring and trunk girdling, Autio and Greene (1992) reported reduced number, length, diameter, and weight of shoots arising from the top of the tree and a reduction in trunk growth by 50% compared to controls. Top scoring appears to be an intermediate form of treatment compared to individual branch girdling and trunk girdling. Hoying and Robinson (1992), who used a chain saw to "ring" and "guillotine" girdle tree trunks, reported that both techniques suppressed trunk cross sectional area increase, average shoot length and average number of shoots per tree. Trunk girdling appears to have a direct effect on the movement of carbohydrates and plant growth regulators from the entire tree to the root system. This suggests its use as a stronger mechanism for control of vegetative growth by completely isolating the aerial portion of the tree and preventing translocation of carbohydrates and growth regulators to and from the root system.

Dann, et al. (1984) presented data supporting the hypothesis that girdling alters the balance between endogenous growth regulators which favor either vegetative or reproductive development. They suggested that the initial effects on the girdled limbs are attributable to the

accumulation of growth regulators produced above the girdle. The reduced flow of growth regulators to the roots eventually results in lowered levels of root-produced hormones. In addition, altered distribution of assimilates between plant organs appears to be the predominant effect of girdling, with growth of fruit being favored over vegetative growth. Shoot length measurements indicated that growth was initially suppressed in earlier treated branches. This suppression, however, was temporary. The initial suppression of vegetative growth, which was lost later in the season, may be an important difference between the response to branch girdling and trunk girdling. Branch girdling may have a direct effect on translocation of carbohydrates and plant growth regulators to the girdled branches, but the roots are only minimally affected because most branches were not girdled. As the girdles heal, translocation of growth regulators and assimilates are restored to girdled branches, thereby allowing for resumption of normal growth patterns. Treatments applied at later times (30 or more DAFB) had little effect on vegetative growth because most of the shoot growth had already occurred by the time of treatment.

Few studies have been done to determine the best method of covering girdles. Lavee et al. (1983) determined that the initial healing potential of a girdle wound was dependent on the width of the girdle and treatment given after girdling.

Noncovered girdles and girdle widths over 15 mm showed very slow and partial healing to no healing respectively. PVC tape coverings induced rapid healing. Similar results occurred in my studies. Girdles covered with electrical tape exhibited the greatest healing when applied as late as 60 DAFB. The cover apparently provided for a re-establishment of the cambium; thus the treatment effect was temporary. Strikingly large amounts of callus tissue formed beneath each taped treatment, creating an abnormal bulge or knot surrounding the girdled area. Even though noncovered and nonhealed, girdled branches survived two growing seasons.

Comparison of results among the many published studies is difficult because of the variation in healing. In my study, noncovered girdles healed slowly and incompletely. Tape covered girdles healed quickly but formed an enlarged mass of tissue. TreeKote covered girdles healed rather slowly and poorly. In effect, the way in which the girdle is treated can result in a very temporary to a permanent interruption of phloem transport. Treatments leading to partial bridging of the girdle further confound the interpretation of my data.

Results with our healing studies varied between cultivars. 'Triple Red Delicious' healed less readily than 'Golden Delicious'. 'Delicious' branches receiving girdle treatments exhibited transitional healing depending on the type of girdle. Girdle + tape had a 95% healing. Girdle +

Treekote had 79% healing; and girdle + no cover exhibited only 16% in Experiment 1 while girdle + no cover in Experiment 3 had 33% healing. In Experiment 2, 'Golden Delicious' branches healed 100% percent because all girdles were covered with electric tape. 'Golden Delicious' branches with girdle + no cover in Experiment 4 had a 77% healing (Tables 17, 20, Appendix I-Table 4).

Further study in this area may include: repeated girdling for the assessment of the overall decline in vegetative growth and tree vigor, healing patterns and coverings, the effects of non-adjusted fruit loads and the source-sink relationship of fruit loads, as well as the positive effects of girdling in relation to the negative effects of shading and use of chemical thinners.

My results are too inconsistent to suggest this procedure as a commercial practice, however, girdling does appear to be a very effective research tool, particularly in the area of chemical thinning. The data from Experiment 2 are strong evidence that properly timed girdling can at least partially neutralize certain chemical thinners. Another area of potential use may be in an urban horticulturists's garden to improve flowering, fruit set, retention and yield on a branch by branch basis. Furthermore, the continued usage of girdling in the exploration of physiological changes and interactions within a plant can be recommended.

LITERATURE CITED

- Andrews, C. P., W. B. Sherman, and R. H. Sharpe. 1978. Response of peach and nectarine cultivars to girdling. Proc. Fla. State Hort. Soc. 91:175-177.
- Autio, W. R., and D. W. Greene. 1992. Ringing and scoring to control growth of apple trees: Results from 1991. Fruit Notes, 57(3)1-5.
- Barden, J. A. 1992. Cropload, and limb girdling affect apple fruit size, color, and quality. HortScience 27(6):625 (abstract).
- Batjer, L. P., and M. N. Westwood. 1963. Effects of pruning, nitrogen and scoring on growth and bearing characteristics of young Delicious apple trees. Proc. Amer. Soc. Hort. Sci. 82: 5-10.
- Brown, K., D. I. Jackson, and G. F. Steans. 1988. Effects of chlormequat, girdling, and tipping on berry set in *Vitis vinifera* L. Amer. J. Enol. Vitic. 39:91-93.
- Burkholder, C. L., and M. McCown. 1941. Effect of scoring and of a-naphthyl acetic acid and amide spray upon fruit set and of the spray upon pre-harvest fruit drop. Proc. Amer. Soc. Hort. Sci. 38:117-120.
- Byers, R. E., J. A. Barden, and D. H. Carbaugh. 1990. Thinning of spur 'Delicious' apples by shade, Terbacil, carbaryl, and ethephon. J. Amer. Soc. Hort. Sci. 115(1):9-13.
- Byers, R. E., J.A. Barden, R. F. Polomski, R. W. Young, and D. H. Carbaugh. 1990. Apple thinning by photosynthetic inhibition. J. Amer. Soc. Hort. Sci. 115(1):14-19.
- Carlson, R. F., and K. Yu. 1969. Starch content in cherry stems near loci of graft, banding, and scoring. HortScience. 4(3):246-248.
- Cohen, A. 1977. Girdling effects on tree performance. Proc. Int. Soc. Citriculture 1:178-181.
- Cohen, A. 1984a. Effect of girdling date on fruit size of Marsh seedless grapefruit. J. Hort. Sci. 59:(4)567-573.
- Cohen, A. 1984b. Citrus fruit enlargement by means of summer girdling. J. Hort. Sci. 59:(1)119-125.

- Crane, J. C., and R. C. Campbell. 1957. The comparative effectiveness of girdling and 2, 4, 5-trichlorophenoxyacetic acid for increasing size and hastening maturity of apricots. *Proc. Amer. Soc. Hort. Sci.* 69:165-169.
- Dann, I. R., R. A. Wildes and D. J. Chalmers. 1984. Effects of limb girdling on growth and development of competing fruit and vegetative tissues of peach trees. *Aust. J. Plant Physiol.* 11:49-58.
- Dann, I. R., P. H. Jerie, and D. J. Chalmers. 1986. Short-term changes in cambial growth and endogenous IAA concentration in relation to phloem girdling of peach, *Prunus persica* L. Batsch. *Aust. J. Plant Physiol.* 13:395-402.
- Day, K. R., and T. M. DeJong. 1990. Girdling of early season 'Mayfire' nectarine trees. *J. Hort. Sci.* 65(5):529-534.
- DeLange, J. H., O. Skarpe, and A. P. Vincent. 1974. The influence of cross-pollination and girdling on fruit set and seed content of citrus 'Oranique'. *Scientia Hort.* 2:285-292.
- Dennis, F. G. Jr. 1968. Growth and flowering responses of apple and pear seedlings to growth retardants and scoring. *Proc. Amer. Soc. Hort. Sci.* 93:53-61.
- Dennis, F. G. Jr., and L. J. Edgerton. 1966. Effects of gibberellins and ringing upon apple fruit development and flower bud formation. *Proc. Amer. Soc. Hort. Sci.* 88:14-24.
- DeVilliers, H., J. G. M. Cuttings, G. Jacobs and D. K. Strydom. 1990. The effect of girdling on fruit growth and internal quality of 'Culemborg' peach. *J. Hort. Sci.* 65(2):151-155.
- Dhillon, A. S., and L. Singh. 1949a. The efficacy of cane and trunk ringing of grapevines. *Proc. Amer. Soc. Hort. Sci.* 53:259-262.
- Dhillon, A. S., and L. Singh. 1949b. The influence of thinning and ringing on the cropping and quality of grapes and the vigor of grapevines. *Proc. Amer. Soc. Hort. Sci.* 53:263-268.

- Drinkard, A. W. Jr. 1915. Some effects of pruning, root pruning, ringing, and stripping on the formation of fruit buds on dwarf apple trees. Va. Agr. Exp. Sta. Tech. Bul. 16:1-120.
- Drinkard, A. W. Jr. 1917. Further observations on the effects of pruning, root pruning, ringing, and stripping on the formation of fruit buds on dwarf apple trees. Va. Agr. Expt. Sta. Tech. Bul 17:137-146.
- Elfving, D. C, E. C. Loughheed, and R. A. Cline. 1991. Daminozide, root pruning, trunk scoring, and trunk ringing effects on fruit ripening and storage behavior of 'McIntosh' apple. J. Amer. Soc. Hort. Sci. 116:(2):195-200.
- Embree, C. G., and A. D. Crowe. 1985. Winter injury to Gravenstein apple strains as influenced by trunk scoring. Can. J. Plant Sci. 65:981-984.
- Erner, Y. 1988. Effects of girdling on the differentiation of inflorescence types and fruit set in 'Shamouti' orange trees. Israel J. Bot. 37:173-180.
- Evert, D. R., and D. A. Smittle. 1990. Limb girdling influences rooting, survival, total sugar, and starch of dormant hardwood peach cuttings. HortScience 25(10):1224-1226.
- Fagan, F. N. 1929. The management of filler apple trees by ringing and severe heading back. Proc. Amer. Soc. Hort. Sci. 25:229-231.
- Fernandez-Escobar, R. R. Martin, P. Lopez-Rivares, and M. Paz Suarez. 1987. Girdling as a means of increasing fruit size and earliness in peach and nectarine cultivars. J. Hort. Sci. 62:(4)463-468.
- Ferree, D. C., and J. W. Palmer. 1982. Effect of spur defoliation and ringing during bloom on fruiting, fruit mineral level, and net photosynthesis of 'Golden Delicious' apple. J. Amer. Soc. Hort. Sci. 107(6):1182-1186.
- Fishler, M., E. E. Goldschmidt, and S. P. Monselise. 1983. Leaf area and fruit size on girdled grapefruit branches. J. Amer. Soc. Hort. Sci. 108(2):218-221.

- Furr, J. R., P. C. Reece, and G. Hrniciar. 1945. Nitrogen absorption of ringed orange trees in sand culture. Proc. Amer. Soc. Hort. Sci. 46:51-54.
- Furr, J. R., and W. W. Armstrong. 1956. Flower induction in Marsh grapefruit in the Coachella Valley, California. Proc. Amer. Soc. Hort. Sci. 67:176 - 182.
- Goldschmidt, E. E. , N. Aschkenazi, Y. Herzano, A. A.Schaffer. 1985. A role for carbohydrate level in the control of flowering citrus. Scientia Hort 26:159-166.
- Goren, R., and E. E. Goldschmidt and S. P. Monelise. 1971. Hormonal balance in bark and leaves of Shamouti orange trees (Citrus sinensis L. Osbeck) in relation to ringing. J. Hort. Sci. 46:443-451.
- Goren, R., and S. P. Monselise. 1971. Effects of ringing on yields of low-bearing orange trees. J. Hort. Sci. 46:435-441.
- Greene, D. W., and W. J. Lord. 1978. Evaluation of scoring, limb spreading and growth regulators for increasing flower bud initiation and fruit set on young 'Delicious' apple trees. J. Amer. Soc. Hort. Sci. 103(2):208-210.
- Greene, D. W., and W. J. Lord. 1983. Effects of dormant pruning, summer pruning, scoring, and growth regulators on growth, yield, and fruit quality of 'Delicious' and 'Cortland' apple trees. J. Amer. Soc. Hort. Sci. 108(4): 590-595.
- Greene, L. 1937. Ringing and fruit setting as related to nitrogen and carbohydrate content of 'Grimes Golden' apples. J. Agr. Res. 54:863-875.
- Griggs, W. H., and A. L. Schrader. 1941. Effect of branch ringing before and after blossoming in the fruit set of the 'Delicious' apple. Proc. Amer. Soc. Hort. Sci. 38:89-90.
- Hartmann, H. T. 1950. The effect of girdling on flower type, fruit set, and yields in the olive. Proc. Amer. Soc. Hort. Sci. 56: 217-225.
- Heinicke, A. J. 1932. The assimilation of carbon dioxide by apple leaves as affected by ringing the stem. Proc. Amer. Soc. Hort. Sci. 29:225-229.

- Hennerty, M. J., and C. G. Forshey. 1971. Effects of defruiting, scoring, defoliation, and shading on the carbohydrate content of "Golden Delicious" apple trees. *J. Hort. Sci.* 46:153-161.
- Hochberg, R., S. P. Monselise, and J. Costo. 1977. Summer girdling and 2,4-D effects on grapefruit sizes. *HortScience* 12:228.
- Howlett, F. S. 1941. Ringing in relation to fruit set in the apple. *Proc. Amer. Soc. Hort. Sci.* 39:212-216.
- Hoying, S. A., and T. L. Robinson. 1992. Effects of chain saw girdling and root pruning of apple trees. *Acta Hort.* 322:167-172.
- Iwahori, I., A. Garcia-Luis, P. Santamaria, C. Monerri, J. L. Guardiola. 1990. The influence of ringing on bud development and flowering in 'Satsuma' mandarine. *J. Expt. Bot.* 41(231) 1341-1346.
- Jacob, H. E. 1928. Some responses of the seedless varieties of *Vitis vinifera* to girdling. *Proc. Amer. Soc. Hort. Sci.* 25:223-229.
- Krezdorn, A. H., and H. D. Brown. 1970. Increasing yields of the 'Minneola,' 'Robinson,' and 'Osceola' varieties with gibberellic acid sprays and girdling. *Proc. Fla. State Hort. Soc.* 83:29-34.
- Lahav, E., B. Gefen, and D. Zamet. 1971. The effect of girdling on the productivity of avocado. *J. Amer. Soc. Hort. Sci.* 96(3):396-398.
- Lahav, E., D. Zamet, S. Gazit, and U. Lavi. 1986. Girdling as a means of shortening the juvenile period of avocado seedlings. *HortScience* 21(4):1038-1039.
- Lavee, S., A. Haskal and Y. Bental. 1983. Girdling olive trees, a partial solution to biennial bearing. I. Methods, timing and direct tree response. *J. Hort. Sci.* 58(2):209-218.
- Lilleland, O., and J. G. Brown. 1936. Growth study of the apricot fruit III. The effect of girdling. *Proc. Amer. Soc. Hort. Sci.* 34:264-71.

- Magness, J. R., and F. L. Overley. 1930. Relation of leaf area to size and quality of apples and pears. *Proc. Amer. Soc. Hort. Sci.* 26:160-162.
- Monselesse, S. P., R. Goren, I. Wallerstein. 1972. Girdling effects on orange fruit set and young fruit abscission. *HortScience* 7(5):514-515.
- Murneck, A. E. 1938. Branch ringing and fruit set of Minkler and Arkansas (Black Twig) varieties of apples. *Proc. Amer. Soc. Hort. Sci.* 35:24-26.
- Murneck, A. E. 1939. Further results on the influence of branch ringing on fruit set and size. *Proc. Amer. Soc. Hort. Sci.* 36:398-400.
- Murneck, A. E. 1940. Fruit production as affected by branch ringing. *Proc. Amer. Soc. Hort. Sci.* 37:97-100.
- Murneck, A. E. 1941. Relative carbohydrate and nitrogen concentration in new tissues produced on ringed branches. *Proc. Amer. Soc. Hort. Sci.* 38:133-136.
- Murneck, A. E. 1943. Effects of branch ringing on biennial bearing of York and Golden Delicious apples. *Proc. Amer. Soc. Hort. Sci.* 42:163-166.
- Polomski, R. F., J. A. Barden, R. E. Byers, and D. D. Wolf. 1988. Apple fruit nonstructural carbohydrates and abscission as influenced by shade and Terbacil. *J. Amer. Soc. Hort. Sci.* 113(4):506-511.
- Powell, A. and C. Howell. 1981. Using girdling, scoring and a growth regulator to increase yields and fruit size of peaches. *HortScience* 16(3):440-441 (abstr.).
- Powell, A. and J. Howell. 1985. Peach growers increase size with girdling. *Amer. Fruit Grower* 105:12-14.
- Priestley, C. A. 1970. Some observations on the effect of cropping on the carbohydrate content in trunks of apple trees over a long period. *Compact Fruit Tree* 14:135-139.
- Schaffer, A., E. E. Goldschmidt, R. Goren, and D. Galili. 1985. Fruit set and carbohydrate status in alternate and nonalternate bearing *Citrus* cultivars. *J. Amer. Soc. Hort. Sci.* 110(4):574-578.

- Schechter, I., J. T. A. Proctor, and D. C. Elfving. 1994. Apple fruit removal and limb girdling affect fruit and leaf characteristics. *J. Amer. Soc. Hort. Sci.* 119(2):157-162.
- Schumacher, R., F. Fankhauser, and W. Stadler. 1986. Influence of growth regulators, ringing and root cutting on apple quality and physiological disorders. *Acta Hort.* 179:731-742.
- Shamel, A. D. and C. F. Pomeroy. 1943. Effect of trunk girdling on the performance of 'Washington Navel' orange trees. *Proc. Amer. Soc. Hort. Sci.* 44:80-84.
- Trochoulis, T. and G. H. O'Neill. 1976. Girdling of 'Fuerte' avocado in subtropical Australia. *Scientia Hort.* 5:239-242.
- Veinbrants, N. 1972. Effects of succinic acid-2,2-dimethyl hydrazide (Alar) or scoring on growth and flower initiation of young apple trees. *Aust. J. Expt. Agr. & An. Hus.* 12:89-95.
- Wallerstein, I., R. Goren, and Y. Ben-Tal. 1978. Effect of ringing on root starvation in sour orange seedlings. *J. Hort. Sci.* 53:109-113.
- Wallerstein, I., R. Goren, and S. P. Monselise. 1974. The effect of girdling on starch accumulation in sour orange seedlings. *Can. J. Bot.* 52:935-937.
- Webster, D. H. and A. D. Crowe. 1969. Effects of gibberellic acid, N-dimethylaminosuccinamic acid (Alar), ringing and thinning on McIntosh apple shape. *J. Amer. Soc. Hort. Sci.* 94: 308 - 310.
- Weinberger, J. H. and F. P. Cullinan. 1932. Further studies on the relation between leaf area and size of fruit, chemical composition, and fruit bud formation in Elberta peaches. *Proc. Amer. Soc. Hort. Sci.* 29:23-27.
- Westwood, M. N. and H. O. Bjornstad. 1974. Fruit set as related to girdling, early cluster thinning and pruning of Anjou and Comice pear. *HortScience.* 9(4):342-344.

APPENDIX I

Table 1 : Fruit number/cm² BCSA on 'Delicious' apple branches at harvest as affected by time (DAFB) of girdling and wound treatment.^z (Expt. #1, 1993)

Treatment	0	15	30	60	90
Control	4.6c ^y	5.8ab	4.9ab	4.7a	5.9ab
Girdled + No cover	8.1a	7.3a	6.4a	6.4a	7.1a
Girdled + Tape	6.3bc	3.7ba	6.2a	6.2a	6.1ab
Girdled + TreeKote	6.6ab	5.7ab	6.5a	6.5a	4.9b

^z Fruit thinned to maximum of 7 fruit/cm² BCSA. Interaction of girdling time x girdle cover significant by F-test ($P \leq 0.05$).

^y Mean separation within columns by Duncan's multiple range test, ($P \leq 0.05$).

Table 2 : Main effects of girdling treatments on 'Delicious' harvest yield (kg) per branch, 1993.* (Expt. #1, 1993)

Treatment	Weight
Control	0.11a
Girdled + No Cover	0.09b
Girdled + Tape	0.11a
Girdled + TreeKote	0.11a

* Mean separation within columns by Duncan's multiple range test, ($P \leq 0.05$).

Table 3 : Healing rating of girdle as affected by time (DAFB) of girdling and wound treatments^z (Expt #1, 1993)

Treatment	0	15	30	60	90
Control	. ^y
Girdled + No cover	1.0c	1.8b	1.4b	2.0b	1.2b
Girdled + Tape	4.0a	4.0a	4.0a	4.0a	3.6b
Girdled + TreeKote	2.8b	4.0a	4.0a	4.0a	2.8a

^z Healing rating scale 1=<25%, 2=26-50%, 3=51-75%, 4=76-100%.

Interaction of girdling time x girdle width significant by F-test ($P \leq 0.05$).

^y Mean separation within columns by Duncan's multiple range test, ($P \leq 0.05$).

Table 4: Main effects of timing and wound treatments on percent healing of 'Delicious' apple branches.² (Expt #1, 1993)

Timing (DAFB)	% Healing	Treatment	% Healing
0	51b	Control	.
15	75a	Girdle + No Cover	16c
30	67a	Girdle + Tape	95a
60	76a	Girdle + TreeKote	79b
90	47b		

² Mean separation within columns by Duncan's multiple range test, ($P \leq 0.05$).

Table 5 : Main effects of girdling treatments on 'Delicious' apple weight (gm).^z (Expt #1, 1993)

Treatment	Weight
Control	141a
Girdled + No Cover	103b
Girdled + Tape	118ab
Girdled + TreeKote	119ab

^z Mean separation within columns by Duncan's multiple range test, (P= 0.07).

Table 6 : Main effects of girdling treatments on 'Delicious' apple firmness (newtons).² (Expt #1, 1993)

Treatment	Fruit Firmness
Control	76b
Girdled + No Cover	79a
Girdled + Tape	75b
Girdled + TreeKote	75b

² Mean separation within columns by Duncan's multiple range test, ($P \leq 0.05$).

Table 7: Main effects of timing (DAFB) and wound treatments on water sprout occurrence.* (Expt #1, 1993)

Timing (DAFB)	Water sprouts	Treatment	Water sprouts
0	2.8a	Control	.
15	2.1a	Girdle + No Cover	2.5ab
30	1.8a	Girdle + Tape	1.6b
60	3.0a	Girdle + TreeKote	2.7a
90	2.2a		

* Mean separation within columns by Duncan's multiple range test, (DAFB, P = 0.36; Treatment, P = 0.26).

VITA

Carl Eugene Mitchell was born on 6 March 1964 in Richmond, Virginia. He graduated from Lee-Davis High school in his home town of Mechanicsville, Virginia. He entered Virginia Tech in September of 1982 and graduated in December 1986 with a Bachelor of Science degree in Animal Science and again in June 1987 with a Bachelor of Science in Agricultural Education. He formally started graduate studies towards a Master of Science degree in Horticulture in May 1992 and received his degree in September 1994.

A handwritten signature in black ink, appearing to read 'Carl E. Mitchell', written in a cursive style.