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Causes of Soft Fruit in Sour Cherry (*Prunus cerasus* L.)

presented by

Mario Mandujano

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Major professor

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CAUSE

CAUSES OF SOFT FRUIT IN SOUR CHERRY (Prunus cerasus L.)

By

Mario Mandujano

A THESIS

Submitted to
MICHIGAN STATE UNIVERSITY
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ABSTRACT

CAUSES OF SOFT FRUIT IN SOUR CHERRY (Prunus cerasus L.)

By

Mario Mandujano

Michigan cherry growers often have severe problems with soft 'Montmorency' sour cherries. Causal factors may include weather conditions, orchard practices, harvesting methods, and conditions during holding of fruits prior to processing. In this study efforts were concentrated on determining the effects of orchard practices, including shading to reduce solar radiation, irrigation, nutrient level, and application of growth regulators, especially ethephon and gibberellin. Fruit firmness was evaluated with a computer driven measuring device that compresses individual fruits until a preset force is attained. Firmness decreased as maturity approached, then stabilized in both 1993 and 1994. Significant fruit softening occurred only during mechanical harvesting. No treatments consistently increased firmness, but maturity was hastened and firmness reduced by spraying with ethephon. Sprays of calcium and potassium did not affect firmness, and gibberellin increased fruit size slightly without affecting maturity. Some cherry orchards bore softer cherries than others. "Soft" fruit, as defined by industry standards, were observed only rarely in harvested fruit. Soft cherries appeared to be caused by excessive bruising, and were always found in conjunction with mechanical damage. Advanced maturity and heavy cropping appeared to predispose the cherries to greater softening during harvest.

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My sincere gratitude to my parents who always believed in me and encouraged me to work hard and aim high. My father's advice and example have been both inspirational and invaluable.

Finally, the unceasing support and love from my wife Lourdes has helped make the impossible possible, and my sons Bernardo and Adrian make my life worth living.

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I. INTRODUCTION

The four Great Lakes states (Michigan, New York, Wisconsin and Pennsylvania) together produce 90-95 % of the U.S. sour cherry (Prunus cerasus L.) crop. Michigan is by far the largest producer, with about 75% of the total U.S. crop (Ricks, et al., 1982). In 1993 Michigan produced 270 million pounds of the approximately 320 million pound U.S. crop (Michigan Agricultural Statistics, 1993).

Mechanical harvesting of sour cherries began over 30 years ago. Increased mechanized harvesting has been accompanied by increasing numbers of questions regarding the effects of mechanization on fruit quality. Early research was directed at increasing pitted yield by reducing excessive fruit bruising. Bruising causes a breakdown of the tissues of the fruit and, if severe, can result in "soft" fruit (see below). Improved harvesting, handling, holding and processing methods reduced bruising, but a wide gap remained between ideal and actual pitted yields (LaBelle, et al., 1964; Whittenberger, et al., 1965, 1969; Diener, et al., 1968; Gaston, et al., 1968; Bolen, et al., 1970; Tennes, et al., 1970). Mechanical harvesting of cherries results in additional bruising in comparison with careful hand harvest. Cherries are initially bruised during mechanical harvesting when the falling fruit impacts on hard surfaces and on other fallen fruit, or when they are squeezed or scraped during conveying. Also, additional bruising occurs during processin

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processing when fruit is dumped into tanks, conveyed, sorted and dropped onto hard surfaces several times en route toward the pitter. The amount of bruising received during harvesting and handling operations is inversely related to the initial firmness of the fruit (Parker, et al., 1966; Tennes, et al.,1966).

In recent years the sour cherry industry in Michigan has been plagued with fruits that lack firmness and do not firm up during soaking. Such fruits are described as follows: the flesh of a soft cherry will collapse and the pit can be felt when the fruit is rolled between the thumb and forefinger with slight pressure (USDA, 1993). The problem of soft 'Montmorency' sour cherries has occurred erratically in the Michigan industry for decades. Soft cherries were a problem even when all tart cherries for processing were hand picked and delivered to the canneries dry in wooden lugs. The adoption of mechanical harvesting did not create this problem, but its use can make it worse (Whittenberger et al., 1965,1968). Soft cherries are not confined to any one area or orchard, since in any given orchard cherries may be firm one year and soft the next. Apparently, fruit firmness is influenced by environmental conditions and cultural treatments; the principal factors implicated have been poor distribution of rainfall, excessive cloudy weather combined with low seasonal temperatures, high temperature during harvest, low calcium, high nitrogen, and heavy cropping (Bedford, et al., 1955). Excessive water or nitrogen may result in the production of soft cherries, particularly during the 3 or 4 week period immediately prior to harvest (Bedford, et al., 1955). Studies with many fruits, including cherries, showed that softer fruit were associated with heavy ap

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heavy application of both nitrogen and potassium (Curwen, 1966; Beaumont, 1933).

In the 1950s researchers demonstrated that 'Montmorency' cherries dropped 10 ft (3 m) once, or 3 ft (0.91 m) three times, to stretched minnow netting would remain essentially unbruised (Whittenberger and Hills, 1960). However, the same fruit would be severely bruised and softened after 3 drops of 3 ft each to a flat hard surface. Hand-picked cherries normally lose 12 to 14% of their total weight when pitted; about half of this loss is attributed to pit removal (Whittenberger, et al., 1964). However, mechanically harvested cherries lose from 14 to 24% of their total weight; much of the additional weight loss is due to juice lost through the ruptured skin of bruised cherries before pitting (Bolen, et al., 1970).

Soft cherries are difficult to handle and pit on the processing line. A soft score of 5% of fruit can lead to rejection and resultant loss of income for the grower, and/or problems in proper pitter operation and loss in pitter yield for the processor. In 1986 and 1992 Michigan sour cherry growers had severe problems with soft cherries during mechanical harvesting; fruit split on hitting the catching frame or were flaccid on arrival at the processing plants, resulting in a high percentage of cull fruit (Dennis, et al., 1994).

The primary objectives of this research were to identify the horticultural factors involved in preconditioning the cherry fruits to be soft, and also to identify on the tree potentially soft fruit as defined above. The principal factors studied were the effects of growth regulators, light intensity, crop load, nutrition and irrigation.

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II. REVIEW OF LITERATURE

A. SOUR CHERRY FARMER'S ALMANAC

Following is a sampler of what cherry farmers believe about firmness of sour cherries. This clearly is not scientific evidence, but may provide clues as to the cause(s) of soft cherries. When there is a heavy crop, fruit color tends to be poor. Also, too many cherries are shaken down at one time and bruise each other. Several short bursts with the shaker are thought to be superior to longer ones. When trees are over-fertilized, fruits are larger and the farmer must take special care in handling them. Late harvested fruit contain more sugar, so a longer chilling period is required to firm them. Cherry growers believe that fruit should not be harvested when the temperature is too high, and should not be allowed to build up on the catching frame and conveyer. Farm wisdom also says that the percentage of soft fruit increases in proportion to the number of times the fruit is handled. The problems of cooling the harvested fruit also sit heavily on the minds of cherry farmers. They recommend about 40 to 45 tanks on a semi truck, using a six inch discharge flume into the plant. Water should be added to the bulk tanks on the semi truck in the orchard before the fruit is transferred from the smaller tanks used, in order to cushion the transfer. Water temperature is also important, and if too many tanks are taken to the orchard, water becomes warm before the cherries are harvested.

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Cherry farmers also recommend that when temperature rises above 30 °C, harvesting should be suspended. Cherries will not re-firm under such conditions, and should not be harvested after noon on such days. While the wisdom reported above is not scientific, it guides cultural practices. Such practices often provide solutions to problems, or can be used in guiding experimental approaches to solutions. Cherry farmers know that proper pruning eliminates willowy wood, reduces tree height and facilitates mechanical harvest. There is no evidence that such practices result in firmer fruit, but certainly fruit quality will be better.

B. GENERAL ASPECTS OF FRUIT QUALITY

Brown and Bourne (1988) established that fruit firmness is a combination of skin and flesh strength, and is an important factor in determining sour or sweet cherry quality and in maintenance of this quality during harvest, handling and shipping. Firmness may also be related to the susceptibility of cherry fruits to mechanical damage and infection by rot organisms (Ogawa, et al.,1972).

In recent years the cherry industry has been plagued with sour cherries that lack firmness at harvest time, and do not firm up during soaking; these result in a mutilated product in the can. This change in firmness, according to Bedford and Robertson (1955), could not be attributed to any one geographical area or orchard, since in any given orchard, cherries could be firm one year and soft the next.

Bedford and Robertson (1955) concluded that the firmness or strength of the cherry structure was influenced directly by growing conditions; the principal factors involved seemed to be water,

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temperature, humidity and nitrogen fertilizer. Usually, too much water or nitrogen resulted in the production of soft cherries, particularly during the three or four week period immediately prior to harvest (Bedford and Robertson, 1955).

Whittenberger (1952) reported that the edible tissues of the sour cherry are composed of thin-walled cells cemented together with pectic substances. If both were strong, the cherry was firm and gave a high drained weight; if one or both were weak, tissues were soft and drained weight was low (Whittenberger, et al., 1952). Excess nitrogen fertilizer also tended to produce soft cherries if sufficient moisture was available for rapid absorption; however, this apparently did not occur at below-normal rainfall or above normal temperature conditions (Bedford and Robertson, 1957).

Research by Bedford and Robertson (1957) also indicated that the addition of calcium to the cherries before processing increased their firmness, and the effect increased with calcium concentration. The addition of calcium to the cherry soak water may increase firmness and eliminate, at least partially, the loss of firmness resulting from tearing or crushing during pitting (Tennes, et al., 1967). Studies in British Columbia and Washington showed that postharvest dips or preharvest sprays of calcium chloride ($CaCl_2$) improved fruit firmness of fresh and canned sweet cherries (Drake and Proebsting, 1985). In 1988 Utah cherry growers observed that holding freshly harvested sour cherries in $CaCl_2$ solutions for a half hour before beginning continuous circulation of cold water improved fruit firmness (Anderson, 1992). Postharvest fruits soaked in 3% calcium chloride for extended time periods always were firmer than ones soa

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ones soaked in tap water. Moreover, Henderson and Campbell (1991) observed that a preharvest foliar spray of calcium chloride increased sour cherry protein content and quality rating (no measurement device for firmness was reported).

Whittenberger (1953, 1964) found that recurrent bruising often caused serious losses in quality and product yield. LaBelle and Moyer (1960) showed that bruising and elapsed time after harvest, but not soaking in cold water, were important factors affecting product firmness and drained weight. Moreover, the amount or extent of bruising received during harvesting, handling and processing determined whether cherries gained or lost weight when soaked in water. LaBelle (1964), and Parker (1966) reported that cherries largely recovered from a single bruise if given sufficient time, and regained much of their original firmness. Tennes, et al. (1967) reported that bruise level, soak time and temperature all influenced quality, product yield and pitter efficiency of sour cherries. Decrease in soluble solids during the soaking period was most rapid with fruit that was most severely bruised. In general unbruised cherry tissues lost much less soluble solids than bruised cherries.

Fruit firmness is an important factor in fruit quality, and cannot be attributed to any one factor. Several factors have been identified as affecting fruit firmness, including water supply, temperature, humidity, nitrogen fertilizer, calcium concentration and bruising due to harvesting, handling and processing.

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C. PECTIC SUBSTANCES.

Pectic substances are polyuronides composed mainly of 1,4-linked ∞-D-galacturonic acid with neutral sugars, typically galactose and arabinose, as side chains (Pilnik and Voragen, 1970) . They are the major components of the primary cell walls and of the middle lamella of plant tissues (Northcote, 1963). Doesburg (1965) showed that cherry fruit are particularly rich in pectic substances, which have been associated with the texture of fresh and processed products.

Fils-Lycaon and Buret (1990) reported that the total pectic content of cherry fruit increased during ripening. Their studies showed an increase in total pectin content 6 weeks after anthesis, a constant level from 8.5 to 11 weeks after anthesis, and a decrease thereafter. According to Northcote (1963) degradation occurs just after the ripe stage. However, pectins drastically decreased from 90% for green fruit to 45% for overripe fruit. Fruit firmness declined very quickly until 7.5 weeks after anthesis, then remained constant (Fils-Lycaon, and Buret, 1990). Al-Delaimy, et al. (1966) reported that the total pectin content of sour cherries picked two weeks prior to commercial harvest was considerably higher than that of fruit from two later harvests.

Softening of fruit during maturation is related to changes in the fruit pectic composition. This relationship involves a conversion of water insoluble pectic substances to water soluble forms (Stier et al., 1956, Postlmayr et al., 1956, Gee and McCready, 1957, Hulme, 1958, and LaBelle and Moyer, 1960). Both nitrogen and potassium supply influence the water insoluble pectic content (Curwen, et al., 1966).

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Increasing potassium to a high level in the absence of nitrogen resulted in fruit with a reduced water insoluble pectic content. A reduction of calcium was also noted, which may have resulted in the formation of less water insoluble pectic substances, producing softer fruit.

Softening of cherry fruits during maturation is related to changes in the fruit pectic composition, and the relationship involves a conversion of water insoluble pectic substances to water soluble forms.

D. POLYGALACTURONASE (PG)

During ripening there are significant changes in the cell wall structure, consisting primarily of an increase in soluble polyuronide and a loss of galactose and arabinose (Wallner and Bloom, 1977; Gross, 1979). PG activity increases during ripening and has a major role in cell wall degradation and fruit softening (Sheehy, et al., 1988).

The softening of sour cherry fruit during ripening has not been studied extensively. Al-Delaimy, et al. (1966) could not detect PG activity in either fresh or frozen sour cherry fruits. However, a large body of evidence from other crops (tomato, kiwifruit, orange, banana, apple, etc.) suggests that PG plays a major role in the softening process (DellaPenna, et al., 1987). Seymour, et al. (1987) reported that changes in the levels of polyuronide solubilization during ripening are not closely related to the levels of PG.

The mechanism related to fruit softening is not fully understood. However, PG activity is involved in polyuronide solubilization and softening of tomato fruits (Wallner and Bloom,

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1977). Changes in firmness occurring during ripening in fruit tissues have been largely attributed to enzymatic dissociation of the cell walls between adjacent cells, and polygalacturonase correlates well with the softening of these tissues (Hall, 1987).

E. CONDITIONS AND TREATMENTS THAT MAY AFFECT FIRMNESS

1. Shading.

Fruit trees require light for photosynthesis and carbohydrate production, which are necessary for nutritional maintenance of the trees and for new growth. Flore and Layne (1990) showed that good light distribution within the tree canopy was necessary to assure maturity and flower bud formation for the following year. They concluded that shading could have a profound effect on the yield and growth of cherry trees. Flore and Layne (1985) reported that ripening was delayed on closely spaced, short trees and noted that a leaf-to-fruit ratio of less than 2.0 usually resulted in a limited carbohydrate supply, and could delay ripening by several days.

Additional research by Flore and Layne (1990) showed that shading had a profound effect on fruit maturation, as indicated by color and fruit retention force. Fruits in the interior of the tree were often greener and harder to remove than those on the exterior of the tree where exposure to sunlight was better. Shading equal to 36 and 21 percent full sun, applied on June 24 (the beginning of Phase III) delayed attainment of the optimum fruit retention force needed for machine harvest by 6 and 15 days, respectively. Flore and Layne (1990) concluded that light was a major factor associated with

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uniformity of ripening and could affect harvest time , especially if ripening of the fruit in the interior of the tree lagged far behind that of fruit on the exterior. In larger fruits, like apples, the most positive relationship between light and fruit quality is usually related to soluble solids, followed by fruit size. Low light reduces size, delays horticultural maturity, and increases firmness (Robinson, et al., 1983). Sweet and sour cherries, by comparison, have a short growth and maturation period, and fruit color will develop at relatively low light levels. In sweet cherries reduction of light to 36 percent full sun reduced flower bud formation, while reduction to below 10 percent caused embryo abortion and fruit drop (Patten and Proebsting, 1986). When Patten and Proebsting (1986) shaded sweet cherry fruits from petal fall to harvest, the cherries took 12 days longer to reach a dark red color. Soluble solids were higher for fruit shaded from pit hardening to harvest than for those not shaded, or for those shaded from petal fall to harvest; this difference was probably due to regeneration of the phloem in the early treated limbs. The degree of fruit softening upon maturity was less for unshaded fruits than for shaded fruits. Unshaded fruits were the firmest, followed by fruits shaded from pit hardening to harvest, with the fruit shaded from petal fall to harvest being the softest.

Clearly the literature indicates that shading can have a profound effect on growth, maturation and yield of sour cherries. Shaded fruit generally contain less soluble solids and are softer than those not shaded.

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2. Leaf:fruit ratio

Of all the tree fruit quality parameters examined, leaf : fruit ratio had the largest variability (Teryl, et al., 1987). Facteau, et al. (1983) sampled limbs with different leaf : fruit ratios and found the natural log of leaf : fruit ratio to be linearly related to fruit weight at a given color. Fruit firmness was positively correlated with soluble solids, and with the natural log of the leaf : fruit ratio.

Spayd, et al. (1986) examined the effect of crop load on sweet cherry quality and found that cherries from heavily cropped trees were lower in color, softer, had lower sugar and acid levels, and were less mature than cherries from lightly cropped trees. Patten, et al. (1986) reported that fruit quality was affected by tree factors such as: date of anthesis, location of fruit within the canopy, and ovary diameter at initial set. Flowers that opened early in the season produced better fruit at harvest than those that opened late, and fruits on young wood were larger and had higher soluble solids at harvest than fruits on old wood. Fruits on shaded limbs were slower to mature, softer at maturity and lower in color and soluble solids than fruits on unshaded limbs (Patten and Proebsting 1986). Teryl and Loescher (1987) also reported a positive correlation between fruit firmness and soluble solids, and between firmness and leaf:fruit ratio. Additional research done by Patten, et al. (1986) showed that fruit weight and soluble solids were greater for early-bloom fruit than for late-bloom fruit, but firmness was not affected.

Fruit firmness is clearly affected by leaf : fruit ratio. Low leaf : fruit ratios can affect fruit maturity and fruits on shaded limbs are slower to mature, softer at maturity and lower in color and soluble solids. Le

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solids. Leaf-fruit ratio is among the most important sources of variability in fruit quality.

3. Mineral nutrition

In 1950 Stanberry and Clore investigated the effect of nitrogen and phosphorus fertilizers on 'Bing' sweet cherries. They found that nitrogen application to unproductive cherry trees generally increased the yield and size of the fruit, but that heavy applications resulted in soft fruit . They also reported a common belief among growers that potassium applied in combination with nitrogen produced a firmer cherry and hastened maturity, but indicated that they knew of no experimental data to support the claim. Their research showed that moderate application of nitrogen (2 lb N/tree) was usually associated with firmer cherries, while potassium application resulted in softer fruit (firmness was graded on the basis of surface pitting characterized by sub-epidermal breakdown, but no actual measurements of fruit firmness were performed). N and NP contributed to the better holding condition of the fruit. When both were applied in medium amounts, an interesting interaction occurred which resulted in firmer fruit.

Increasing the calcium content of cherry fruits by spraying several times with calcium chloride during fruit development, or by post-harvest dipping in $CaCl_2$ solutions, led to an increase in the firmness of the fruit (Cooper and Bangerth, 1976). Sixty percent (Anderson, 1992) of total calcium in plants is associated with the cell wall. Calcium acts as a chelating agent in cross-linking phospholipids and other proteins in the cell membranes. Such stabilization helps

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maintain membrane integrity and the pectin-protein complexes of the cell wall middle lamella. Membrane leakage increases during tissue senescence. Calcium causes a condensation of membrane surfaces and decreases water permeability (Anderson, 1992). The calcium content of tomato cell walls increases to the fully grown immature stage, then drops to a level found just before the onset of ripening and softening of the tissue (Rigney and Wills, 1981).

The fundamental role of calcium during fruit maturation and the subsequent redistribution during ripening process is not yet clear. Some research indicates that an increase in the concentration of calcium in the external solution leads to an increase in the calcium level of the leaves and then the fruit.

4. Ethephon

Ethephon is a fruit-ripening agent commonly used to promote cherry fruit abscission for improved mechanical harvest and to minimize damage to fruit and tree (Bukovac, et al., 1969; Looney, et al., 1970). No data are known as to its effects on firmness, but one would predict that treatment would result in a softer fruit.

Ethephon is a water soluble plant growth regulator that is degraded within plant cells resulting in the liberation of ethylene. The ethylene release within the plant is responsible for biological activity, such as abscission, coloration, maturation and increase in soluble solids (Amchem, 1967; Cooke and Randall, 1968). Wittenbach and Bukovac (1973) reported that the fruit abscission response to ethephon was very temperature-dependent. The optimum range was 16 to 29 °C, with poor performance resulting from ethephon appli

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application below 16 °C (Bukovac, et al., 1969). Olien and Bukovac (1978) found that with high temperature, particularly for prolonged periods, the ethylene dose could exceed that considered optimal for fruit loosening, thereby inducing leaf abscission and gummosis. They reported that ethephon was the major source of ethylene when applied to sour cherry trees, and showed that the major effect of temperature is on the rate of ethylene generation from ethephon (Olien and Bukovac, 1982b). After application, the ethephon concentration decreased progressively over time, until at some point the concentration was so low that even a large increase in temperature would not release sufficient ethylene to produce a physiological response (Olien and Bukovac, 1978).

Ethephon is also applied to 'Montmorency' sour cherry trees to speed maturity and thereby permit early harvest. The optimum level is 300 to 500 ppm (Anderson, 1969). Fruits from treated trees were more mature in appearance and were a darker red than those from untreated trees. They were also slightly lower in soluble solids when treated with ethephon plus urea than with ethephon alone (Anderson, 1969). Ethephon apparently increased the ripening rate of all fruit on the treated trees, but such fruit were no more uniform in maturity than were control fruits.

The literature relating the effects of ethephon on fruit firmness of sour cherries is scant, but research on sweet cherries indicates that ethephon significantly increased the amount of fruit removed during the first 3-sec shake during harvest, both bruising and the total percent of fruit with persisting stems were consistently reduced following ethephon application (Bukovac, et al., 1979). Subsequent shakes of

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shakes of ethephon-treated trees produced a higher grade and less bruised fruit than was usually obtained from a second shake of non-treated trees.

The effects of ethephon are determined by many factors, such as applied dose, absorption, time of application, pH and temperature. While many factors are involved, temperature seems to be the critical one.

5. Gibberellic Acid (GA_3)

Gibberellic acid, when applied at 10 to 30 ppm early in stage III of fruit growth, increased size and firmness in sweet cherry fruit (Proebsting, et al., 1973). Proebsting, el al. (1973) noted that color, firmness and size were more affected by sprays applied in early June (during early stage III of fruit growth) than either two weeks earlier or later. Other studies indicated that the differences appeared to be due more to a change in fruit characteristics than to a simple delay in maturity (Dostal and Leopold; 1967, Russo et al., 1968; Dilley, et al., 1969). Treatment with GA tends to delay fruit ripening; it delays softening more than it delays coloring or soluble solids development, thus permitting the harvesting of firmer fruit.

Multiple applications of GA to sweet cherries by Facteau, et al. (1982, 1985) increased fruit firmness, weight, and soluble solids, and delayed harvest. Firmness was positively related to number of applications (10 - 50 ppm per application) of GA_3, and also to soluble solids and leaf:fruit ratio. The higher the soluble solids levels, the greater was the differential in firmness between GA_3-treated and control fruit (Proebsting, et al., 1973; Facteau, et al. 1985). GA_3 is currently

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currently used extensively by Washington growers to delay harvesting of 'Bing' cherries for fresh marketing. The recommended rate of application of GA_3 to sweet cherries is 10 ppm when fruit is light green to straw-colored as a method of increasing size and firmness and to delay harvest.

F. INSTRUMENTS FOR MEASURING FIRMNESS

For many years attempts have been made to measure cherry firmness directly or to discover a parameter whose value is closely related to firmness, but firmness is not easily assessed. Firmness is a textural attribute and an important factor in determining the overall quality of the fruit. In order to measure firmness in a manner approaching that of the human "thumb test", measurement of the deflection of a cherry subjected to a constant force over a fixed area should suffice. In 1925 Magness and Taylor developed a hand-held fruit pressure tester, which is still widely used for measuring firmness in many larger fruits. Whittenberger and Marshall (1950) measured firmness with a spring-loaded compression device. Cherry firmness was also measured by Bedford, et al. (1962) with a tenderometer (developed by Armour Co. Illinois), consisting of a probe assembly and a read-out box. The probe assembly contains ten penetration needles mounted on a manifold, which is in turn attached to an electronic strain gauge. The probe assembly also contains a handle for holding it, and an inverted U shaped member to serve as a penetration stop indicator . In 1964 LaBelle, et al. reported that the resistance of the cherry tissue to the shearing-crushing action of

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action of pitting was a more satisfactory guide to cherry firmness than other methods of measuring firmness.

Several techniques for measuring firmness of tart cherries were investigated by Parker, et al. (1966). These included: measuring the time required for a cherry to roll a given distance on a sloped plane; dropping cherries on a sloped plane and measuring the distance of bounce; and stacking ten cherries in a vertical tube, subjecting them to a load, and measuring the amount of compression. Cherries stacked vertically and subjected to a specific force should compress a distance inversely related to their firmness. When cherries were dropped onto an inclined surface, there was no apparent relationship between length of bounce and firmness. Also, various slopes, surface conditions and drop heights were tried without success. This instrument was successful in detecting small bruises (for example, a three foot drop vs. unbruised cherries) but it failed to detect the effects of larger bruises (Parker, et al.,1966).

The puncture-load (PL) meter, initially developed to measured diameter, consisted of a rigidly mounted micrometer dial with its rod vertical. It was able to detect differences in cherry firmness following slight bruising (Diener, et al., 1969). Mature cherries have a much higher percentage of soluble solids than immature cherries; thus, this instrument seemed well-suited to measuring both soluble solids and cherry firmness. The disadvantage of this method was its low capacity; only 24 cherries could be measured per hour (Parker, et al., 1966). Parker, et al, (1966) measured the relationship between soluble solids and cherry firmness, but found no apparent relationship when soluble solids were greater than 14 percent.

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Cherries containing less than 14 percent soluble solids had the lowest deflection.

Sour cherry firmness has also been measured using a durometer. Using this method, a pair of measurements are made on the same fruit, one with the skin intact, one with the skin removed. In 1974 research using the durometer showed the effects of mechanical harvesting, cooling and pitting on fruit firmness. The research indicated an initial firmness of 52 units, a loss of 11.5 units upon mechanical harvesting, and 7.7 units of re-firming on the cooling pad. Mechanical harvesting reduced firmness more in one geographical location than in another, and the percentage of re-firming decreased as the harvesting season progressed (Kenworthy and Silsby, 1974).

Brown and Bourne (1988) have measured firmness with pressure testers, force gauges and a shear press, but with limited success. Many other methods and instruments have been developed to measure firmness in small fruits: Bouyoucus and Marshall (1950), and Ourecky and Bourne (1968) with strawberries, Lustig and Bernstein (1987) with cherries, and Rohrbach (1981), Wolfe, et al. (1982), and Slaughter and Rohrbach (1985) with blueberries.

In 1993 Timm, et al. developed a method that approximated the "thumb test" mentioned earlier, involving deflection of a cherry during compression at a constant rate of increase (App. Fig. A1). They measured firmness by slightly compressing the fruit between two parallel surfaces and recording force versus deformation. They also found that many of the instruments used to detect firmness were designed for larger fruits, such as apples, peaches and pears, and we

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and were not sensitive enough to measure firmness in small fruits such as cherries, blueberries and strawberries.

This computer-driven device seems to be the most practical and accurate of all the firmness measurement methods. Each fruit is compressed until a preset force (e.g., 150 g) is reached. Force versus deflection is plotted and used to calculate a value (MCS = mean chord stiffness) roughly equivalent to the preset maximum force divided by the distance moved by the compression plate. Firmer fruits produce larger values (e.g., 150 g/2mm = 75 units) than do softer ones (e.g., 150 g/3mm = 50 units) Actual values are based upon the slope of the tangent to the force/deflection curve, rather than the simplified examples given above. This system is capable of distinguishing between bruise treatments, harvest treatments and fruit maturity levels.

Fruit firmness has been a difficult characteristic to assess in the sour cherry. It has been measured with pressure testers, force gauges and the shear press for many years with limited success. Although the durometer has sometimes proven useful, its use is not recommended due to variability in the readings obtained. The computer-driven testing machine mentioned above has been used effectively to measure components of firmness in sour cherries and other fruit crops.

My objective in the research to be described was to determine what factors might be responsible for the soft fruit problem in Michigan sour cherry orchards.

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III. MATERIALS AND METHODS

In 1993, a study was initiated to compare the effects of several cultural and environmental factors on firmness of fruit of sour cherry (*Prunus cerasus* cv. Montmorency). Seven orchard sites were selected in three areas: Traverse City, Belding and East Lansing. Tree age ranged from four to fifteen years. Two of the seven orchards were located on experimental stations operated by Michigan State University.

A. EXPERIMENTS CONDUCTED IN 1993

The experiments are outlined in Table 1.

1. Shading, Horticultural Teaching and Research Center (HTRC), East Lansing, MI.

Five trees planted in 1982 were selected for vigor and good cropping. Four limbs approximately 4-5 cm in diameter at the base were chosen on each tree. Shade cloth was used to cover two limbs on each of five trees, and the following treatments applied: a) no treatment, b) girdled 1 cm. ring of bark removed at the base; c) girdled and shaded (10 percent full sun) at the beginning of growth stage II (June 6), d) same as (c), but applied at the beginning of stage III (June 21). The girdles, which were covered with grafting compound, prevented movement of photosynthates from other parts of the tree during the period of shading.

Table 1. Treatments applied in 1993

ORCHARD	GROWER	LOCATION	TREATMENTS	EXPERIMENTAL DESIGN	*COMMERCIAL HARVEST	SAMPLING TIME		TREE AGE(YR)
						From	To	
1	MSU	East Lansing	Shading	RCB	July 15-18	2 Jul	9 Aug	12
2	Heffron	Belding	Leaf:fruit ratio	RCB	July18-20	8 Jul	12 Aug	5
3	Heffron	Belding	Ethephon	RCB	July18-20	8 Jul	12 Aug	4
4	Heffron	Belding	Gibberellin	RCB	July18-20	8 Jul	12 Aug	4
5	MSU	Traverse City	Nitrogen	RCB	July 25-28	22 Jul	18 Aug	12
6	MSU	Traverse City	Irrigation	RCB	July 25-28	22 Jul	18 Aug	12
7	Mitchell	Northport	Gibberellin	RCB	August 3-5	22 Jul	18 Aug	6
8	Gregory	Suttons Bay	Potassium	-	July 25-28	29 Jul	10 Aug	15
9	Gregory	Suttons Bay	Calcium	-	July 25-28	4 Aug	18 Aug	15

* Approximate, varying according to location.

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Fruit samples were harvested at intervals of 5 to 7 days, beginning 2 weeks before commercial harvest (July 1) and extending over a period of 5 weeks (August 3).

2. Leaf:fruit ratio, Heffron Orchard, Belding, MI

Twenty-five heavily cropping trees were selected. The effect of leaf: fruit ratio was assessed by partial hand removal of fruits on June 1-2, removing: a) none (control) b) half, c) two-thirds, d) three-quarters, or e) four-fifths of the fruit clusters. The remaining fruit clusters were distributed evenly throughout the trees. An additional 10 trees that differed in cropload were selected in the same orchard. One group of five trees had good foliage but a light crop and the second group had good foliage and a heavy crop.

Unfortunately, a fungal infection caused abscission of many leaves in this orchard. On July 3, the trees were reclassified into three groups, according to their leaf: fruit ratio at harvest time, as follows:

(a) few leaves, many fruits. l/F

(b) moderate leaf and fruit number. l/f

(c) many leaves, few fruits. L/f

The numbers of leaves per fruit were estimated to be approximately 0.25, 0.5 and 3.0, respectively, based upon photographs taken just prior to harvest. A total of five trees were selected per treatment, and were blocked by location in the orchard. Sampling began on July 10, and ended on August 13. Three trees were sampled per treatment on each date.

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3. Irrigation, NWM Experimental Station, Traverse City, MI.

Two rows of 24 trees each were selected and each was divided into six plots of four trees each. Trickle irrigation was assigned at random to one plot in each adjacent pair of plots, the remainder serving as controls (RCB design). Irrigation began on May 28, 1993. An emitter was placed 1.22 m from the trunk on each side of each tree, and each emitter delivered 3.78 liter of water per hour for a total of 12 hours per day (91 liters of water per tree per day). One tree per treatment in each of 3 blocks was sampled at each sampling time. Sampling began two weeks before commercial harvest and ended August 18. None of the trees was treated with ethephon. The total monthly natural precipitation for non-irrigated trees during May, June, July and August 1993 was 69, 163, 94 and 123 millimeter, respectively.

4. Nitrogen application, NWM Experimental Station, Traverse City, MI.

'Montmorency' on Mahaleb rootstock sour cherry trees were planted in 1978. Nitrogen fertilizer was applied, beginning at the sixth leaf, as follows: a) no nitrogen b) low nitrogen (0.23 kg N/tree per year), c) medium nitrogen (0.45 kg N/tree per year), and d) high nitrogen (0.91 kg N/tree per year), all applied on the surface close to the trunk of the tree. The medium rate is that normally used by Michigan sour cherry growers.

Trees that had received a) no nitrogen, c) medium nitrogen and d) high nitrogen in three of the blocks were used for evaluation of firmness. Each plot consisted of 3 trees, and the center tree in each plot

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plot was sampled. Sampling began on July 21 and ended August 18 (two weeks before commercial harvest to three weeks after harvest); no ethephon was applied.

5. Foliar applications of potassium and calcium, Gregory's Orchards, Sutton's Bay, MI.

Fruit samples were collected from two orchards where growers had applied potassium in non-replicated trials. " Nutra-K " [(Custom Chemicides. P.O. Box 11216, Fresno, CA 93772) 27% K_2O; actual form of potassium is potassium carbonate] (2.1 L/ha) was sprayed on every other drive row on July 7. On July 12, Nutra-K (2.1 L/ha) was again applied in the treated area to drive rows not sprayed on July 7, making a total of 4.2 L/ha.

"Trans-Cal" [(Trans National Agronomy, 470 Market St. SW, Suite 101, Grand Rapids, MI 49503) 8% Ca (calcium nitrate)] was sprayed weekly for six weeks beginning June 7, treating alternate drive rows in alternate weeks. During each of the first three weeks 2.1 L/ha was applied; during the last three weeks 3.2 L/ha was applied each week. Ethephon (1.1 L/ha) was applied in both K and Ca blocks on July 27.

Fruits from two trees treated with calcium or potassium were compared with fruits from two non-treated trees close by. Sampling began on July 29 (potassium) or August 3 (calcium) and continued until August 10 or 18, respectively.

6. Gibberellin (GA3) treatment.

Exp. 1. Heffron Orchard, Belding MI. Out of approximately 400

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6- year-old trees, fifteen were selected for moderate cropload. These were divided into three blocks with five trees in each block. GA_3 was applied at 10 and 20 ppm, using a hand gun; control trees were left untreated. The gibberellin was applied on July 3, three weeks before commercial harvest, during early phase III of fruit development. Fruit color had started to change from green-yellow to yellow-pink at this time (Facteau, 1982). Sampling started on July 14, and continued through August 13.

Exp. 2. Mitchell Orchard, Northport, MI. Twelve trees were selected, blocked for uniformity, and divided into four groups of three trees each (RCB). GA_3 at 0, 20, and 40 ppm was applied on July 13, approximately three weeks before commercial harvest, with a hand operated high pressure sprayer, each treatment being applied to one tree in each of the 4 blocks. Samples were taken from July 22 to August 18 (Note that fruit maturation is delayed one week in Northport relative to Traverse City).

7. Ethephon treatment.

Exp. 1. NWM Experiment Station, Traverse City MI. Non-irrigated trees in the block used for the irrigation experiment were selected for treatment with ethephon. Three branches were selected on each of four trees and the following treatments were assigned at random, using trees as blocks: 0, 150, and 300 ppm applied with a hand-held pistol grip sprayer. The control was sprayed with water. Three trees were sampled at each sampling time. The first sample was taken on July 29 and the last on August 9.

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Exp. 2. Heffron Orchard, Belding MI.

Ten 6-year-old trees were selected and divided into two blocks with five trees in each block. Ethephon was applied at 150 and 300 ppm, using a hand gun; control trees were left untreated. On July 9, two weeks before commercial harvest, 5 trees were sprayed with each concentration of ethephon. The same five control trees were used for both this trial and the gibberellin experiment (see exp. 6 above). Sampling began on July 14, and continued through August 13.

B. EXPERIMENTS CONDUCTED IN 1994.

All fruits sampled in 1993 were hand picked from the trees. Because no truly soft fruits were found, emphasis in 1994 was on the effect of treatments, ethephon in particular, on firmness before and after mechanical harvest. Orchards used and treatments applied are shown in Table 2.

1. Irrigation and nitrogen.

For the nitrogen and irrigation treatments, trees were identical with those used in 1993 (NWM Experimental Station), and the same treatments were applied. Natural precipitation for May, June, July and August 1994 was 34, 48, 121, and 64 millimeters, respectively.

2. Ethephon treatment.

Experiments were performed in three commercial orchards near Traverse City to evaluate the effects of ethephon treatment.

Table 2. Treatments applied in 1994

ORCHARD	GROWER	LOCATION	TREATMENTS	EXPERIMENTAL DESIGN	TIME OF HARVEST	*TREE AGE
1	MSU	Traverse City	Irrigation	RCB	3,9 August	12
2	MSU	Traverse City	Nitrogen	RCB	27 Jul	15
3	Plamondon	Suttons Bay	Ethephon	-	26 Jul	15
4	Bardenhagen	Suttons Bay	Ethephon	-	30 Jul	12
5	Shimeck	Maple City	Ethephon	-	2, 9 August	15
6	Gregory	Suttons Bay	Ethephon, Ca	-	29 Jul	12
7	MSU	East Lansing	Ethephon	RCB	-	12

* Approximate

** All the ethephon treatments at 300 ppm (1.2 L/100 L H20)

Ethephon was applied by the growers using airblast equipment. Growers selected the dates based upon their harvesting schedules; in several orchards early vs. late applications were made to permit evaluation of time of treatment; ethephon (300 ppm) [1 pint Ethrel (21.7% AI)/100 gallons/A= 125 ml/100 L/Ha]. The orchards chosen all had a history of soft cherries, and most had heavy crops. Three groups of 3 trees each were selected in each orchard to receive the ethephon treatments. Adjacent untreated trees were used for comparison, when available.

An additional experiment was conducted at the Horticulture Teaching and Research Center, East Lansing. Fruits from the orchard in East Lansing were not mechanically harvested. Twelve trees were selected for each treatment (RCB) as follows: ethephon (300 ppm) applied a) 14 days (July 1), b) 10 days (July 5), or c) 7 days (July 8) before commercial harvest. Three additional trees were left as untreated controls. Samples were hand harvested beginning just before the first ethephon application on July 1, and ending on August 3.

3. Foliar application of calcium.

The calcium experiment was performed at Gregory's orchard near Traverse City. A calcium foliar application [Trans-cal (8% Ca)] was applied by the grower using airblast equipment. A series of sprays in outside alternate rows was applied at the end of fruit set (June 7) and at fruit development (July 5).

4. Time of harvest over a 24-hour period, soaking, and holding temperature, HTRC, East Lansing.

Three 'Montmorency' sour cherry trees with similar crop load were chosen, and all were sprayed with ethephon (300 ppm) with a hand gun on July 1, twelve days prior to harvest. On July 12, one day before the experiment began, 24 pails of water (9.5 L/pail) were left at room temperature (23.3 ° C), 24 pails in a cold room (2.8 °C), and 24 paper plates were placed in both locations. Four different treatments were applied: warm wet (fruits in pails of water at 22 ° C), warm dry (fruit in plates at 23.3 ° C), cold wet (fruits in pails of water at 1.1 ° C) and cold dry (plates with fruits in the cold room at 2.8 ° C). Temperatures are those measured; water temperature may have been lower than air temperature in the cold room because of evaporative cooling and/or contact with the cold floor.

On July 13 at 0700 hr one thermometer was placed in each of the three trees and the air temperature was recorded every hour. The fruit temperature in each tree was also measured every hour, using a thermocouple thermometer. For each harvest on July 13-14, five samples of 30 fruits without stems were randomly selected from each tree at 0800, 1100, 1400, 1700, 2000, 2300, 0200 and 0500 hrs. One of the five samples was used to measure diameter, color and firmness. The additional four samples were used for the 4 different treatments described above. At the end of the four hour holding period, firmness and fruit weight were measured.

C. METHODS OF SAMPLING AND FRUIT MEASUREMENTS.

1993. Thirty fruits with stems attached were harvested from each limb (limb treatments) or tree (whole tree treatments). Larger samples were taken for comparison, but 30 fruits was found to be sufficient to give minimal coefficients of variation. Random samples were taken from the limb, or from around the circumference of the tree within 2 meters of the ground, placed in zip-lock plastic bags, and transported on ice from the orchard to the evaluation area in an adjacent building.

Fruit measurements:

Fruit cheek diameter (±0.1 mm) was measured with an electronic caliper.

Fruit color was measured on one (cheek) side of each fruit using a tristimulus color analyzer (Chroma Meter, Model CR 200, Minolta, Ramsey, NJ). This instrument records in L*a*b* color space coordinates. The L* scale represents a light-dark axis and ranges from zero (black, no reflection) to 100 (white, perfect diffuse reflection). The a*-scale value represents a red/green axis, with positive value indicating a red hue and negative values a green hue. The b*-scale represents a yellow/blue axis with a positive values indicating a yellow hue and a negative value a blue hue. When representing color measuring, the L* axis is positioned in the center of, and perpendicular to, the a* and b* plane (Timm and Guyer, 1995). Only values for L* are reported. In this thesis the term "color" will be used to indicate the value of L*, high values indicating greener, less mature fruit, low values deeper red, more mature fruit.

Fruit firmness was evaluated using the computer-driven measuring device (Timm, et al., 1993) described previously (see p. 20). Firmness was measured across the cheek diameter, using fruits with attached stems, unless otherwise noted. In 1993 a preset force of 150 g was set for sour cherry fruit. This was established based upon tests of several preset forces from 150 to 350 g. It was observed that forces greater than 150 g did not give symmetrical displacement curves. Firmness values increased with increasing force, but the structure and elastic properties of the fruit were destroyed and the fruit was damaged. In contrast, a preset force of 300 g is optimum for sweet cherry fruits.

Fruit removal force (FRF), or the force in grams required to remove the fruit from its stem, was determined by using a Hunter push-pull mechanical force gauge, model LKG-1, fitted with a curved stainless steel claw (1.27 cm wide, 0.076 cm thick, 7.62 cm long). A slot (0.46 cm wide) extended from the open end of the claw around the curve to hold the fruit during separation. The fruit stem was inserted in the slot, and the pull force exerted in the center of the claw.

Fruit weight was recorded after removal of the stems (30 fruits/sample). The fruits were then held at -20 °C until soluble solids were evaluated.

Soluble solids. The 30 fruits in a zip-lock bag were allowed to thaw at 20 °C, then crushed with the fingers. A sample of the expressed juice was placed on the prism of a refractometer (Mark II refractometer, Reichert Scientific Instrument). The readings give percentage values (brix) of the soluble constituents, primarily sugars.

1994. In blocks harvested mechanically, the first sample was hand harvested. Thirty fruits with stems attached were harvested from each tree and the following data were recorded as described above for 1993: fruit removal force, diameter, color, firmness, weight, and soluble solids. The second sample was taken just after the fruits were mechanically harvested; fruits were collected as they dropped into the tanks of water on the harvester and were placed in a plastic container. A sample of approximately 8 kg of fruit was divided into three equal parts and each sub-sample placed in a 20 L pail of cold water taken from the cooling tanks. The first subsample was used to measure firmness immediately after harvest, while the remaining two were put into mesh bags, each containing about 1.5 kg of fruit. The two bags were placed in tanks on a cooling pad and well water was circulated through the tanks for four hours (the approximate time they are held in the cooling tanks prior to processing). Water temperatures ranged from 50° to 56° F (10° to 13° C) in the orchard, and 40° to 48° F (4° to 8° C) on the cooling pads. The two bags of cherries were then combined and divided into three portions (two portions of about 1.0 kg each and the third of 300 g), each being placed in a pail through which cold water was circulated. The first portion was weighed, pitted with a hand-operated pitter, and then reweighed to evaluate percent loss in pitting, the second was used to measure firmness, and the third sample was graded subjectively for firmness and postharvest mechanical injuries.

D. STATISTICAL ANALYSIS

A randomized complete block design was used for the studies, using trees as blocks, and Tukey's test was used to determine differences between treatment means.

IV. RESULTS

A. RESULTS, 1993

1. Shading

Shading, combined with girdling, delayed fruit ripening three weeks, based upon fruit removal force, although the firmness of mature fruits was not affected (Table 3). Fruit growth, coloration and accumulation of soluble solids were similarly delayed. The effects of later shading (June 21) were similar but much less pronounced. Dates of maturity, based upon fruit removal force, were July 7 for the unshaded controls, and July 26 for limbs shaded either June 4 or June 21 (Fig. 1). Girdling alone had no significant effect except for a small increase in soluble solids. Shaded fruits were consistently lighter in color than controls, but still reached maturity; both shading treatments reduced fruit weight. Early shading in particular resulted in smaller, less mature fruits (Fig. 1).

Fruit removal force started decreasing very rapidly just before harvest time (July 14) and was higher in shaded fruit on all sampling dates. Fruits on shaded limbs had markedly lower soluble solids in early samples, but the content increased with time. Soluble solids in fruit on late shaded limbs remained low even on the last sampling date; values ranged from just over 5 to slightly below 10 brix. This difference in response between shading treatments was probably due to regeneration of the phloem following early shading/girdling

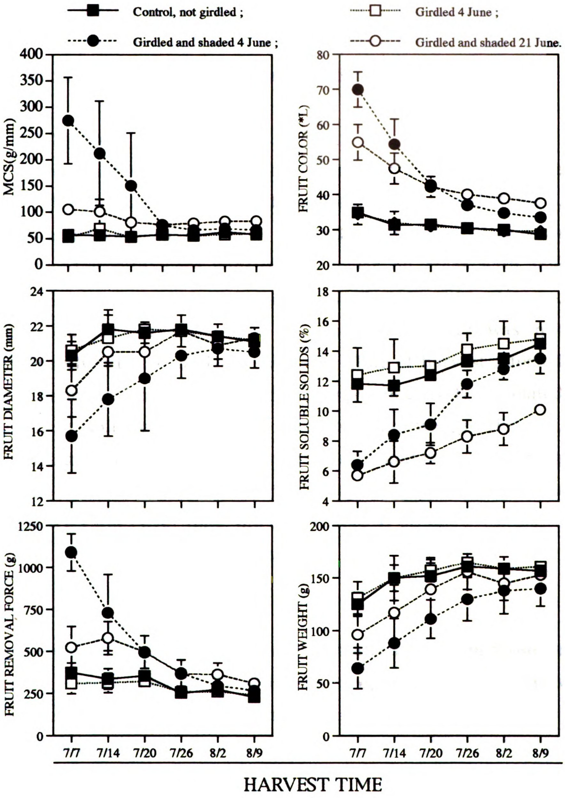
Table 3. Main effects of shading limbs with shade cloth (10% full sun) applied 4 and 21 June and time of sampling on fruit characteristics of 'Montmorency' sour cherry. Horticulture Teaching and Research Center, East Lansing MI, 1993.

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
TREATMENT						
CONTROL	57.3 c B [z]	31.1 c B	21.3 a A	12.9 b A	303 c C	151 a A
GIRDLED (G)	56.6 c B	31.1 c B	21.3 a A	13.6 a A	284 c C	154 a A
G + EARLY SHADED	106.7 a A	45.4 a A	19.0 c B	10.3 c B	541 a A	112 c C
G + LATE SHADED	84.0 b A	43.5 b A	20.5 b A	7.8 d C	440 b B	134 b B
DATE						
7-Jul	106.2 a A	48.5 a A	18.7 c C	9.1 d D	574 a A	104 d C
14-Jul	84.7 ab AB	41.2 b B	20.3 b B	9.9 cd CD	489 b B	126 c B
20-Jul	66.8 b B	36.8 c C	20.7 ab AB	10.4 c C	416 c B	140 b A
26-Jul	64.0 b B	34.5 d CD	21.4 a A	11.9 b B	313 d C	153 a A
2-Aug	68.2 b B	33.3 d D	21.1 ab AB	12.4 ab AB	298 d C	150 ab A
9-Aug	67.1 b B	32.3 d D	21.0 ab AB	13.2 a A	261 d C	152 a A
INTERACTION [y]	***	***	***	***	***	***

[z] Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

[y] *** Significant at $P \leq 0.001$.

Figure 1. The effect of shading (10% full sun) and time of harvest on fruit characteristics of 'Montmorency' sour cherry. Horticulture Teaching and Research Center, East Lansing, MI. 1993.



Control, not girdled ;
Girdled and shaded 4 June ;
Girdled 4 June ;
Girdled and shaded 21 June.
MCS(g/mm)
FRUIT COLOR (*L)
FRUIT DIAMETER (mm)
FRUIT SOLUBLE SOLIDS (%)
FRUIT REMOVAL FORCE (g)
FRUIT WEIGHT (g)
7/7 7/14 7/20 7/26 8/2 8/9
HARVEST TIME

vs. no such regeneration following the late treatment. Interaction between harvest time and shading was highly significant, as effects of shading decreased with time. Fruit firmness was highly correlated with all other fruit parameters measured (Fig 2).

2. Leaf:fruit ratio

Trees with low leaf/fruit ratios had firmer fruits than did those with high leaf/fruit ratios during the entire ripening period (Table 4, Fig. 3) and fruit maturation was delayed. Fruit diameter, soluble solids and weight were consistently lower on trees with low leaf/fruit ratios, and fruit color varied considerably within the tree. Fruit removal force was the only parameter that was not significantly affected by leaf/fruit ratio. Time of harvest affected every parameter measured. Fruit firmness was negatively correlated with fruit soluble solids, fruit diameter and weight (Fig. 4). Significant interactions between leaf:fruit ratio and time of sampling for data on color and soluble solids were apparently due to changes in relative values over time; the data (Table 4) do not show major shifts in these relationships, however.

3. Irrigation

Fruits on irrigated trees were consistently softer than those on non-irrigated trees (Fig. 5) with one exception (July 22). Fruit diameter and weight were greater in irrigated trees, but color, soluble solids and fruit removal force were unaffected (Fig. 5). Although time of harvest affected every parameter measured, no interactions between irrigation and time of harvest were significant

Figure 2. Correlations between firmness and several other fruit characteristics. Shaded (10% full sun) experiment. Horticulture Teaching and Research Center, East Lansing MI, 1993.

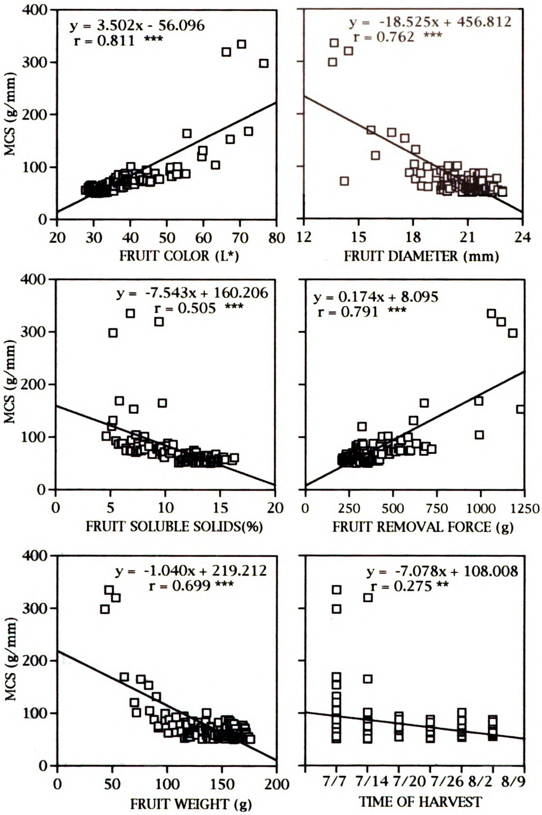

y = 3.502x - 56.096
r = 0.811 ***
MCS (g/mm)
FRUIT COLOR (L*)
y = -18.525x + 456.812
r = 0.762 ***
FRUIT DIAMETER (mm)
y = -7.543x + 160.206
r = 0.505 ***
MCS (g/mm)
FRUIT SOLUBLE SOLIDS(%)
y = 0.174x + 8.095
r = 0.791 ***
FRUIT REMOVAL FORCE (g)
y = -1.040x + 219.212
r = 0.699 ***
MCS (g/mm)
FRUIT WEIGHT (g)
y = -7.078x + 108.008
r = 0.275 **
7/7 7/14 7/20 7/26 8/2 8/9
TIME OF HARVEST

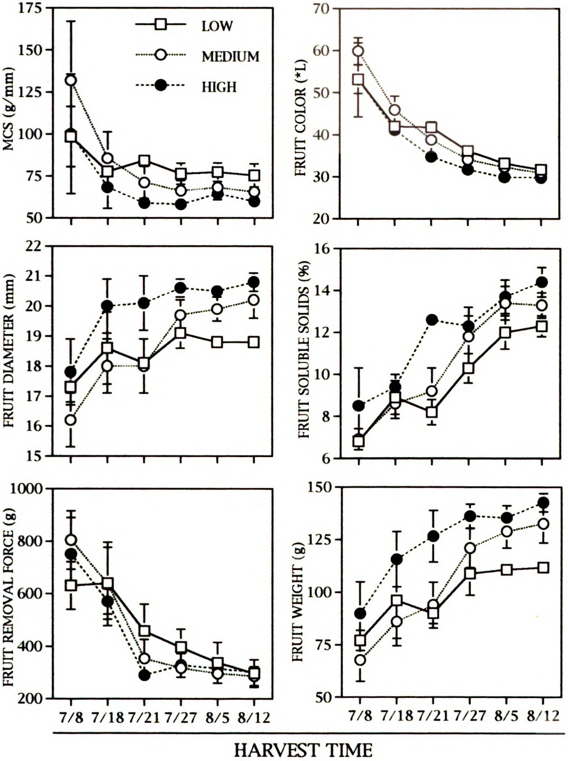
Table 4. Effects of leaf:fruit ratio and time of sampling on fruit characteristics of 'Montmorency' sour cherry. Heffron Orchard, Belding MI, 1993.

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
LEAF:FRUIT						
Low	81.4 A[z]	39.7 A	18.5 B	9.8 C	460 ns	99 b C
Medium	81.4 A	40.3 A	18.7 B	10.6 B	449 ns	105 b A
High	68.2 B	35.6 B	20.7 A	11.7 A	417 ns	128 a B
DATE						
8-Jul	110.0 A	53.4 a A	17.4 c C	7.7 d D	706 A	81 C
15-Jul	77.1 B	41.3 b B	18.9 bc ABC	9.2 c C	612 A	100 B
21-Jul	71.3 B	38.1 b BC	18.7 bc BC	9.9 c C	371 B	104 B
27-Jul	66.8 B	34.4 c CD	19.8 ab AB	11.4 b B	343 B	122 A
5-Aug	69.9 B	32.5 c D	21.0 a A	12.6 a AB	325 B	129 A
12-Aug	66.8 B	31.3 c D	19.9 ab AB	13.0 a A	296 B	128 A
INTERACTION [y]	ns	*	ns	***	ns	ns

[z] Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

[y] ns, *** Not significant or significant at $P \leq 0.001$, respectively.

Figure 3. The effects of leaf:fruit ratio and time of harvest on fruit characteristics of 'Montmorency' sour cherry. Heffron Orchard, Belding, MI, 1993.



LOW
MEDIUM
HIGH
MCS (g/mm)
175
150
125
100
75
50
FRUIT COLOR (*L)
70
60
50
40
30
20
FRUIT DIAMETER (mm)
22
21
20
19
18
17
16
15
FRUIT SOLUBLE SOLIDS (%)
16
14
12
10
8
6
FRUIT REMOVAL FORCE (g)
1000
800
600
400
200
FRUIT WEIGHT (g)
150
125
100
75
50
7/8 7/18 7/21 7/27 8/5 8/12
7/8 7/18 7/21 7/27 8/5 8/12
HARVEST TIME

Figure 4. Correlations between fruit firmness and several other fruit characteristics. Leaf:fruit ratio experiment. Heffron Orchard, Belding MI, 1993.

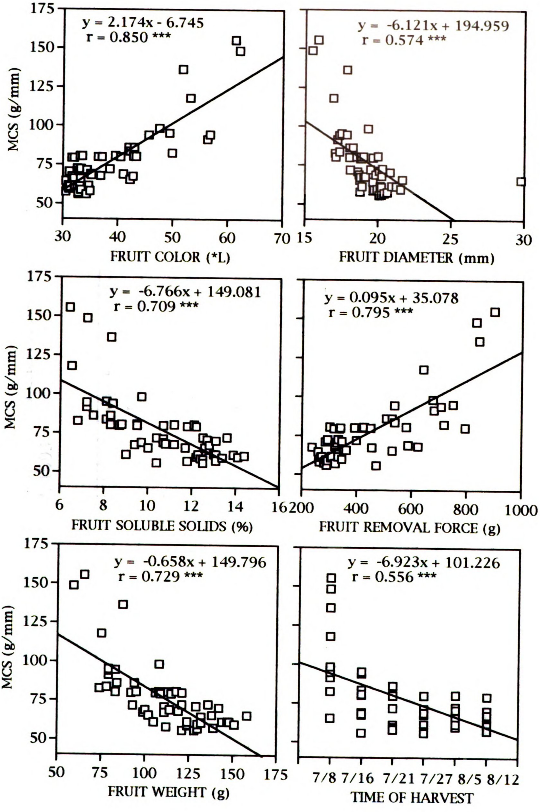

y = 2.174x - 6.745
r = 0.850 ***
MCS (g/mm)
FRUIT COLOR (*L)
y = -6.121x + 194.959
r = 0.574 ***
FRUIT DIAMETER (mm)
y = -6.766x + 149.081
r = 0.709 ***
FRUIT SOLUBLE SOLIDS (%)
y = 0.095x + 35.078
r = 0.795 ***
FRUIT REMOVAL FORCE (g)
y = -0.658x + 149.796
r = 0.729 ***
FRUIT WEIGHT (g)
y = -6.923x + 101.226
r = 0.556 ***
TIME OF HARVEST
7/8 7/16 7/21 7/27 8/5 8/12

Table 5. Effect of irrigation applied beginning 28 May and time of sampling on fruit characteristics of 'Montmorency' sour cherry. NWM Horticultural Research Station, Traverse City, MI. 1993

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
IRRIGATION						
-	57.6 a z	33.0 ns	19.9 b	11.7 ns	310 ns	129 b
+	56.1 b	32.7 ns	20.4 a	11.9 ns	318 ns	136 a
TIME						
22-Jul	58.9 a A	38.8 a A	18.8 c B	10.3 b B	451 a A	102 c C
29-Jul	58.0 ab A	32.9 b B	20.0 b A	11.8 a A	357 b B	129 b B
4-Aug	58.6 ab A	31.3 bc BC	20.4 ab A	12.0 a A	338 b B	139 ab AB
10-Aug	52.9 c B	30.9 c C	20.4 ab A	12.5 a A	250 c C	141 ab AB
18-Aug	55.8 bc AB	30.4 c C	21.0 a A	12.5 a A	176 d D	154 a A
INTERACTION y	ns	ns	ns	ns	ns	ns

z Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

y not significant

Figure 5. The effects of irrigation treatment and time of harvest on fruit characteristics of 'Montmorency' sour cherry. NWM Horticultural Research Station, Traverse City, MI. 1993.

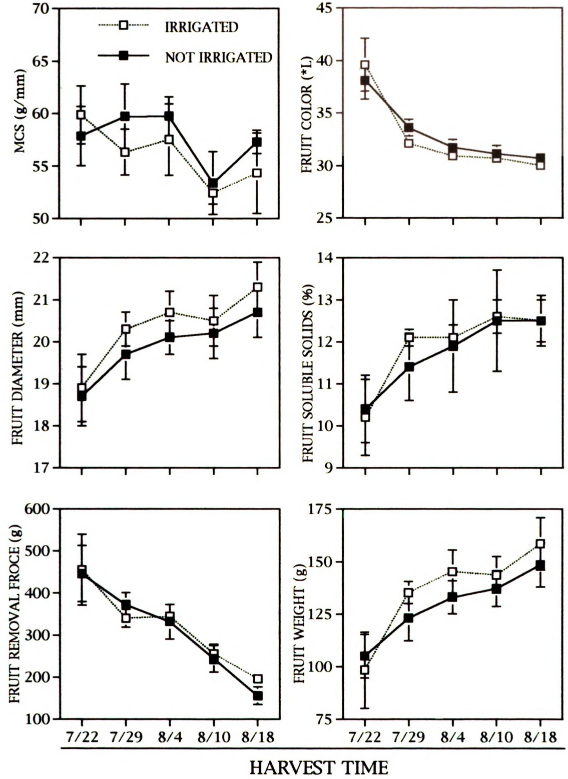
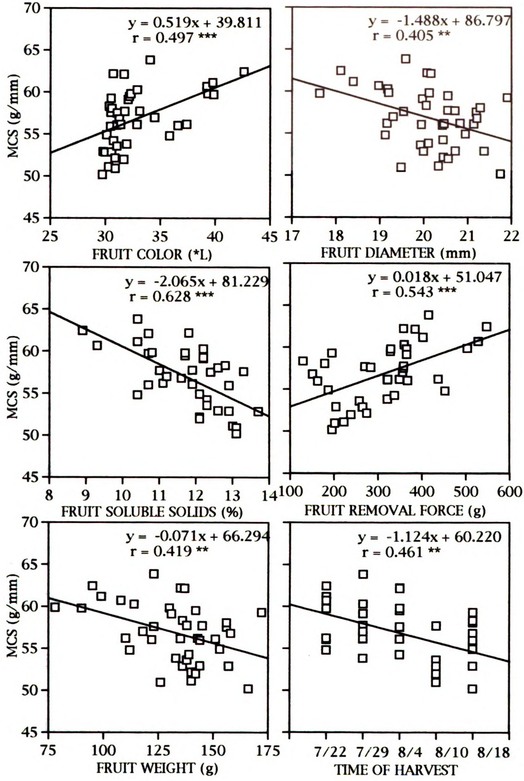

IRRIGATED
NOT IRRIGATED
MCS (g/mm)
70
65
60
55
50
FRUIT COLOR (*L)
45
40
35
30
25
FRUIT DIAMETER (mm)
22
21
20
19
18
17
FRUIT SOLUBLE SOLIDS (%)
14
13
12
11
10
9
FRUIT REMOVAL FROCE (g)
600
500
400
300
200
100
FRUIT WEIGHT (g)
175
150
125
100
75
7/22
7/29
8/4
8/10
8/18
HARVEST TIME

Figure 6. Correlations between firmness and several other fruit characteristics. Irrigation experiment. NWM Horticultural Research Station, Traverse City, MI, 1993.


y = 0.519x + 39.811
r = 0.497 ***
MCS (g/mm)
FRUIT COLOR (*L)
y = -1.488x + 86.797
r = 0.405 **
FRUIT DIAMETER (mm)
y = -2.065x + 81.229
r = 0.628 ***
FRUIT SOLUBLE SOLIDS (%)
y = 0.018x + 51.047
r = 0.543 ***
FRUIT REMOVAL FORCE (g)
y = -0.071x + 66.294
r = 0.419 **
FRUIT WEIGHT (g)
y = -1.124x + 60.220
r = 0.461 **
TIME OF HARVEST
7/22
7/29
8/4
8/10
8/18

(Table 5). Correlations between firmness and each parameter were also highly significant at $P \leq 0.01$ or $P \leq 0.001$ (Fig. 6).

4. Nitrogen application

Fruits on trees receiving the highest rate of nitrogen were consistently firmer overall than those from trees receiving none (Table 6, Fig. 7), but the effect of the lower rate was not significant. Trees receiving the least nitrogen (0 kg N/tree) bore somewhat larger fruits (possibly because of reduced cropload), with higher soluble solids but reduced color (Table 6, Fig. 7). Color and fruit removal force were not affected by nitrogen. For most characteristics, only the 22 July sample differed from later samples. However, fruit removal force decreased and weight increased consistently during the sampling period. There was no interaction between harvest time and nitrogen level (Table 6).

The correlations between fruit firmness and the other parameters measured were all significant (Fig. 8). Firmness decreased as fruit color (*L values) and fruit removal force decreased, and as fruit diameter, soluble solids, and fruit weight increased. Therefore fruit firmness was affected gradually as maturity advanced and the fruit became softer.

5. Foliar application of potassium and calcium

Potassium. Potassium sprays had no consistent effect on firmness (Table 7, Fig. 9), and correlations of firmness with other parameters were non-significant, except for fruit removal force and time of harvest (Fig. 10). Potassium treatment appeared to accelerate

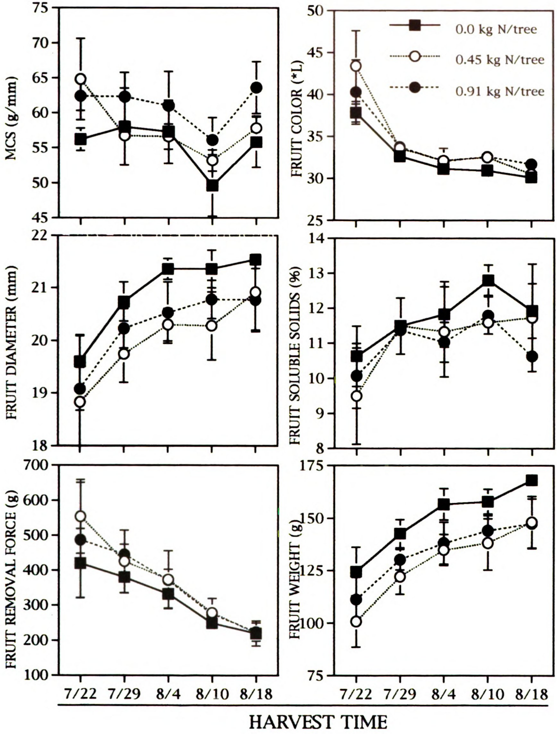
Table 6. Effects of nitrogen fertilizer and time of sampling on fruit characteristics of 'Montmorency' sour cherry. NWM Horticultural Research Station, Traverse City, MI. 1993

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
NITROGEN						
0.00 kg N/tree	55.4 b B[z]	32.6 b A	20.9 a A	11.7 a	320 ns	150 a A
0.45 kg N/tree	57.8 ab AB	34.4 a A	20.0 b B	11.1 ab	370 ns	129 b B
0.91 kg N/tree	61.1 a A	34.1 a A	20.3 b B	11.0 b	360 ns	134 b B
DATE						
22-Jul	61.2 a A	40.5 a A	19.2 c B	10.1 b B	487 a A	112 d C
29-Jul	59.0 a AB	33.4 b B	20.2 b A	11.5 a A	417 ab AB	132 c B
4-Aug	58.3 a AB	31.8 bc B	20.7 ab A	11.4 a AB	359 bc BC	143 b A
10-Aug	53.0 b B	32.0 bc B	20.8 ab A	12.1 a A	267 cd CD	147 ab A
18-Aug	59.1 a AB	30.8 c B	21.1 a A	11.4 a AB	221 d D	155 a A
INTERACTION[y]	ns	ns	ns	ns	ns	ns

[z] Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

[y] not significant

Figure 7. The effects of nitrogen treatment and time of harvest on fruit characteristics of 'Montmorency' sour cherry. NWM Horticultural Research Station, Traverse City, MI. 1993.



MCS (g/mm)
75
70
65
60
55
50
45
FRUIT COLOR (*L)
50
45
40
35
30
25
0.0 kg N/tree
0.45 kg N/tree
0.91 kg N/tree
FRUIT DIAMETER (mm)
22
21
20
19
18
FRUIT SOLUBLE SOLIDS (%)
14
13
12
11
10
9
8
FRUIT REMOVAL FORCE (g)
700
600
500
400
300
200
100
FRUIT WEIGHT (g)
175
150
125
100
75
7/22
7/29
8/4
8/10
8/18
7/22
7/29
8/4
8/10
8/18
HARVEST TIME

Figure 8. Correlations between fruit firmness and several other fruit characteristics. Nitrogen experiment. NWM Horticultural Research Station, Traverse City, MI. 1993.

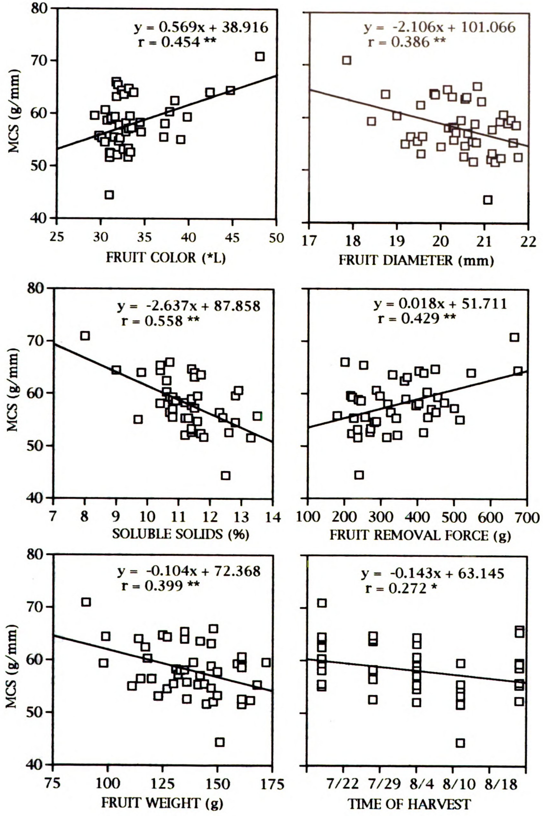
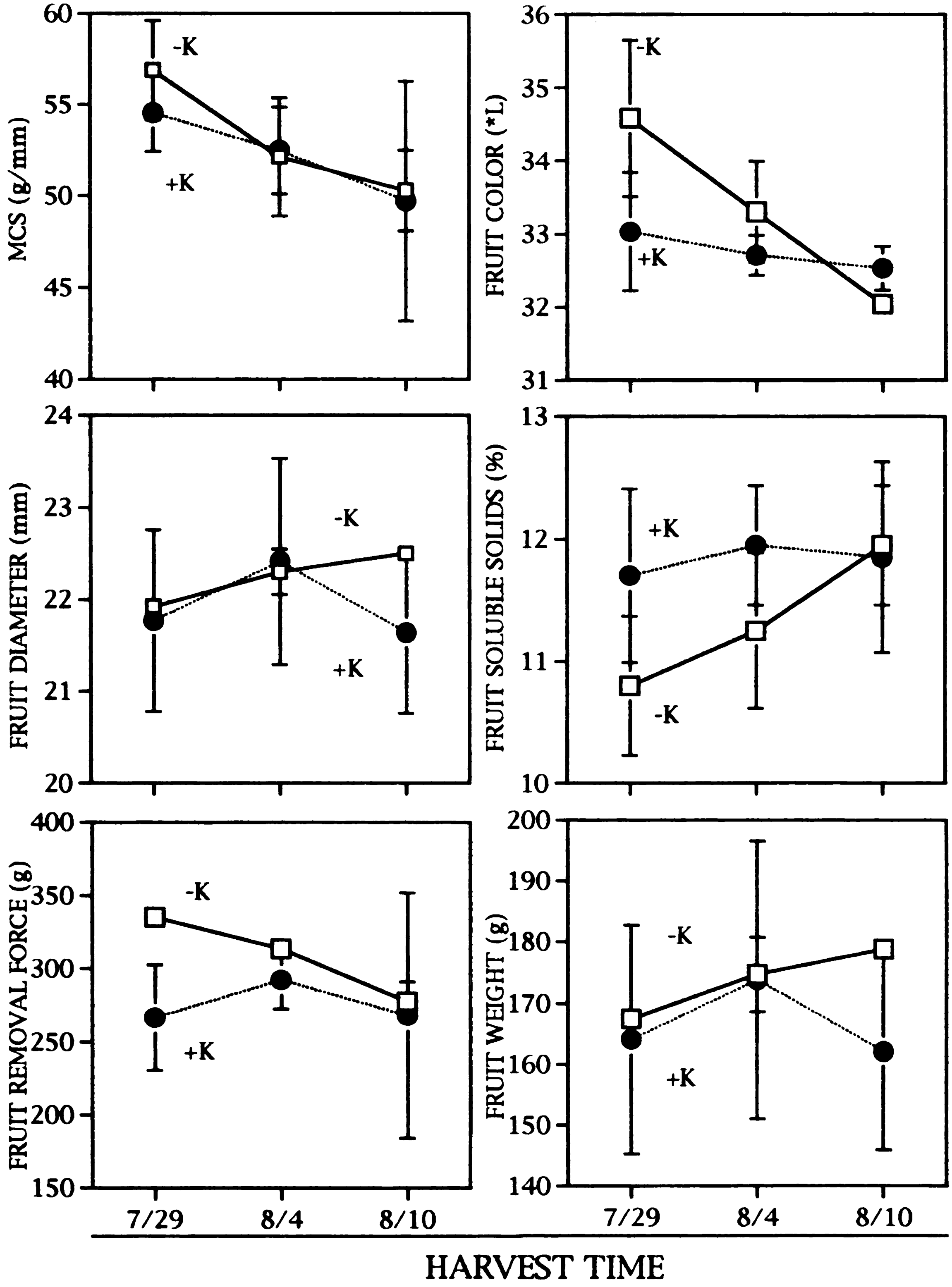

y = 0.569x + 38.916
r = 0.454 **
MCS (g/mm)
FRUIT COLOR (*L)
y = -2.106x + 101.066
r = 0.386 **
FRUIT DIAMETER (mm)
y = -2.637x + 87.858
r = 0.558 **
MCS (g/mm)
SOLUBLE SOLIDS (%)
y = 0.018x + 51.711
r = 0.429 **
FRUIT REMOVAL FORCE (g)
y = -0.104x + 72.368
r = 0.399 **
MCS (g/mm)
FRUIT WEIGHT (g)
y = -0.143x + 63.145
r = 0.272 *
7/22 7/29 8/4 8/10 8/18
TIME OF HARVEST

Table 7. Effects of potassium and time of sampling on fruit characteristics of 'Montmorency' sour cherry. Gregory Orchard, Traverse City, MI, 1993.

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
POTASSIUM						
-	53.1[z]	33.3	22.2	11.3	309	174
+	52.2	33.8	21.9	11.8	276	167
DATE						
4-Aug	55.7	33.8	21.9	11.3	301	166
10-Aug	52.3	33	22.4	11.6	303	174
18-Aug	50	32.3	22.1	11.9	273	170

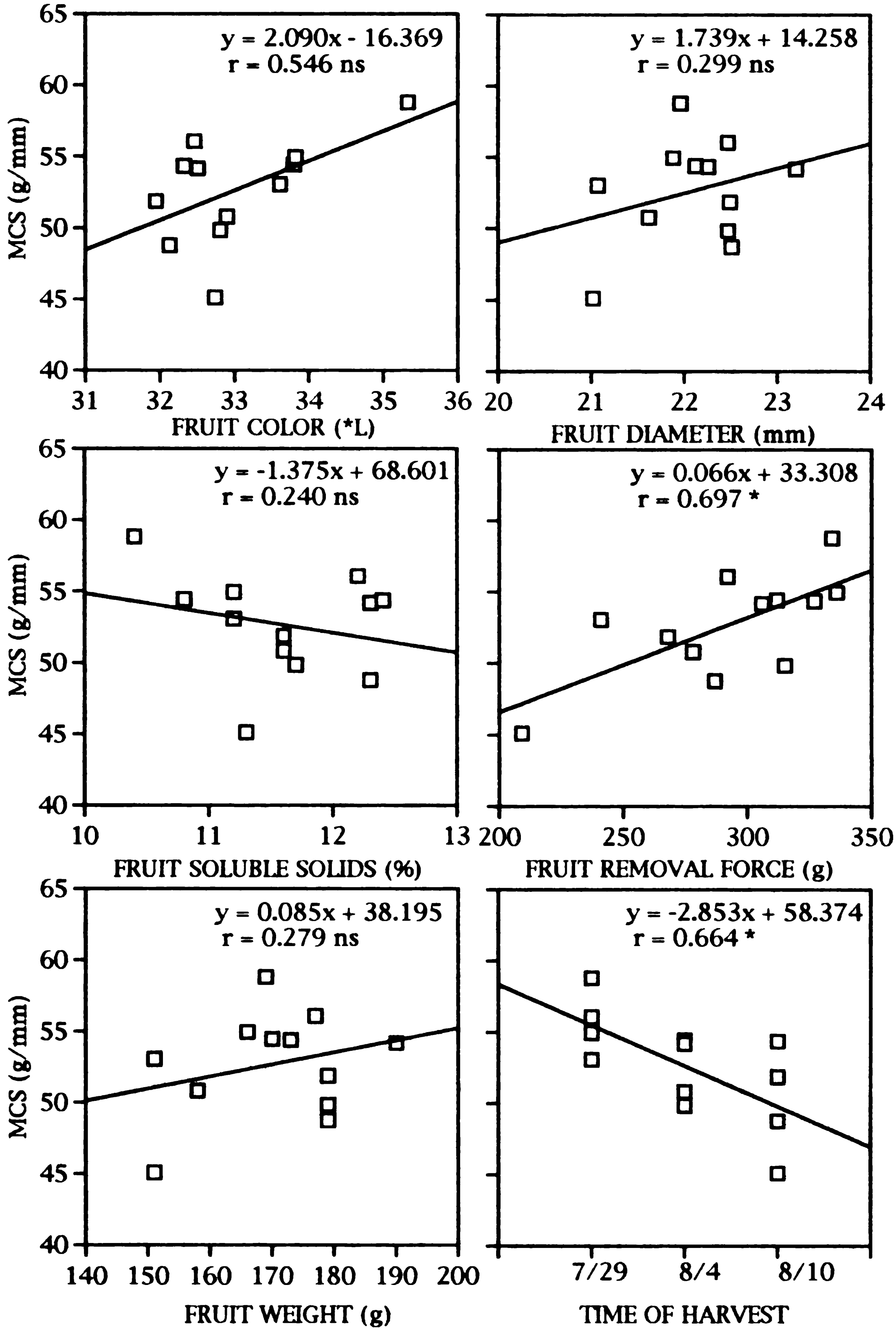
[z] no effects (potassium,date, interaction) were significant at $P \leq 0.05$.

Figure 9. The effect of potassium treatment and time of harvest on fruit characteristics of 'Montmorency' sour cherry. Gregory Orchard, Traverse City, MI. 1993.



MCS (g/mm)
60
55
50
45
40
-K
+K
FRUIT COLOR (*L)
36
35
34
33
32
31
-K
+K
FRUIT DIAMETER (mm)
24
23
22
21
20
-K
+K
FRUIT SOLUBLE SOLIDS (%)
13
12
11
10
+K
-K
FRUIT REMOVAL FORCE (g)
400
350
300
250
200
150
-K
+K
FRUIT WEIGHT (g)
200
190
180
170
160
150
140
-K
+K
7/29
8/4
8/10
7/29
8/4
8/10
HARVEST TIME

Figure 10. Correlations between firmness and several other fruit characteristics. Potassium experiment. Gregory Orchard. Traverse City, MI. 1993.



y = 2.090x - 16.369
r = 0.546 ns
MCS (g/mm)
FRUIT COLOR (*L)
y = 1.739x + 14.258
r = 0.299 ns
FRUIT DIAMETER (mm)
y = -1.375x + 68.601
r = 0.240 ns
MCS (g/mm)
FRUIT SOLUBLE SOLIDS (%)
y = 0.066x + 33.308
r = 0.697 *
FRUIT REMOVAL FORCE (g)
y = 0.085x + 38.195
r = 0.279 ns
MCS (g/mm)
FRUIT WEIGHT (g)
y = -2.853x + 58.374
r = 0.664 *
7/29
8/4
8/10
TIME OF HARVEST

maturation of the fruit, reducing fruit removal force and increasing soluble solids on the first sampling date (July 29); however, this effect was not evident in later samples (Fig. 9).

Calcium. The calcium spray did not increase firmness, but both soluble solids and fruit removal force were higher in treated fruits (Table 8). Firmness decreased between 29 July and 4 August, but values for 10 August were similar to those for 29 July. Interaction between calcium and time of harvest was not significant, nor were correlations between firmness and fruit color, diameter, soluble solids, fruit removal force or fruit weight (Fig. 11, 12).

6. Gibberellin (GA3) treatment

a. Exp. 1. Belding. Gibberellin increased fruit weight and delayed maturity, slowed color development (higher *L values), and increased fruit removal force, but did not affect fruit firmness, fruit diameter or fruit soluble solids (Table 9). Although both color and weight continued to change with time, firmness, diameter, fruit removal force and soluble solids changed little after 21 July (Table 9, Fig. 13). Interactions between gibberellin and time of harvest were significant for firmness, color, and soluble solids, but these interactions did not reflect consistent patterns over time (Fig. 13). Correlations between fruit firmness and fruit color, diameter, soluble solids, fruit removal force and fruit weight were highly significant when all sampling times were included (Fig 14). However, none of these relationship was significant when data for the first sampling were excluded (data not shown). On this date fruit removal force was

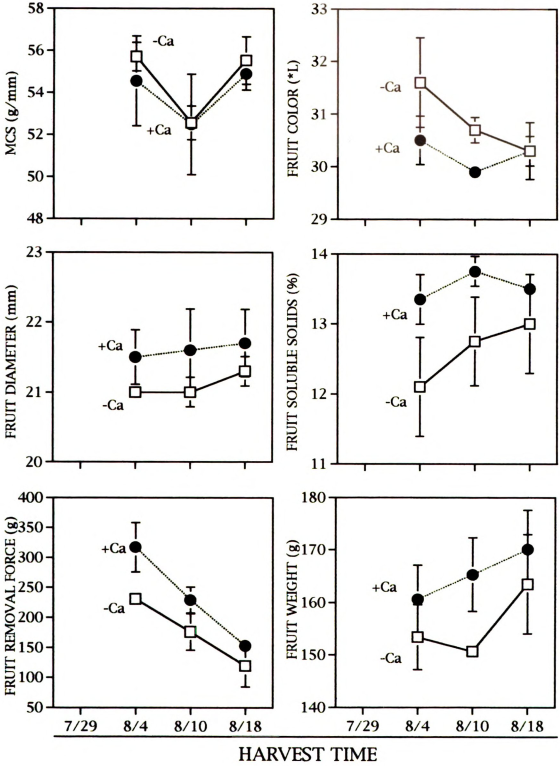
Table 8. Effects of calcium and time of sampling on fruit characteristics of 'Montmorency' sour cherry. Gregory Orchard. Suttons Bay, MI, 1993.

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
CALCIUM						
-	54.6	30.9	21.1	12.6 b	176 b	156
+	54.0 ns	30.2 ns	21.6 ns	13.5 a	233 a	165 ns
TIME						
29-Jul	55.1 a	31	21.3	12.7	274 a A	157
4-Aug	52.5 b	30.3	21.3	13.3	203 b AB	158
10-Aug	55.2 a	30.3 ns	21.5 ns	13.3 ns	136 b B	167ns
INTERACTION	ns	ns	ns	ns	ns	ns

z Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

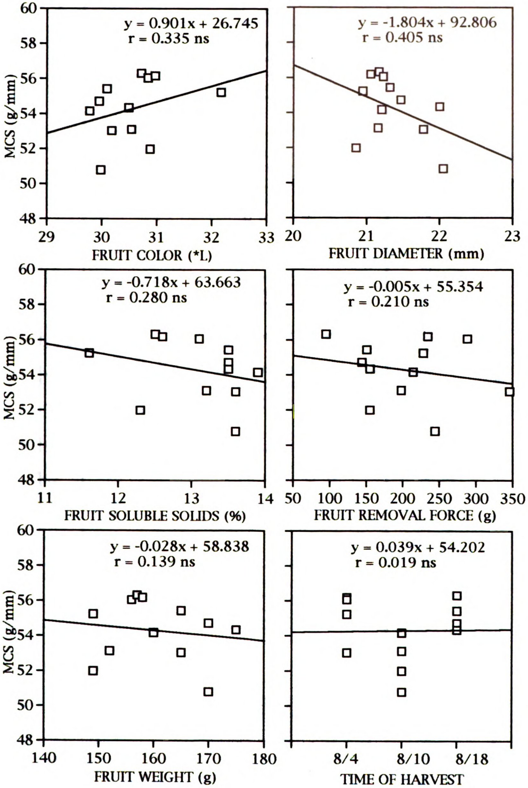
y ns, not significant at $P \leq 0.05$.

Figure 11. The effects of calcium treatment and time of harvest on fruit characteristics of 'Montmorency' sour cherry. Gregory Orchard, Suttons Bay, MI, 1993.



58
56
54
52
50
48
MCS (g/mm)
-Ca
+Ca
33
32
31
30
29
FRUIT COLOR (*L)
-Ca
+Ca
23
22
21
20
FRUIT DIAMETER (mm)
+Ca
-Ca
14
13
12
11
FRUIT SOLUBLE SOLIDS (%)
+Ca
-Ca
400
350
300
250
200
150
100
50
FRUIT REMOVAL FORCE (g)
+Ca
-Ca
180
170
160
150
140
FRUIT WEIGHT (g)
+Ca
-Ca
7/29
8/4
8/10
8/18
7/29
8/4
8/10
8/18
HARVEST TIME

Figure 12. Correlations between firmness and several other fruit characteristics. Calcium experiment. Gregory Orchard. Suttons Bay, MI. 1993.



y = 0.901x + 26.745
r = 0.335 ns
MCS (g/mm)
FRUIT COLOR (*L)
y = -1.804x + 92.806
r = 0.405 ns
FRUIT DIAMETER (mm)
y = -0.718x + 63.663
r = 0.280 ns
MCS (g/mm)
FRUIT SOLUBLE SOLIDS (%)
y = -0.005x + 55.354
r = 0.210 ns
FRUIT REMOVAL FORCE (g)
y = -0.028x + 58.838
r = 0.139 ns
MCS (g/mm)
FRUIT WEIGHT (g)
y = 0.039x + 54.202
r = 0.019 ns
8/4
8/10
8/18
TIME OF HARVEST

Table 9. Effect of gibberellin spray applied 3 July and time of sampling on fruit characteristics of 'Montmorency' sour cherry. Heffron Orchard, Belding MI, 1993.

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
GIBBERELLIN						
0 ppm	59.1 ns [z]	33.7 b B	21.2 ns	12.3 ns	395.0 b B	146.1 ab
10 ppm	57.4 ns	35.7 a A	21.1 ns	12.0 ns	401.7 b B	144.1 b
20 ppm	58.8 ns	35.6 a A	21.7 ns	12.4 ns	442.1 a A	150.9 a
TIME						
8-Jul	69.9 a A	46.6 a A	19.9 b B	11.5 c B	754.9 a A	116.6 c C
16-Jul	56.9 bc BC	36.4 b B	20.9 ab AB	12.0 bc AB	456.6 b B	138.0 b B
21-Jul	52.2 c C	33.4 c C	21.6 a A	12.1 bc AB	320.4 c C	151.1 a AB
27-Jul	53.0 c C	31.8 cd CD	22.2 a A	12.9 a A	302.4 c C	156.2 a A
5-Aug	58.3 b BC	31.6 cd CD	21.9 a A	12.3 ab AB	331.0 c C	161.4 a A
12-Aug	60.2 b B	30.2 d D	21.6 a A	12.5 ab A	312.1 c C	159.0 a A
INTERACTION [y]	*	**	n.s.	**	n.s.	n.s.

[z] Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

[y] ns, *, **, not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ respectively.

Figure 13. The effect of gibberellin treatment and time of harvest on fruit characteristics of 'Montmorency' sour cherry. Heffron Orchard. Belding, MI. 1993.

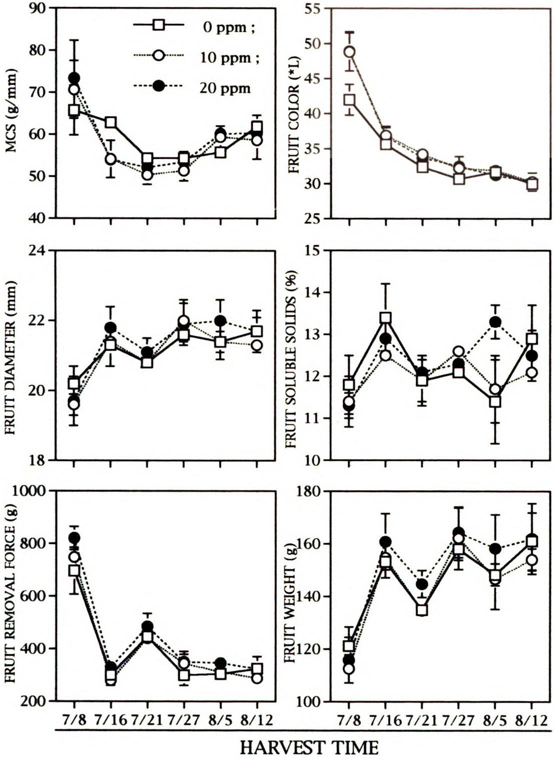
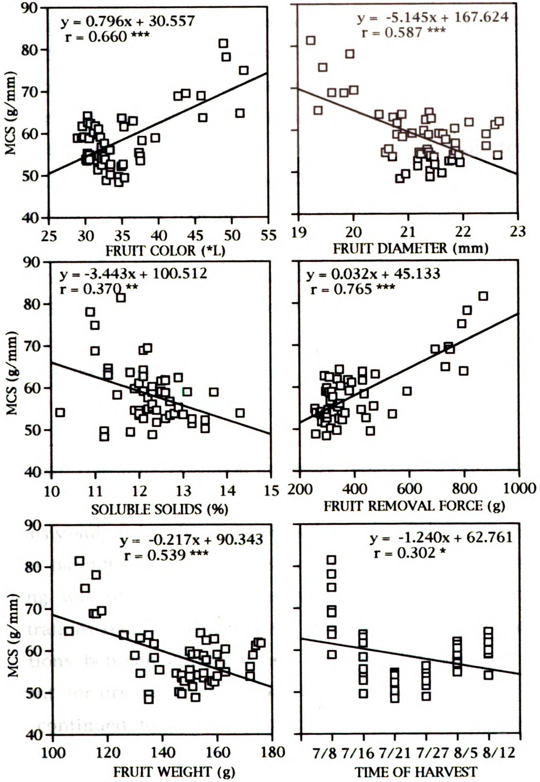

0 ppm ;
10 ppm ;
20 ppm
MCS (g/mm)
FRUIT COLOR (*L)
FRUIT DIAMETER (mm)
FRUIT SOLUBLE SOLIDS (%)
FRUIT REMOVAL FORCE (g)
FRUIT WEIGHT (g)
7/8 7/16 7/21 7/27 8/5 8/12
HARVEST TIME

Figure14. Correlations between fruit firmness and several other fruit characteristics. Gibberellin treatment. Heffron Orchard. Belding, MI. 1993.



y = 0.796x + 30.557
r = 0.660 ***
MCS (g/mm)
FRUIT COLOR (*L)
y = -5.145x + 167.624
r = 0.587 ***
FRUIT DIAMETER (mm)
y = -3.443x + 100.512
r = 0.370 **
MCS (g/mm)
SOLUBLE SOLIDS (%)
y = 0.032x + 45.133
r = 0.765 ***
FRUIT REMOVAL FORCE (g)
y = -0.217x + 90.343
r = 0.539 ***
MCS (g/mm)
FRUIT WEIGHT (g)
y = -1.240x + 62.761
r = 0.302 *
7/8 7/16 7/21 7/27 8/5 8/12
TIME OF HARVEST

very high (755 g), indicating that the fruit was immature.

b. Exp. 2, Northport. Gibberellin increased fruit size and soluble solids and delayed red coloration, but did not influence fruit firmness or fruit removal force (Table 10). During the four week sampling period, the most significant changes in fruit characteristics occurred between 22 and 29 July (normal harvest), as the fruit matured (Fig. 15). However, fruit color, fruit removal force, and fruit size continued to change with time.

Fruit firmness was highly correlated with all other parameters, indicating a strong association with changes in fruit maturity (Fig. 16). Again, however, none of these correlations was significant when the data for the earliest harvest (July 22) were excluded, as these fruits were immature.

7. Ethephon treatment

a. Exp. 1, Belding. Ethephon markedly reduced fruit firmness, fruit removal force, and fruit size (Table 11, Fig. 17). Treated fruits were consistently softer than controls within one week of treatment (13 July), but differences were non-significant thereafter; no further softening was observed in either treatment (Fig. 17). Both concentrations reduced fruit removal force, as well as fruit size. Interactions between ethephon and time of application were significant for firmness, fruit removal force and fruit weight. Fruit weight continued to increase with time in control fruits, but ethephon-treated fruits stopped growing within 10-14 days of treatment (Table 11). Fruit firmness was significantly correlated with

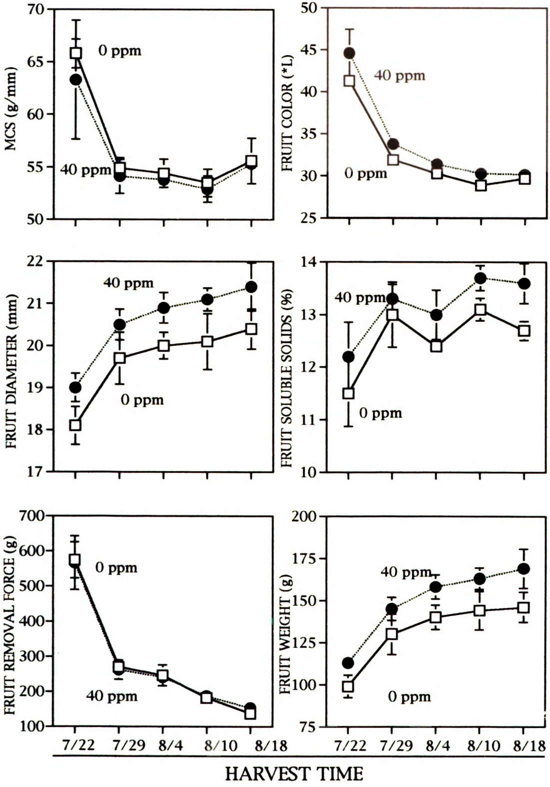
Table 10. Effects of gibberellin spray applied 13 July and time of sampling on fruit characteristics of 'Montmorency' sour cherry. Mitchell Orchard, Northport MI, 1993.

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
GIBBERELLIN						
0 ppm	56.9 ns [z]	32.4 B	19.6 B	12.5 B	282 ns	132 B
40 ppm	55.9 ns	34.1 A	20.6 A	13.1 A	282 ns	149 A
DATE						
22-Jul	64.6 a A	43.0 a A	18.5 c C	11.9 c B	570 a A	106 c C
29-Jul	54.5 b B	32.9 b B	20.1 b B	13.1 ab A	266 b B	138 b B
4-Aug	54.1 b B	30.8 c C	20.5 ab AB	12.7 b A	243 b BC	149 a AB
10-Aug	53.2 b B	29.6 c C	20.6 ab AB	13.4 a A	185 c CD	154 a A
18-Aug	55.5 b B	29.9 c C	20.9 a A	13.1 ab A	145 c D	157 a A
INTERACTION [y]	ns	ns	ns	ns	ns	ns

[z] Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

[y] ns, not significant

Figure 15. The effects of gibberellin treatment and time of harvest on fruit characteristics of 'Montmorency' sour cherry. Mitchell Orchard, Northport, MI. 1993.



MCS (g/mm)
0 ppm
40 ppm
FRUIT COLOR (*L)
40 ppm
0 ppm
FRUIT DIAMETER (mm)
40 ppm
0 ppm
FRUIT SOLUBLE SOLIDS (%)
40 ppm
0 ppm
FRUIT REMOVAL FORCE (g)
0 ppm
40 ppm
FRUIT WEIGHT (g)
40 ppm
0 ppm
7/22 7/29 8/4 8/10 8/18
7/22 7/29 8/4 8/10 8/18
HARVEST TIME

Figure 16. Correlations between fruit firmness and several other fruit characteristics. Gibberellin experiment. Mitchell Orchard, Northport, MI. 1993.

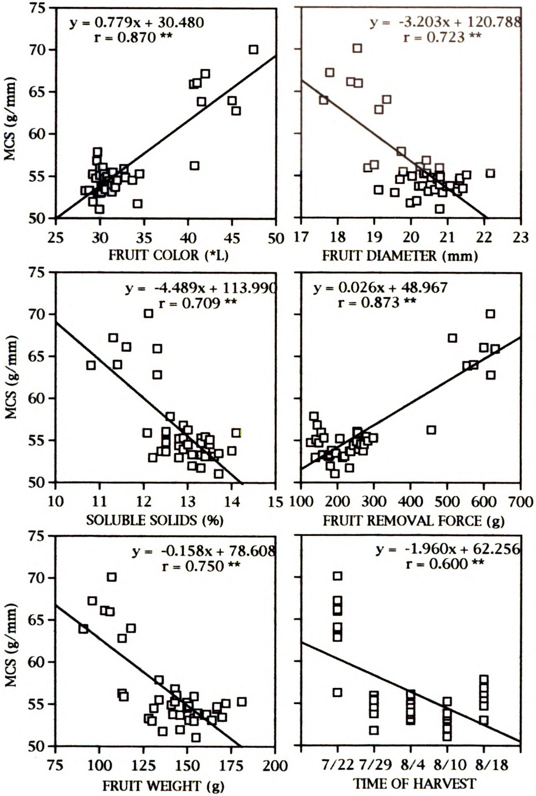

y = 0.779x + 30.480
r = 0.870 **
MCS (g/mm)
FRUIT COLOR (*L)
y = -3.203x + 120.788
r = 0.723 **
FRUIT DIAMETER (mm)
y = -4.489x + 113.990
r = 0.709 **
MCS (g/mm)
SOLUBLE SOLIDS (%)
y = 0.026x + 48.967
r = 0.873 **
FRUIT REMOVAL FORCE (g)
y = -0.158x + 78.608
r = 0.750 **
MCS (g/mm)
FRUIT WEIGHT (g)
y = -1.960x + 62.256
r = 0.600 **
7/22 7/29 8/4 8/10 8/18
TIME OF HARVEST

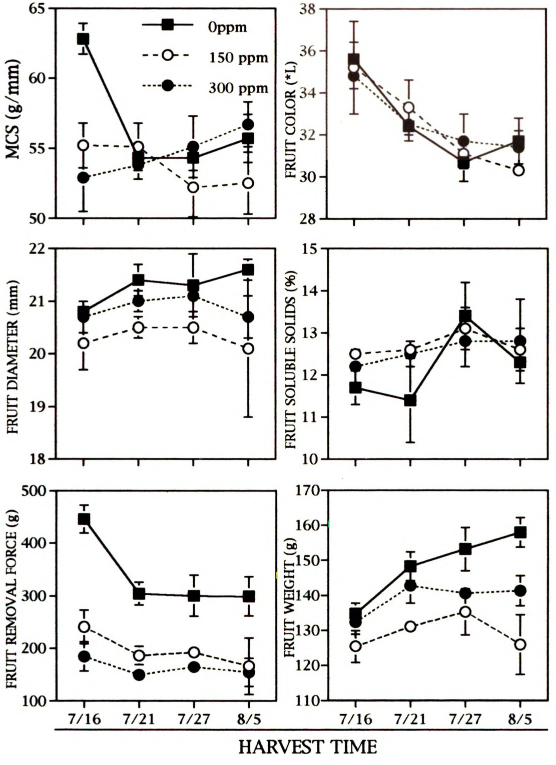
Table 11. Effects of ethephon spray applied 9 July and time of sampling on fruit characteristics of 'Montmorency' sour cherry. Heffron Orchard, Belding MI, 1993.

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
ETHEPHON						
0 ppm	57.0 a A z	32.6 ns	21.3 a A	12.2 ns	338 a A	149 a A
150 ppm	53.8 b B	32.5 ns	20.3 b B	12.7 ns	196 b B	130 c C
300 ppm	54.6 b B	32.6 ns	20.9 b A	12.6 ns	163 c C	139 b B
DATE						
15-Jul	57.0 a A	35.2 a A	20.6 ns	12.13 b B	290 a A	131 b B
21-Jul	54.4 b AB	32.7 b B	21.0 ns	12.16 b B	214 b B	141 a A
27-Jul	53.9 b B	31.2 c B	21.0 ns	13.09 a A	219 b B	143 a A
5-Aug	55.0 ab AB	31.1 c B	20.8 ns	12.6 ab AB	207 b B	142 a A
INTERACTION y	***	n.s.	n.s.	n.s.	*	**

z Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

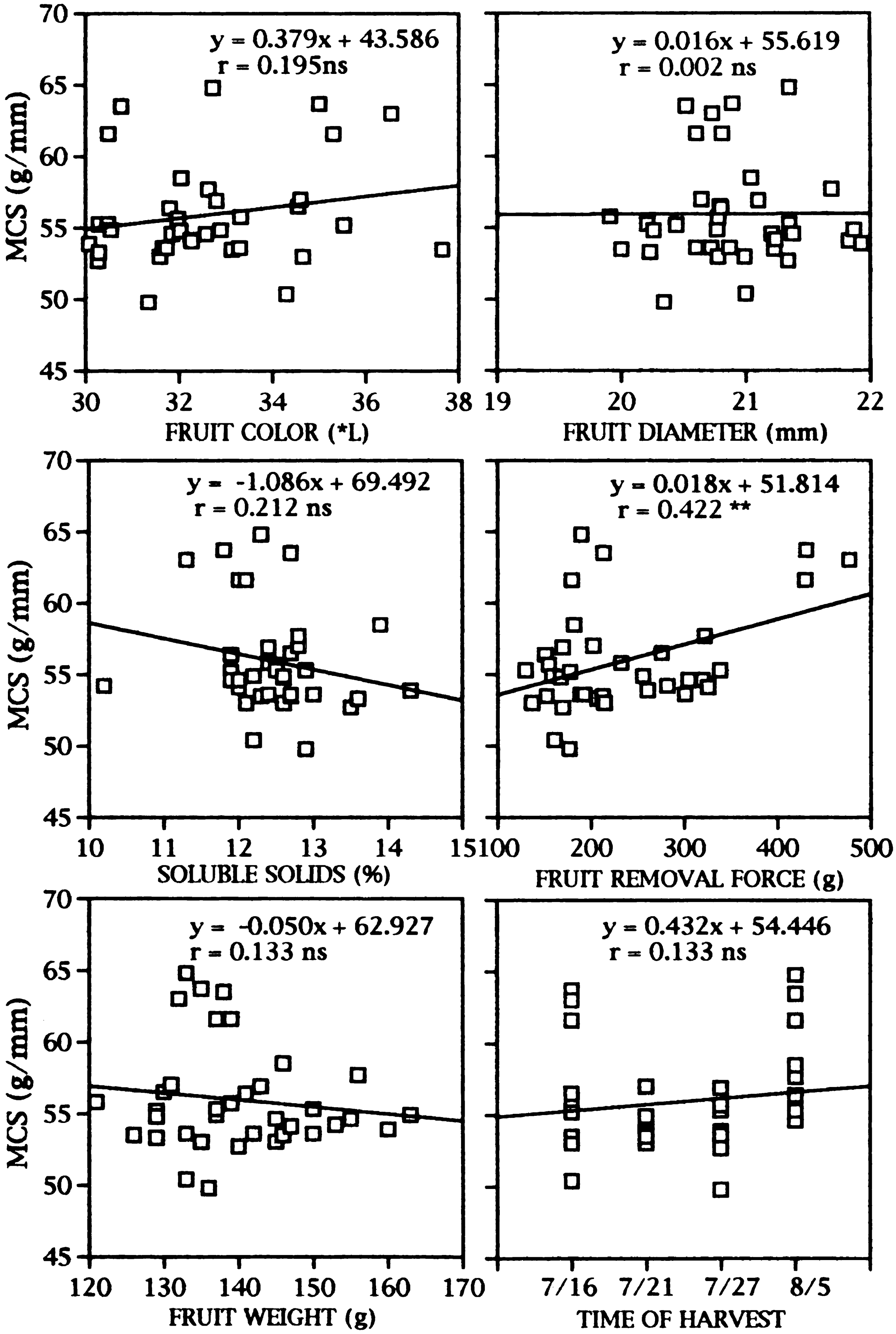
y ns, *, **, ***, Not significant or significant at $P \leq 0.05$, $P \leq 0.01$ or $P \leq 0.001$, respectively.

Figure 17. The effects of ethephon treatment, and time of harvest on fruit characteristics of 'Montmorency' sour cherry. Heffron Orchard. Belding, MI. 1993.



0ppm
150 ppm
300 ppm
MCS (g/mm)
FRUIT COLOR (*L)
FRUIT DIAMETER (mm)
FRUIT SOLUBLE SOLIDS (%)
FRUIT REMOVAL FORCE (g)
FRUIT WEIGHT (g)
7/16
7/21
7/27
8/5
HARVEST TIME

Figure 18. Correlations between fruit firmness and several other fruit characteristics. Ethephon experiment. Heffron Orchard, Belding, MI. 1993.


y = 0.379x + 43.586
r = 0.195ns
FRUIT COLOR (*L)
y = 0.016x + 55.619
r = 0.002 ns
FRUIT DIAMETER (mm)
y = -1.086x + 69.492
r = 0.212 ns
SOLUBLE SOLIDS (%)
y = 0.018x + 51.814
r = 0.422 **
FRUIT REMOVAL FORCE (g)
y = -0.050x + 62.927
r = 0.133 ns
FRUIT WEIGHT (g)
y = 0.432x + 54.446
r = 0.133 ns
TIME OF HARVEST
7/16 7/21 7/27 8/5
MCS (g/mm)

fruit removal force, but not with other parameters (Fig. 18). The apparent increase in firmness between July 16 and August 5 in fruits treated with 300 ppm may be an artifact, as few fruits remained for sampling at the last two dates

b. Exp. 2. NWM Horticultural Research Station. Ethephon treatment again had a marked effect in reducing firmness. The main effect of 300 ppm, but not 150 ppm, was significant at $p \leq 0.01$ (Table 12). Fruits treated with 300 ppm were consistently softer than controls within 5 to 7 days after treatment (Fig. 19); differences on 10 August were not significant, as control fruits had softened by this time. Both concentrations significantly reduced fruit removal force regardless of sampling time, but did not affect soluble solids content consistently.

Time vs. ethephon interaction for data on diameter, fruit removal force, and weight reflected different effects depending upon time of sampling. Differences in fruit removal force were quantitative only; treated fruits were always easier to remove than controls (Fig. 19). However, diameter and weight differences changed over time, with treated fruits being larger than non-treated ones in the first harvest, but not thereafter. Sampling error may have been involved here. Although treated fruit were larger on 29 July, thereafter their growth essentially stopped, whereas control fruits continued to enlarge.

Several correlations between firmness and other parameters were significant, including fruit color, soluble solids, fruit removal force, and time of harvest (Fig. 20). These correlations generally

Table 12. Effects of ethephon spray applied 19 July and time of sampling on fruit characteristics of 'Montmorency' sour cherry. NWM Horticultural Research Station, Traverse City, MI. 1993

MAIN EFFECT	FIRMNESS (g/mm)	COLOR (L*)	DIAMETER (mm)	SS (%)	FRF (g)	WEIGHT (g)
ETHEPHON						
0 ppm	57.6 a A[z]	32.1 ns	19.9 b	11.9 ab	316 a A	131 b B
150 ppm	55.1 b AB	31.9 ns	20.3 a	11.9 a	182 b B	136 a A
300 ppm	53.2 b B	32.4 ns	20.3 a	11.4 b	153 c B	136 a A
TIME						
29-Jul	56.8 a A	33.3 a A	32.1 ns	11.5 b B	246 a A	132 ns
4-Aug	57.4 a A	31.9 b B	31.9 ns	11.5 b B	220 b A	136 ns
10-Aug	51.7 b B	31.2 b B	32.4 ns	12.4 a A	186 c B	135 ns
INTERACTION[y]	ns	ns	**	ns	***	***

[z] Mean separation within main effects by Tukey's test. Differences significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

[y] ns, **, ***, Not significant or significant at $P \leq 0.01$, and $P \leq 0.001$, respectively.

Figure 19. The effect of ethephon treatment and time of harvest on fruit characteristics of 'Montmorency' sour cherry. NWM Horticultural Research Station, Traverse City, MI, 1993.

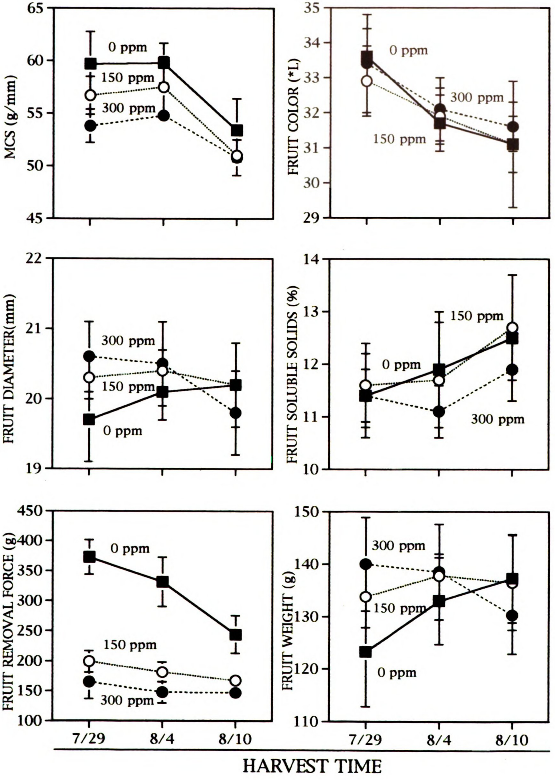
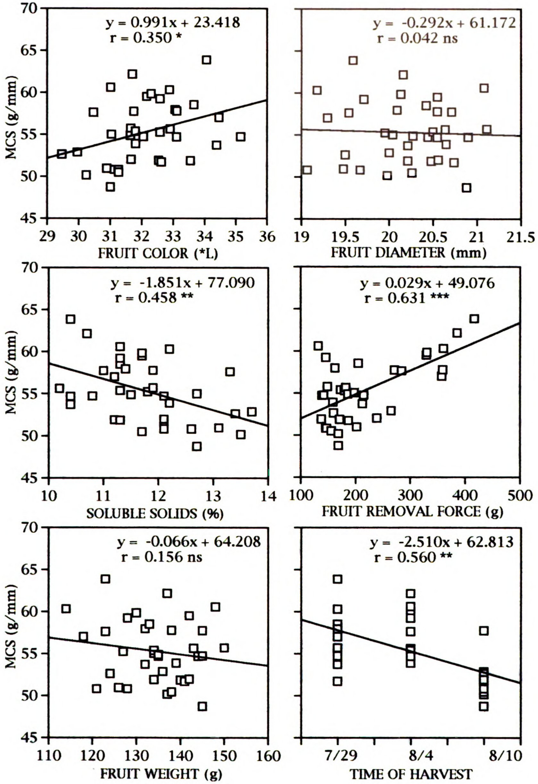

MCS (g/mm)
0 ppm
150 ppm
300 ppm
FRUIT COLOR (*L)
0 ppm
300 ppm
150 ppm
FRUIT DIAMETER(mm)
300 ppm
150 ppm
0 ppm
FRUIT SOLUBLE SOLIDS (%)
150 ppm
0 ppm
300 ppm
FRUIT REMOVAL FORCE (g)
0 ppm
150 ppm
300 ppm
FRUIT WEIGHT (g)
300 ppm
150 ppm
0 ppm
7/29
8/4
8/10
HARVEST TIME

Figure 20. Correlations between fruit firmness and several other fruit characteristics. Ethephon experiment. NWM Horticultural Research Station, Traverse City, MI, 1993.


y = 0.991x + 23.418
r = 0.350 *
MCS (g/mm)
FRUIT COLOR (*L)
y = -0.292x + 61.172
r = 0.042 ns
FRUIT DIAMETER (mm)
y = -1.851x + 77.090
r = 0.458 **
SOLUBLE SOLIDS (%)
y = 0.029x + 49.076
r = 0.631 ***
FRUIT REMOVAL FORCE (g)
y = -0.066x + 64.208
r = 0.156 ns
FRUIT WEIGHT (g)
y = -2.510x + 62.813
r = 0.560 **
TIME OF HARVEST
7/29
8/4
8/10

reflected changes in maturity, with fruit firmness declining as fruit matured.

B. RESULTS, 1994

1. Irrigation and Nitrogen. NWM Horticultural Research Station.

Irrigation had no consistent effect on firmness or other fruit characteristics, but fruits harvested 9 August were consistently softer than those harvested 3 August (Table 13, Fig. 21). Irrigation vs. harvest time interaction reflected only quantitative differences in response. The loss on firmness during harvest was similar for both treatments ($P \leq 0.01$), and soaking did not increase firmness significantly.

Nitrogen. Trees fertilized with 0.45 kg N/tree produced firmer fruits than did trees receiving no nitrogen (Fig. 22). Mechanical harvest reduced firmness for both treatments; fruits regained 50 to 60% of the loss after soaking in cold water for 4 hours. Nitrogen had no significant effects on other parameters measured, although fruit removal force appeared to be reduced (Table 14).

2. Ethephon treatment.

a. Plamondon Orchard. Main effect means (Table 15) indicated that early ethephon treatment reduced firmness significantly, but the effect of the later treatment was non-significant. Fruit firmness was reduced by mechanical harvest; 30 to 60% of the loss was regained upon soaking (Fig. 23). Ethephon-treated fruits, however, recovered less (53-55%) than did non-treated fruits (81%). Early

Table 13. Effects of irrigation and time of harvest on fruit firmness (MCS) of 'Montmorency' cherry. NWM Horticultural Research Station. Traverse City, MI. 1994.

A. Firmness

TREATMENT	HARVEST TIME	INITIAL	HARVESTED	SOAKED	MEAN
NONIRRIGATED	3-Aug	62.5	45.4	45.4	51.1 a [z]
	9-Aug	58.2	39.5	42.2	46.6 b
IRRIGATED	3-Aug	63.8	45.7	47.0	52.2 a
	9-Aug	55.7	34.8	40.7	43.7 b
MEAN	3-Aug	63.1	45.5	46.2	51.6 A
	9-Aug	56.9	37.1	41.5	45.2 B
	NONIRRIGATED	60.4	42.4	43.8	48.9
	IRRIGATED	59.7	40.3	43.9	48.0 ns
	MEAN	60.1 A	41.3 B	43.9 B	

[z] Mean separation within columns and rows by Tukey's test; ns (not significant), P≤0.05 (ab), P≤ 0.01 (AB).

Table 13 (cont'd)

B. Other fruit characteristics

IRRIGATION	COLOR (*L)	DIAMETER (mm)	WEIGHT (g)	FRF (g)	SOLUBLE SOLIDS (%)	PITTED WEIGHT (%)
NOT IRRIGATED	30.1	21.2	159	252	13.3	84
IRRIGATED	30.5 ns	21.6 ns	164 ns	271 ns	13.4 ns	83 ns

z No significant effect of irrigation at $P \leq 0.05$.

Figure 21. Effects of irrigation, time of harvest, and soaking in water on firmness of 'Montmorency' sour cherry fruits. NWM Horticultural Research Station. Traverse City, MI, Harvested 3 and 9 August,1994.

* Tukey's mean comparison significant at $P \leq 0.01$.

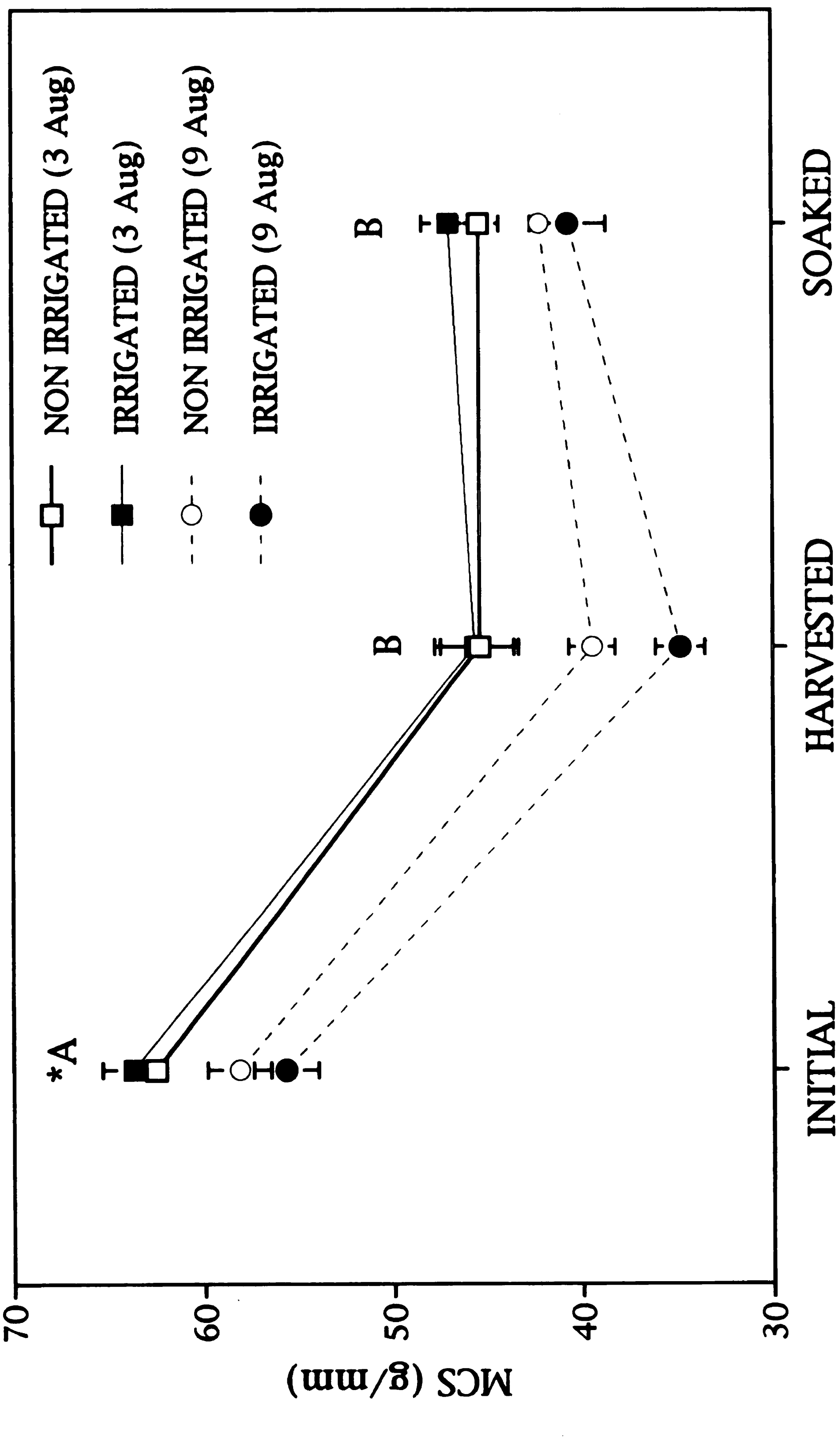

NON IRRIGATED (3 Aug)
IRRIGATED (3 Aug)
NON IRRIGATED (9 Aug)
IRRIGATED (9 Aug)
*A
B
B
MCS (g/mm)
70
60
50
40
30
INITIAL
HARVESTED
SOAKED

Figure 22. Effects of nitrogen application, harvesting and soaking on firmness of 'Montmorency' sour cherry fruits. NWM Horticultural Research Station. Traverse City, MI, Harvested 27 July 1994.

* Tukey's mean comparison significant at $P \leq 0.01$

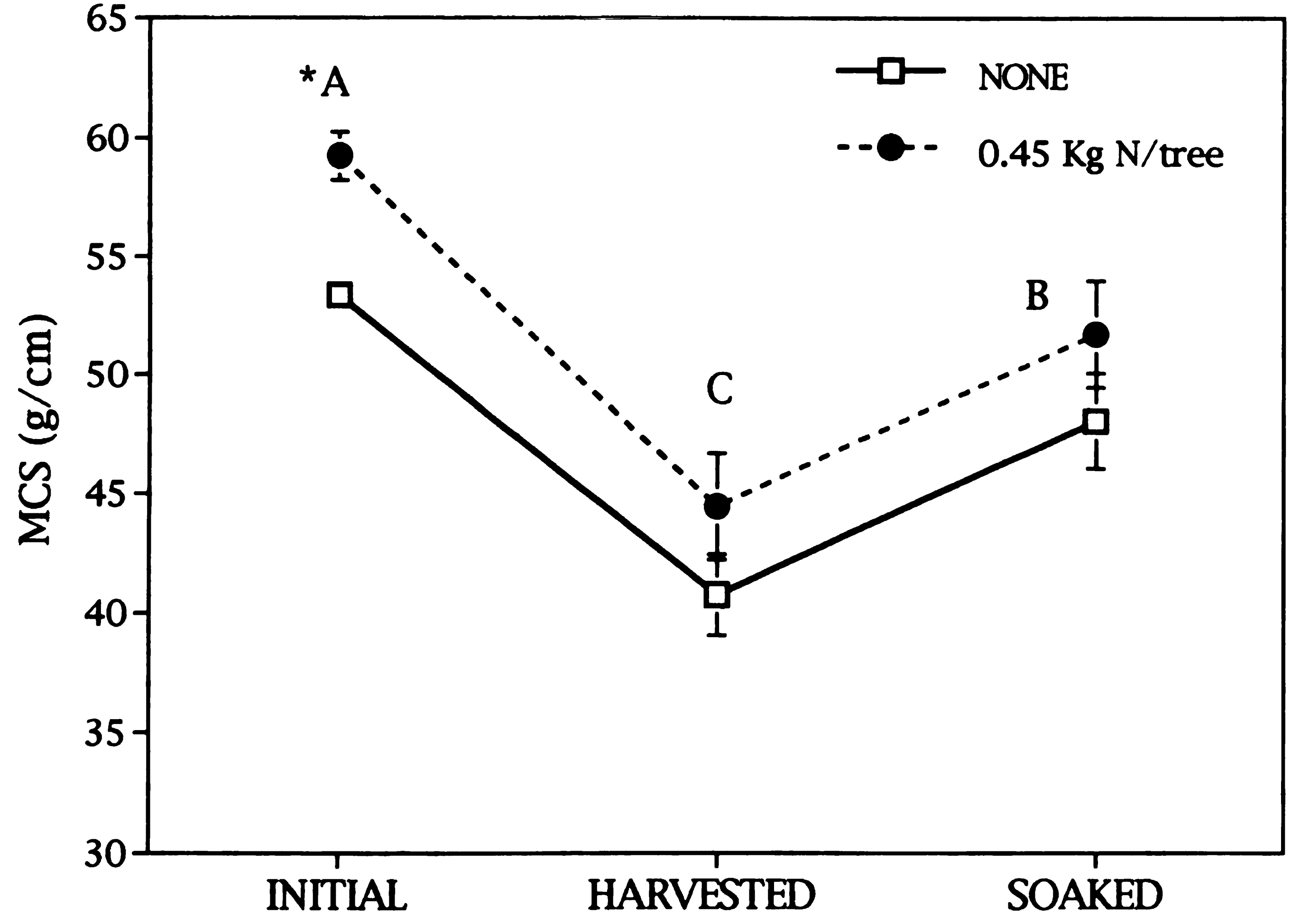

*A
NONE
0.45 Kg N/tree
B
C
65
60
55
50
45
40
35
30
MCS (g/cm)
INITIAL
HARVESTED
SOAKED

Table 14. Effects of nitrogen application on fruit characteristics of 'Montmorency' sour cherry. NWM Horticultural Research Station. Traverse City, MI. Harvested 27 July 1994.

A. Firmness

NITROGEN	ON TREE	HARVESTED	SOAKED	MEAN
CONTROL	53.4	40.8	48.1	47.4 b
0.45 kg N	59.2	44.5	51.2	51.6 a
MEAN	56.3 aB	42.6 cB	49.6 bAB	

Interaction not significant at $P \leq 0.05$.

B. Other fruit characteristics

NITROGEN	COLOR (*L)	DIAMETER (mm)	WEIGHT (g)	FRF (g)	SOLUBLE SOLIDS (%)	PITTED WEIGHT (%)
CONTROL	29.4	21.7	156	196	12.0	86 ns
0.45 kg N	30.9 ns	21.3 ns	147 ns	137 ns	11.7 ns	83 ns

z Mean separation within columns and rows by Tukey's test; ns (not significant), $P \leq 0.05$ (ab), $P \leq 0.01$ (AB).

Table 15. Effects of timing of ethephon application (300 ppm), on fruit characteristics of 'Montmorency' cherry. Plamondon Orchard, Leelanau, MI. Harvested 26 July 1994.

A. Firmness[z]

DATE	ON TREE	HARVESTED	SOAKED	MEAN
NONE	49.2 a	41.2 bc	47.7 a	46.0 a A
12-July	45.5 a	36.1 d	41.1 bc	40.9 b B
16-July	47.2 a	38.3 cd	43.2 ab	42.9 b AB
MEAN	47.3 A	38.5 C	44.1 B	

[z] Mean separation among all treatments of $P \leq 0.05$ (ab), and among main effects at $P \leq 0.05$ (ab) or 0.01 (AB). Interaction between date and treatment significant at $P \leq 0.05$

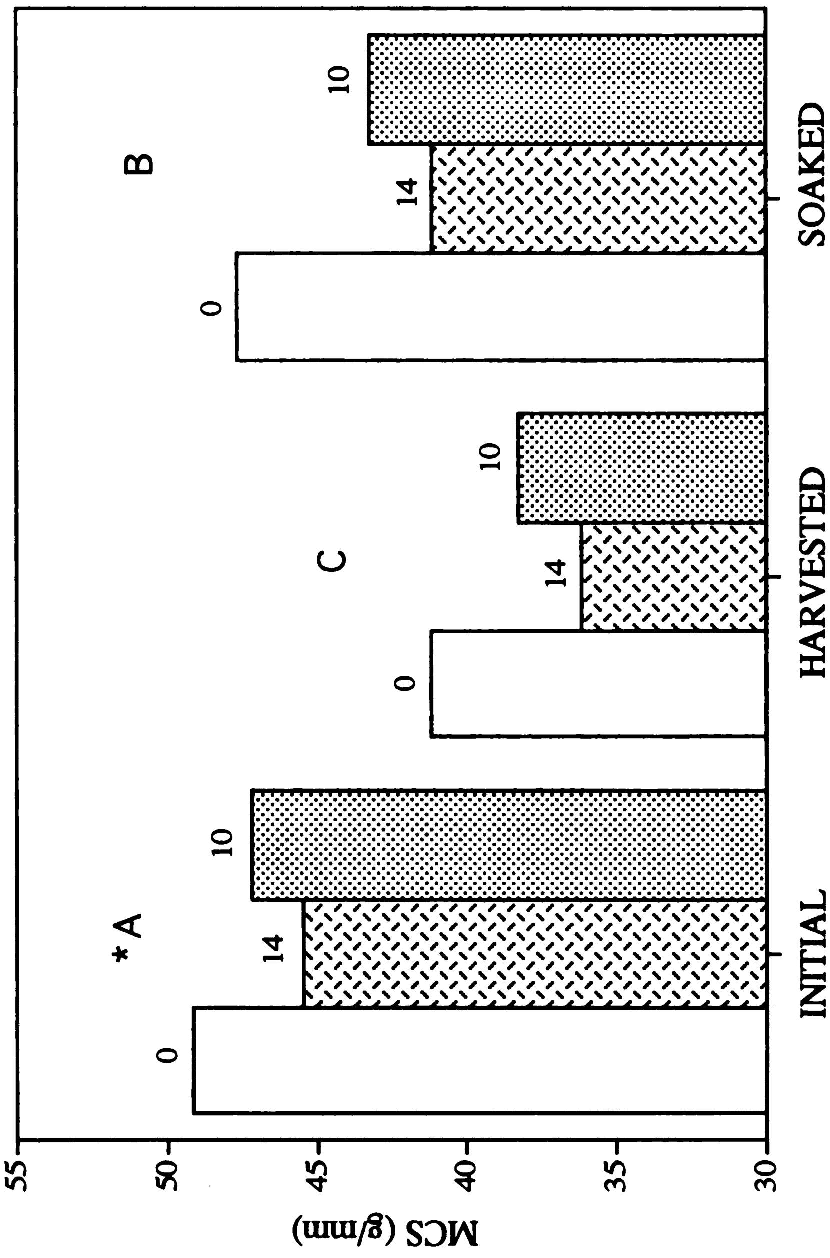
B. Other fruit characteristics

DATE	COLOR (*L)	DIAMETER (mm)	WEIGHT (g)	FRF (g)	SOLUBLE SOLIDS (%)	PITTED WEIGHT (%)
NONE	31.1 a A[y]	22.3 a	173 a	222	12.0 b	85
12-July	28.2 c B	20.8 b	147 b	245	13.3 a	88
16-July	30.0 b A	21.0 b	145 b	193 ns	11.9 b	87 ns

[y] Mean separation within columns by Tukey's test; ns (not significant), $P \leq 0.05$ (ab), $P \leq 0.01$ (AB).

Figure 23. Effects of early (14 days) and late (10 days) application of ethephon (300 ppm), harvesting and soaking in water on firmness of 'Montmorency' sour cherry fruits. Plamondon Orchard, Leelanau, MI, Harvested 26 July 1994.

*Tukey's mean comparison significant to $P \leq 0.01$



MCS (g/mm)
55
50
45
40
35
30
*A
C
B
0
14
10
0
14
10
0
14
10
INITIAL
HARVESTED
SOAKED

ethephon hastened fruit coloration, reduced fruit size and increased soluble solids, whereas the late treatment only reduced fruit size. Fruit removal force and pitted weight were not significantly affected by ethephon.

b. Bardenhagen Orchard. Time of ethephon treatment did not affect firmness or any other fruit characteristic (Table 16). Mechanical harvest reduced firmness in both treatments, and soaking increased it (Fig. 24)

c. Shimeck Orchard. Timing of ethephon treatment did not affect fruit firmness, although fruit removal force was lower with early treatment (Table 17). Firmness was reduced by harvesting (10 and 11 units), but soaking did not increase firmness significantly (Fig. 25).

d. Horticulture Teaching and Research Center, East Lansing, MI. Early ethephon treatment reduced fruit firmness significantly within one week (Fig. 26). The effects of later treatments were non-significant (data not shown).

3. Foliar application of calcium.

Calcium sprays did not affect firmness or any other fruit parameters including fruit color, diameter soluble solids, fruit removal force and pitting weight (Fig. 27). Fruit firmness was reduced by mechanical harvest (18 to 20 units). The fruit recovered 6.2 (-Ca), and 4.6 (+Ca) units on soaking. Firmness was similar for the

Table 16. Effects of timing of ethephon application (300 ppm) on fruit characteristics of 'Montmorency' cherry. Bardenhagen Orchard. Leelanau, MI. Harvested 30 July 1994.

A. Firmness

DATE	ON TREE	HARVESTED	SOAKED	MEAN
15 July	49.1	33.7	36.3	39.7
21 July	47.2	34.5	39.0	40.2 ns y
MEAN	48.2 aA z	34.1 cB	37.6 bB	

z Mean separation within columns and rows by Tukey's test; ns (not significant), $P \leq 0.05$ (ab), $P \leq 0.01$ (AB).

y Date x treatment interaction not significant at $P \leq 0.05$

B. Other fruit characteristics

DATE	COLOR (*L)	DIAMETER (mm)	WEIGHT (g)	FRF (g)	SOLUBLE SOLIDS (%)	PITTED WEIGHT (%)
15 July	33.0	21.1	153	169	11.5	85
21 July	31.8 ns z	21.2 ns	144 ns	198 ns	11.9 ns	86 ns

z No significant effect of timing at $P \leq 0.05$

Figure 24. Effects of early (15 days) and late (9 days) application of ethephon (300 ppm), harvesting and soaking in water on firmness of 'Montmorency' sour cherry fruits. Bardenhagen Orchard, Leelanau, MI, Harvested 30 July 1994.

*, ** Tukey's mean comparison significant at $P \leq 0.05$(a) and $P \leq 0.01$(A)

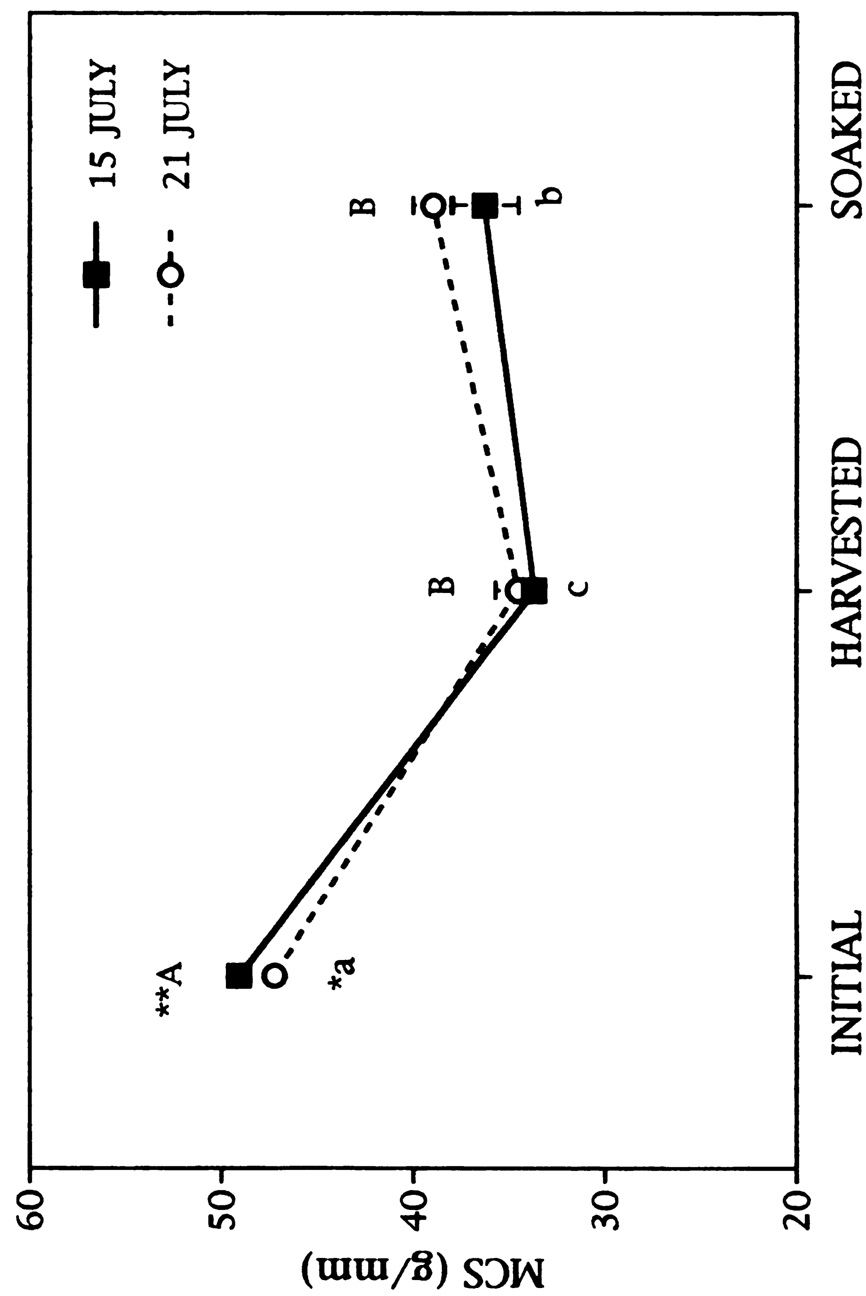

MCS (g/mm)
60
50
40
30
20
INITIAL
HARVESTED
SOAKED
15 JULY
21 JULY
**A
*a
B
c
B
b

Table 17. Effects of timing of ethephon application (300 ppm) on fruit characteristics of 'Montmorency' cherry. Shimeck Orchard, Maple City, MI. Harvested 2 August 1994.

A. Firmness

DATE	ON TREE	HARVESTED	SOAKED	MEAN
22-Jul	48.3	38.6	42.2	43.0
27-Jul	48.9	37.5	39.5	41.9 ns [y]
MEAN	48.6 A[z]	38.1 B	40.8 B	

[z] Mean separation within columns and rows by Tukey's test; ns (not significant), $P \leq 0.05$ (ab), $P \leq 0.01$ (AB).

[y] Interaction not significant at $P \leq 0.05$.

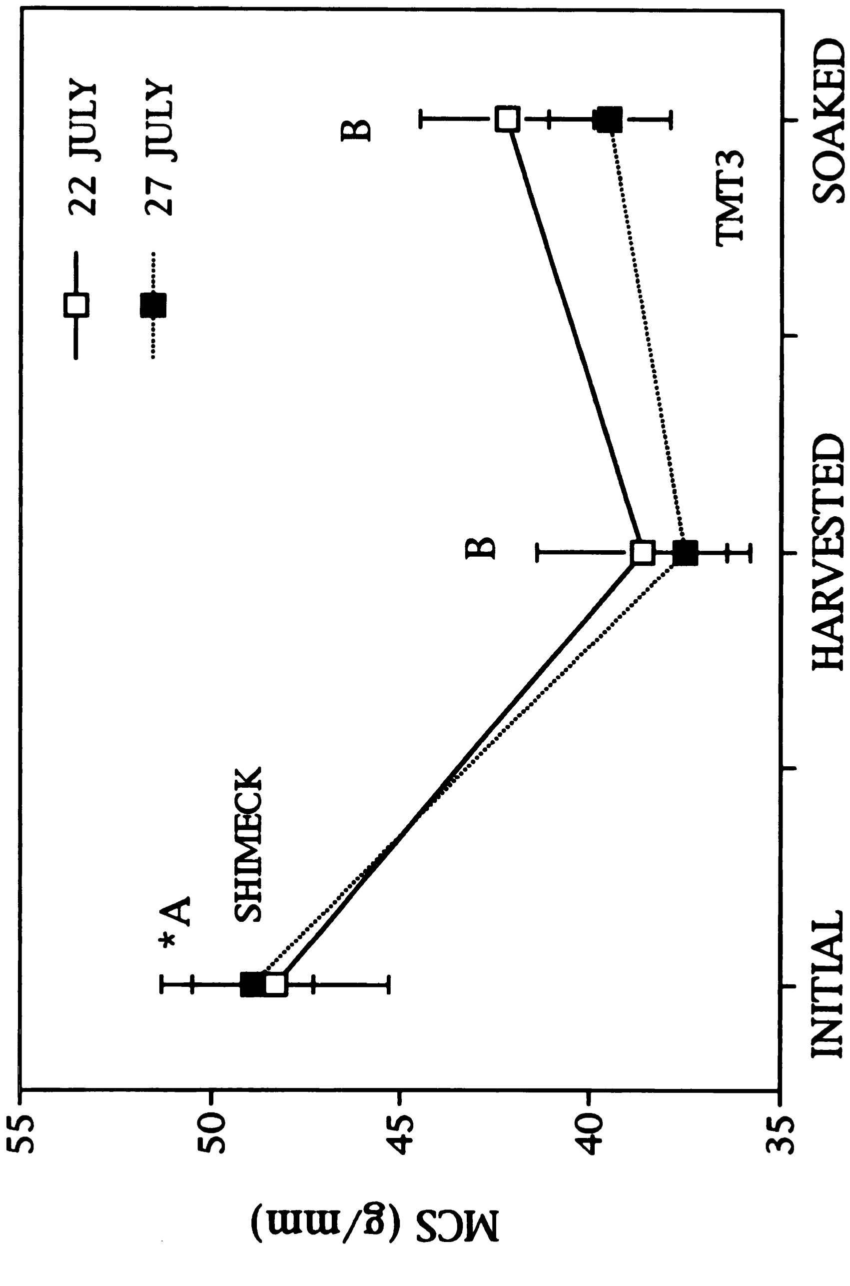
B. Other fruit characteristics

DATE	COLOR (*L)	DIAMETER (mm)	WEIGHT (g)	FRF (g)	SOLUBLE SOLIDS (%)	PITTED WEIGHT (%)
22-Jul	32.5	21.1	144	193	11.3	85
27-Jul	36.8 ns [z]	21.1 ns	144 ns	245 ns	11.2 ns	84 ns

[z] Effect of time of harvest not significant at $P \leq 0.05$.

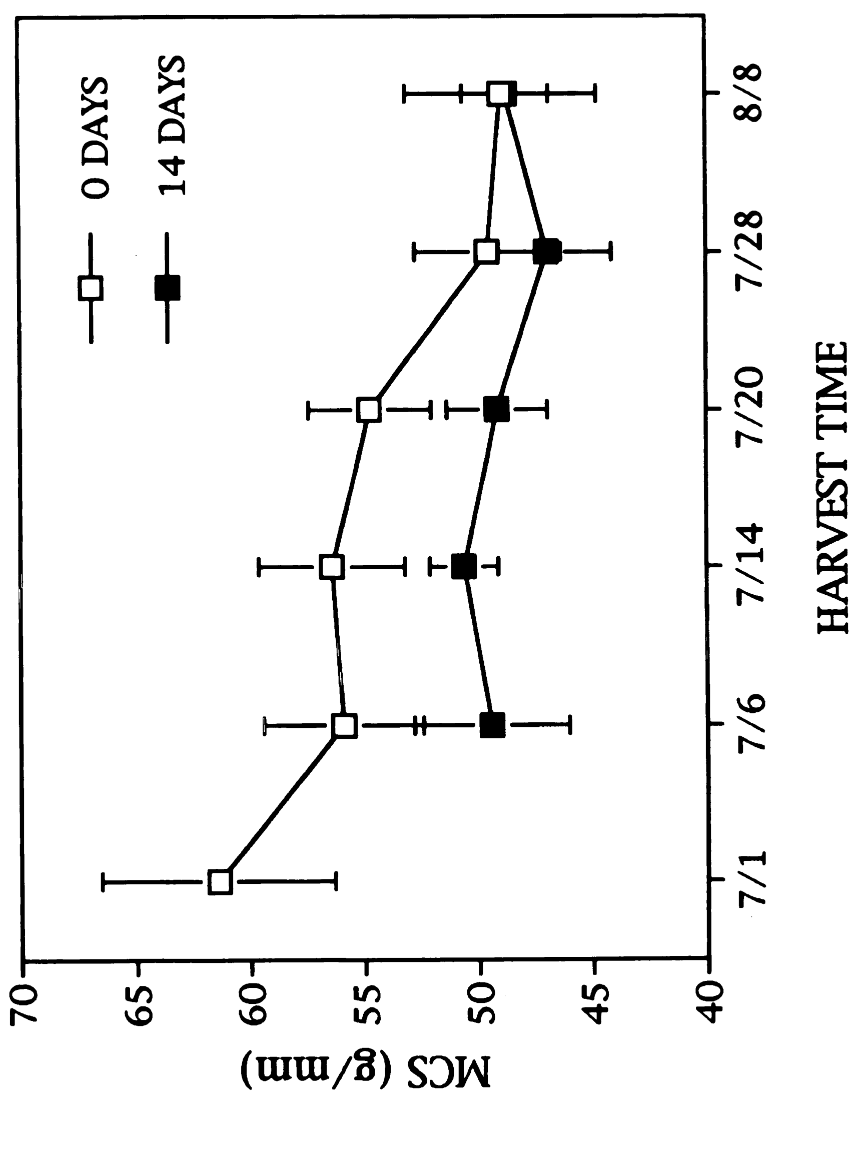
Figure 25. Effects of early (11 days) and late (6 days) application of ethephon (300 ppm), harvesting and soaking in water on firmness of 'Montmorency' sour cherry fruits. Shimeck Orchard, Maple City, MI, Harvested 2 August 1994.

* Tukey's mean comparison significant at $P \leq 0.01$



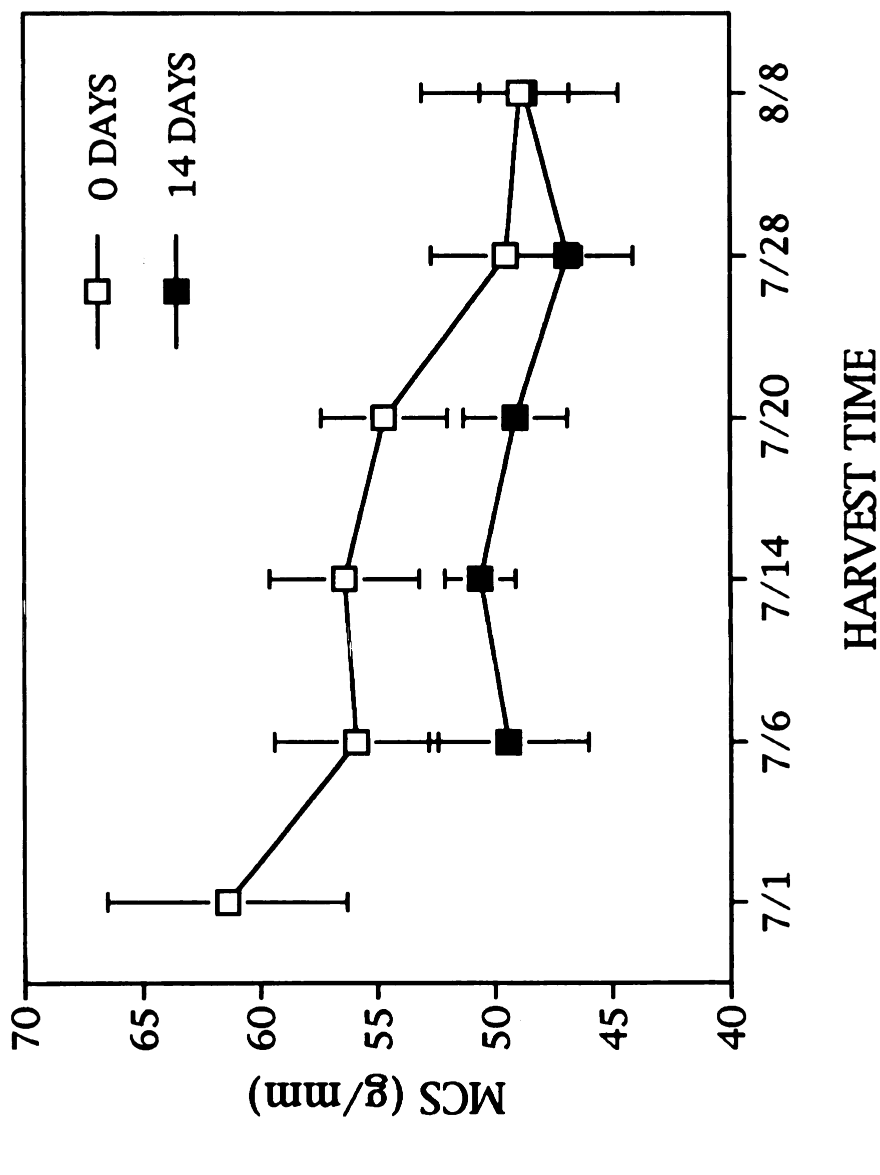
MCS (g/mm)
55
50
45
40
35
INITIAL
HARVESTED
SOAKED
22 JULY
27 JULY
*A
B
B
SHIMECK
TMT3

Figure 26. Effects of early application of ethephon (300 ppm) on firmness of 'Montmorency' sour cherry fruits. Horticulture Teaching and Research Center, East Lansing, MI, 1994



0 DAYS
14 DAYS
MCS (g/mm)
70
65
60
55
50
45
40
7/1
7/6
7/14
7/20
7/28
8/8
HARVEST TIME

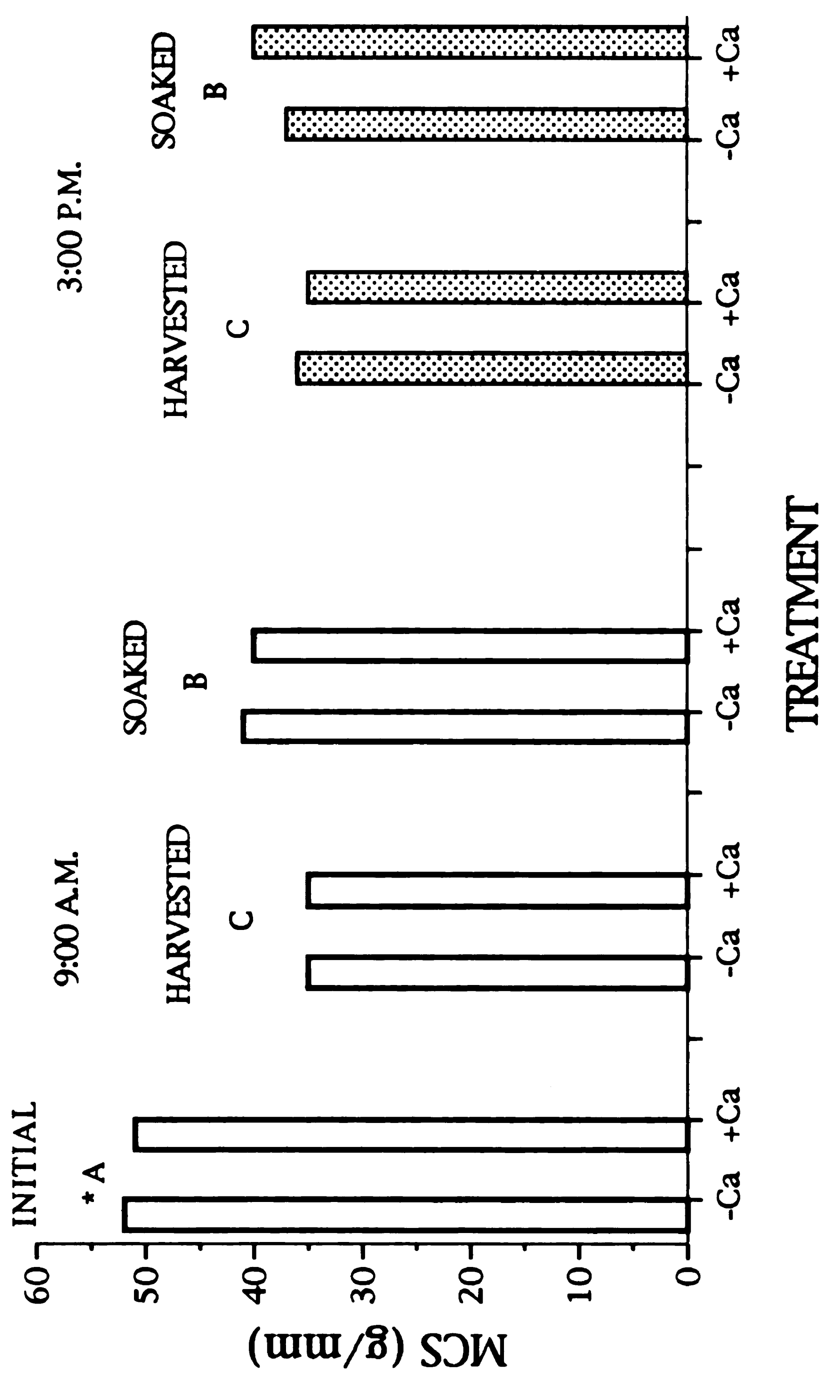
Figure 26. Effects of early application of ethephon (300 ppm) on firmness of 'Montmorency' sour cherry fruits. Horticulture Teaching and Research Center, East Lansing, MI, 1994



MCS (g/mm)
70
65
60
55
50
45
40
0 DAYS
14 DAYS
7/1
7/6
7/14
7/20
7/28
8/8
HARVEST TIME

Figure 27. Effects of calcium ($CaCl_2$) application, harvesting and soaking in water on firmness of 'Montmorency' sour cherry fruits. Gregory Orchard, Suttons Bay, MI. Harvested 29 July 1994.

*Tukey's mean comparison significant at $P \leq 0.01$


MCS (g/mm)
60
50
40
30
20
10
0
INITIAL
* A
9:00 A.M.
HARVESTED
C
SOAKED
B
3:00 P.M.
HARVESTED
C
SOAKED
B
-Ca
+Ca
TREATMENT

fruits harvested at 9:00 A.M. and those harvested at 3:00 P. M (Table 18).

4. Time of harvest during 24 hour period, soaking, and holding temperatures.

Air temperature in the top of the tree ranged from 60° to 97°F (15.6° to 36°C) during the course of the experiment, whereas fruit temperature ranged from 63 to 71 °F (17 to 22 °C) (Fig. 28). Fruit firmness at harvest was relatively low at 17:00 and 23:00 hours on July 14 and at 2:00 hour on July 15 (Fig. 29), but no differences in initial firmness were significant at $P \leq 0.05$ with 3 replications. Firmness of harvested fruits following 4 hours of storage varied over time, those harvested at 8:00 July 14 being softest, those harvested at 20:00 firmest (Table 19, Fig. 29). Soaking had no consistent effect upon firmness of harvested fruit, but fruits held at 38 °F (3.3 °C) were firmer than those held at 74 °F (23 °C) with two exceptions (2:00 and 5:00 a.m. July 15).

Interaction was evident between temperature of storage and both time of harvest and method of storage (dry/wet). The first interaction is explained above. The second resulted from the fact that soaked fruits were softer than dry fruit when cooled, but not when held at ambient temperature.

Correlation of firmness with other parameters.

Firmness could not be correlated across sampling dates with other fruit characteristics as was done in 1993 (Table 20), because each orchard was sampled only once or twice in 1994. Therefore all

Table 18. Effects of calcium ($CaCl_2$) application and time of harvest on fruit characteristics of 'Montmorency' sour cherry. Gregory Orchard, Suttons Bay, MI. Harvested 29 July 1994.

A. Firmness

TIME	9:00 A.M.			3:00 P.M.		
CALCIUM	ON TREE	HARVESTED	SOAKED	HARVESTED	SOAKED	MEAN
Control	51.6	35.0	41.2	35.5	37.1	40.1
Calcium	51.3	35.4	40.0	34.9	39.8	40.3 ns
MEAN	51.5 aA[z]	35.2 cC	40.6 bB	35.2 cC	38.5 cbB	

Interaction not significant at $P \leq 0.05$.

B. Other fruit characteristics

CALCIUM	COLOR (*L)	DIAMETER (mm)	WEIGHT (g)	FRF (g)	SOLUBLE SOLIDS (%)	PITTED WEIGHT (%)
Control	31.9	22.3	187	182	11.8	85
Calcium	31.9 ns	22.7 ns	175 ns	169 ns	12.0 ns	85 ns

[z] Mean separation within columns and rows by Tukey's test; ns (not significant), $P \leq 0.05$ (ab), $P \leq 0.01$ (AB).

Table 19. Effects of time of harvest and method of holding fruits on fruit firmness of 'Montmorency' sour cherry. Horticulture Teaching and Research Center. East Lansing, MI. (July 14-15, 1994).

Interaction:	Time x temperature	*y
	Time x dry/wet	ns
	Temperature x dry/wet	*
	Time x temperature x dry/wet	ns

z Initial firmness not included in statistical analysis.

y ns, *, **, *** Not significant or significant at $P \leq 0.05$, $P \leq 0.01$ or $P \leq 0.001$, respectively.

x Mean separation within main effects by Tukey's test, ns-difference not significant at $P \leq 0.05$, significant at $P \leq 0.05$ (small letters) or $P \leq 0.01$ (capital letters).

		TIME SAMPLED								
TREATMENT		8:00	11:00	14:00	17:00	20:00	23:00	2:00	5:00	MEAN
Initial firmness:		[59.41]	[60.75]	[59.42]	[57.07]	[61.27]	[56.83]	[56.81]	[59.56]	[58.89] z
TEMPERATURE(°C)	SOAK									
3.3	-	63.9	68.3	65.8	65.1	69.5	62.7	60.3	63.8	64.9 A y
	+	62.8	67.4	62.1	61.5	66.5	64.8	60.2	59.7	63.1 AB
23.0	-	57.6	60.2	60.5	59.7	61.7	59.0	61.5	61.4	60.2 C
	+	59.3	62.4	62.0	60.8	62.8	61.0	61.7	59.0	61.1 BC
MEANS:		60.9 c	64.6 ab	62.6abc	61.8 abc	65.1 a	61.9 abc	60.9 bc	61.0 bc	62.3
3.3		63.3	67.9	64.0	63.3	68.0	63.8	60.3	61.8	64.0 a x
23.0		58.5	61.3	61.2	60.3	62.2	60.0	61.6	60.2	60.7 b
	-	60.7	64.3	63.2	62.4	65.6	60.9	60.9	62.6	62.6 ns x
	+	61.1	64.9	62.0	61.1	64.6	62.9	61.0	59.4	62.1 ns

Figure 28. Air and fruit temperature changes during 24 hours in 'Montmorency' sour cherry tree. Horticulture Teaching and Research Center, East Lansing, MI. July 14-15, 1994.

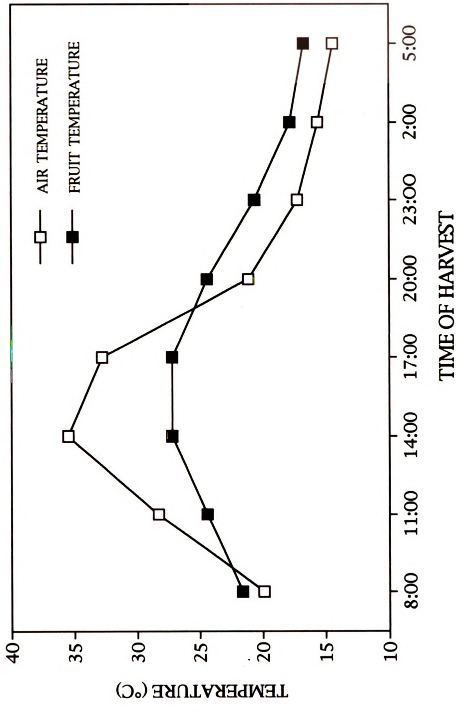

AIR TEMPERATURE
FRUIT TEMPERATURE
TEMPERATURE (°C)
40
35
30
25
20
15
10
8:00
11:00
14:00
17:00
20:00
23:00
2:00
5:00
TIME OF HARVEST

Figure 29. The effects of time of harvest and methods of holding fruits on fruit firmness of 'Montmorency' sour cherry. Horticulture Teaching and Research Center, East Lansing MI. July 14-15, 1994.

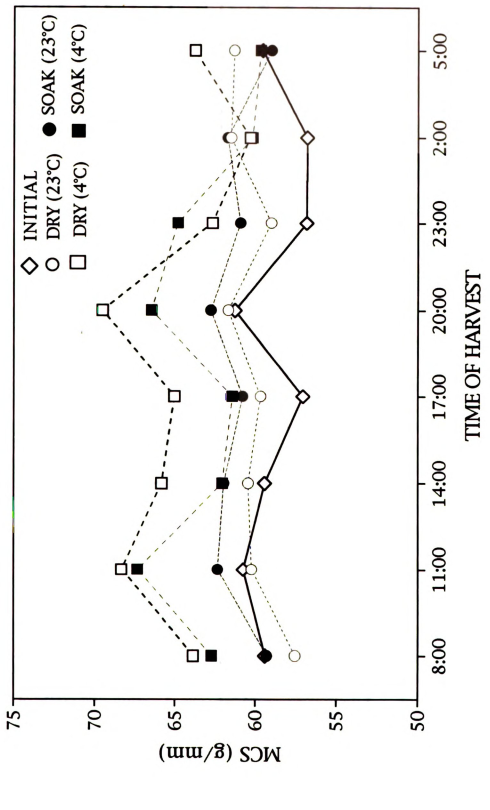

INITIAL
DRY (23°C)
DRY (4°C)
SOAK (23°C)
SOAK (4°C)
MCS (g/mm)
75
70
65
60
55
50
8:00
11:00
14:00
17:00
20:00
23:00
2:00
5:00
TIME OF HARVEST

Table 20. Correlations between firmness and other fruit characteristics in hand-harvested 'Montmorency' sour cherry. 1993

	ETHEPHON(bel)	ETHEPHON (tc)	GIBBERELLIN (bel)	GIBBERELLIN (tc)	NITROGEN
COLOR	-0.049 ns	0.350 *	0.660 ***	0.870 **	0.454 **
DIAMETER	-0.063 ns	-0.042 ns	-0.474 ***	-0.723 **	-0.386 **
SS	-0.074 ns	-0.458 **	-0.370 **	-0.709 **	-0.558 **
FRF	0.282 ns	-0.764 **	0.765 ***	0.873 **	0.429 **
WEIGHT	-0.007 ns	0.631 ns	-0.539 ***	-0.750 **	-0.399 **

	SHADED	LEAF:FRUIT	IRRIGATION	CALCIUM	POTASSIUM
COLOR	0.811 **	0.873 **	0.497 ***	0.335 ns	0.546 ns
DIAMETER	-0.762 **	-0.619 **	-0.405 **	-0.405 ns	0.299 ns
SS	-0.505 **	-0.730 **	-0.628 **	-0.280 ns	-0.240 ns
FRF	0.791 **	0.822 **	0.543 ***	-0.210 ns	0.697 *
WEIGHT	-0.699 **	-0.758 **	-0.419 **	-0.139 ns	0.279 ns

ns, *, **, *** Not significant or significant at the $P \leq 0.05$, $P \leq 0.01$ or $P \leq 0.001$, repectively.

data for hand-harvested fruits were combined for 1994, and firmness plotted against other parameters (Fig. 30), r values (Table 21) were significant for color (-0.358*), soluble solids (+0.574***) and fruit removal force (+0.500**). Firmness was also correlated with the firmness of mechanically harvested fruit both before and after soaking.

Figure 30. Correlation between initial firmness and several other fruit characteristics. Ethephon, nitrogen, irrigation and calcium treatments. Traverse City, MI. 1994.

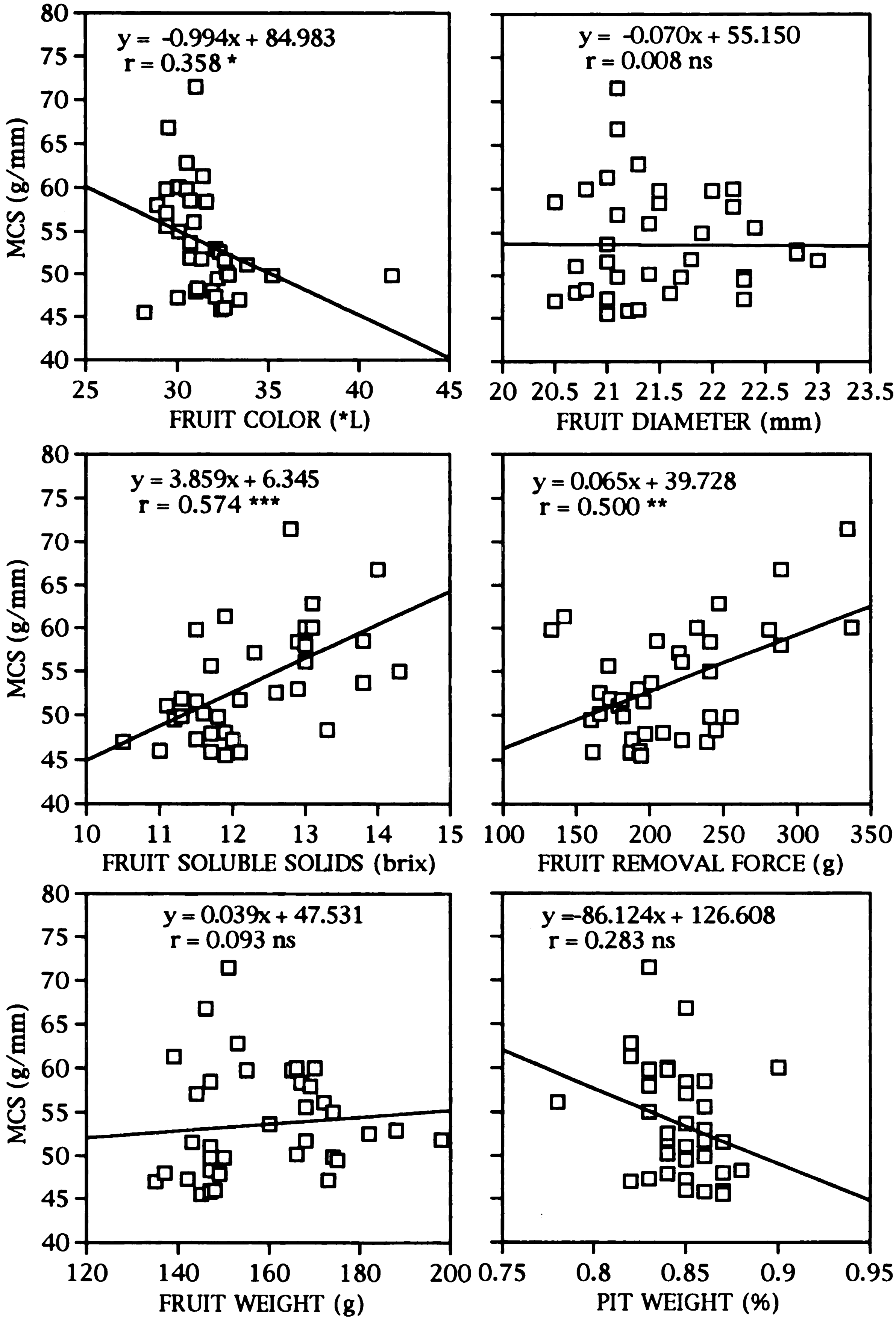

y = -0.994x + 84.983
r = 0.358 *
MCS (g/mm)
FRUIT COLOR (*L)
y = -0.070x + 55.150
r = 0.008 ns
FRUIT DIAMETER (mm)
y = 3.859x + 6.345
r = 0.574 ***
MCS (g/mm)
FRUIT SOLUBLE SOLIDS (brix)
y = 0.065x + 39.728
r = 0.500 **
FRUIT REMOVAL FORCE (g)
y = 0.039x + 47.531
r = 0.093 ns
MCS (g/mm)
FRUIT WEIGHT (g)
y =-86.124x + 126.608
r = 0.283 ns
PIT WEIGHT (%)

Table 21. Correlations between firmness of 'Montmorency' cherry fruits and other fruit characteristics in orchards used in 1994.

FIRMNESS	INITIAL FIRMNESS	COLOR	DIAMETER	SOLUBLE SOLIDS	FRF	WEIGHT	PITTED WEIGHT
INITIAL	-	-0.358 *	0.008 ns	0.574 **	0.500 **	0.093 ns	-0.283 ns
HARVESTED	0.766 ***	-0.300 ns	0.364 *	0.377 *	0.335 *	-0.178 ns	-0.226 ns
SOAKED	0.682 ***	-0.411 *	0.384 *	0.286 ns	0.101 ns	-0.101 ns	-0.177 ns

ns, *, **, *** Not significant or significant at the $P \leq 0.05$, $P \leq 0.01$ or $P \leq 0.001$, repectively.

V. DISCUSSION

A. General

Although considerable research has been devoted to solving the soft cherry problem, its physiological basis remains obscure, and methods of control are limited, at best. In this thesis, a range of treatments were applied and the effects of a number of factors that might be associated with the production of soft cherries were evaluated.

In 1993 only the firmness of carefully hand-harvested fruit was measured. Firmness at maturity ranged from 67 to 48 MCS, depending on orchard and treatment, thus none of the fruits could be considered soft by industry standards. Values for 1994 were generally lower than those for 1993, with a range of 47 to 61 units (Fig. 31). Firmness of sweet vs. sour cherries in 1993 are compared in Fig. 32. The former were much firmer, as would be expected.

After the data had been analyzed, additional information was obtained from a receiving station at Shelby, MI, where soft cherries had been a problem that year. Hopefully the percentage of soft fruit could be correlated with some factor(s) related to site, soil, or harvesting method. Inspection slips were available for 88 loads of cherries harvested between 18 and 31 July. The percentage of soft cherries was low (0-2%) for all samples and no trends were evident that could be related to time of harvest or other known variables.

Figure 31. Firmness of control fruits in 1993 vs. 1994.

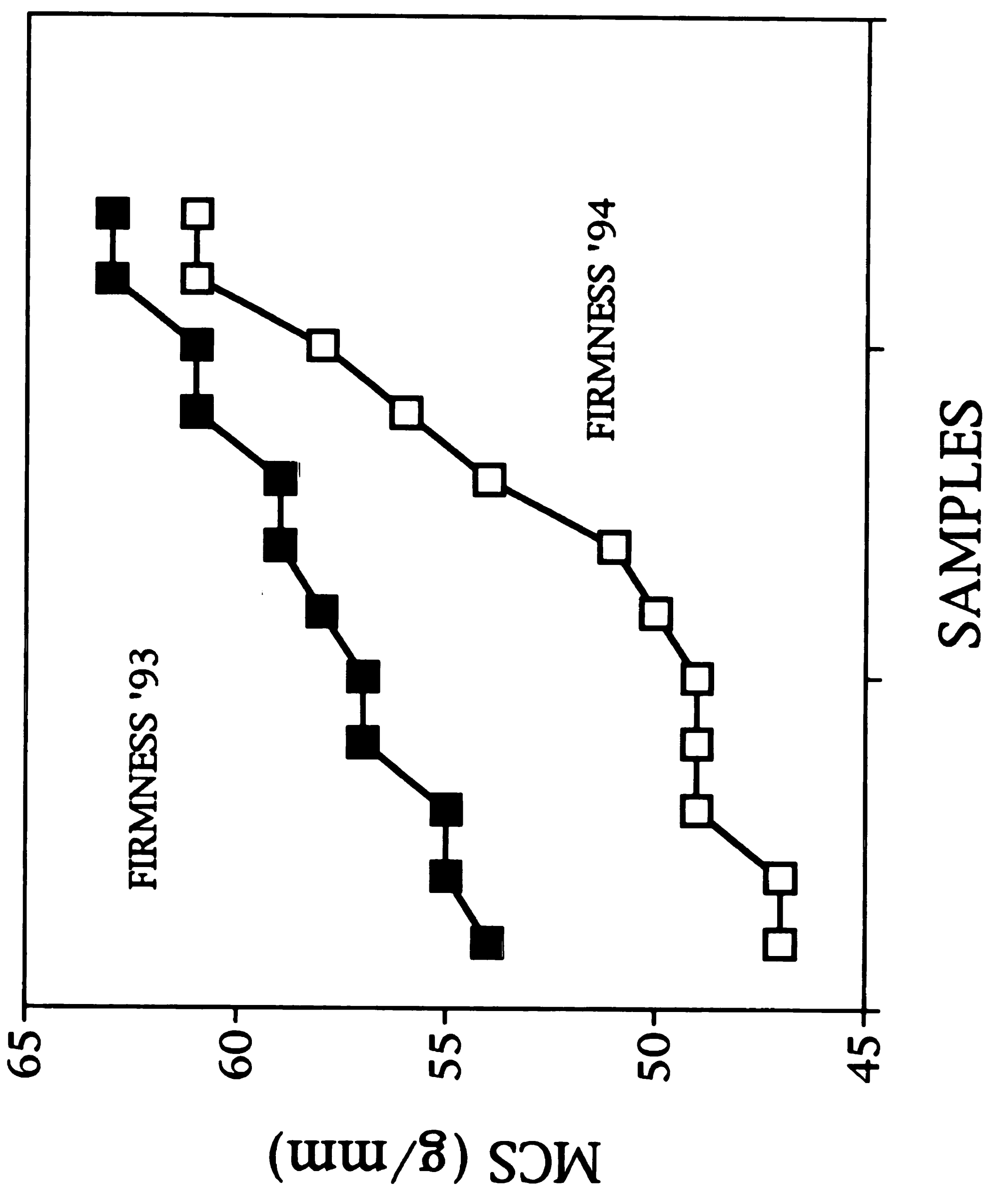

FIRMNESS '93
FIRMNESS '94
MCS (g/mm)
65
60
55
50
45
SAMPLES

Figure 32. Firmness of 'Montmorency' sour cherry vs. 'Ulster' sweet cherry in 1993. Preset force in grams was 300 for 'Ulster', 150 for 'Montmorency'.

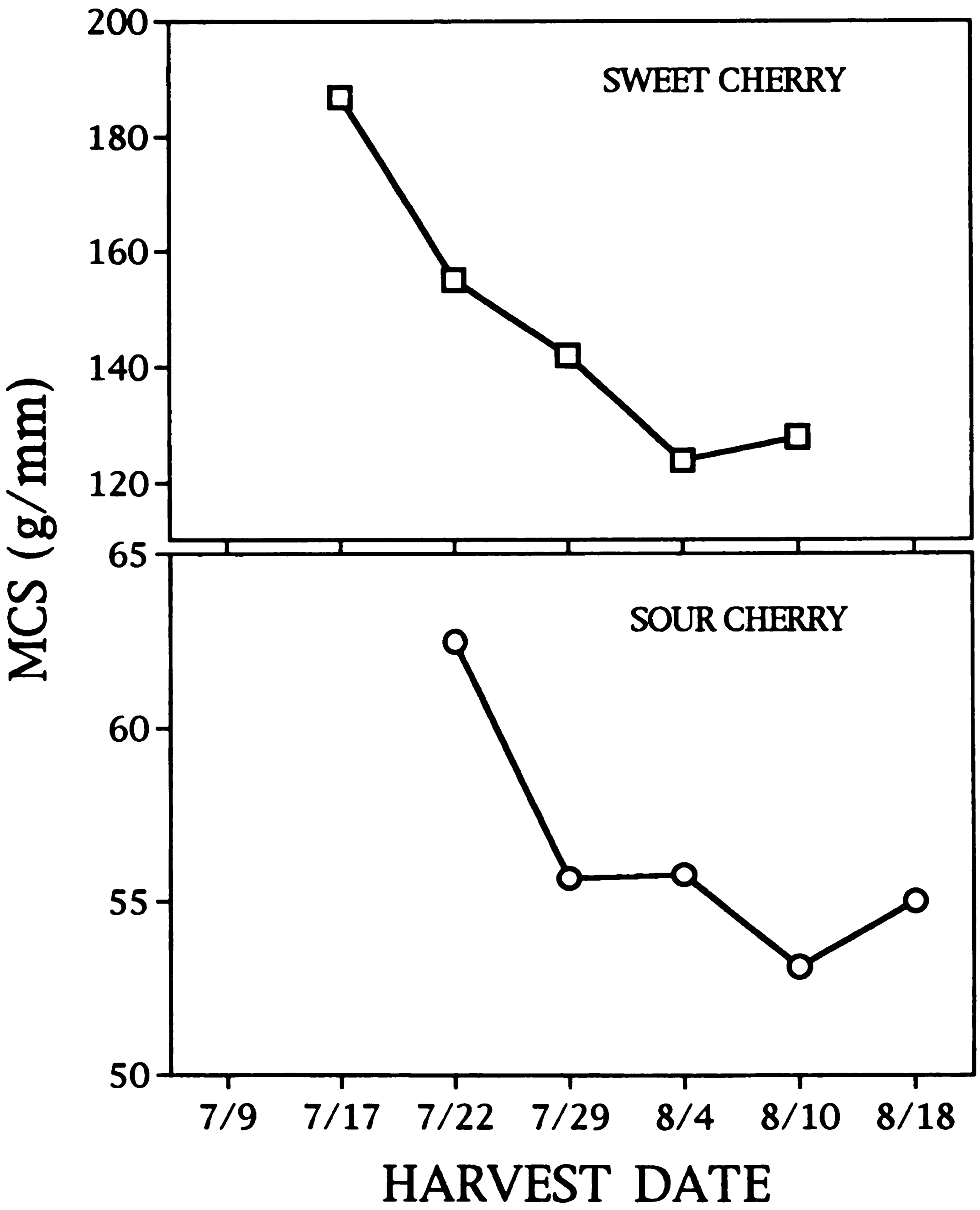
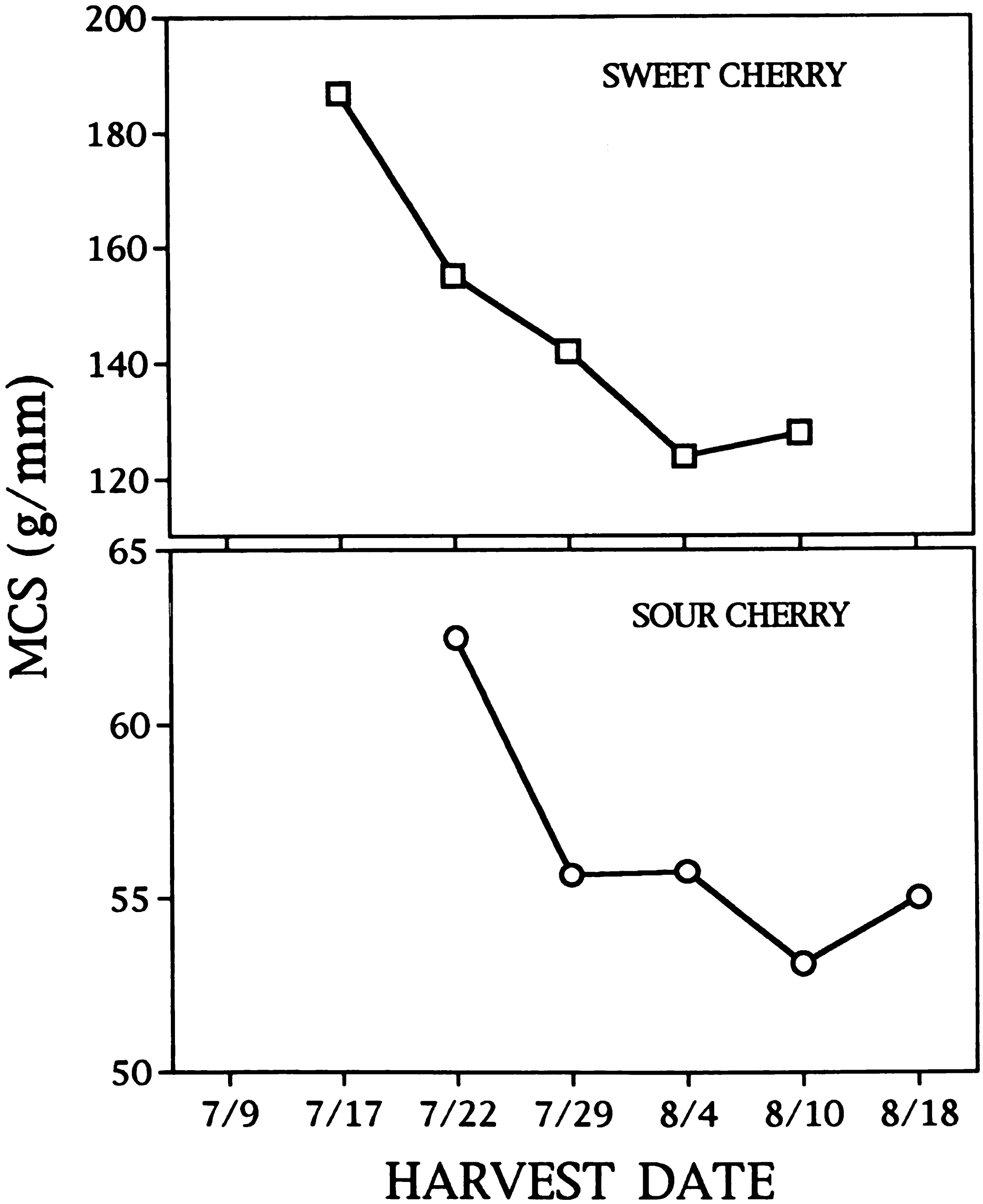

200
180
160
140
120
SWEET CHERRY
65
60
55
50
SOUR CHERRY
MCS (g/mm)
7/9
7/17
7/22
7/29
8/4
8/10
8/18
HARVEST DATE

Figure 32. Firmness of 'Montmorency' sour cherry vs. 'Ulster' sweet cherry in 1993. Preset force in grams was 300 for 'Ulster', 150 for 'Montmorency'.


SWEET CHERRY
SOUR CHERRY
MCS (g/mm)
200
180
160
140
120
65
60
55
50
7/9
7/17
7/22
7/29
8/4
8/10
8/18
HARVEST DATE

The only fact that stood out was that the number of fruits with attached stems was high early in the season--not surprising, given that many fruits were still immature at this time. The lack of soft cherries in the record apparently indicated that such fruits were diverted to juice and never inspected.

Most of the orchards sampled in 1994 were chosen because they had a history of producing soft fruit, yet in none was this a problem that year. Although this was beneficial for growers, it was frustrating for those of us who were attempting to solve the riddle. Firmness was evaluated both in hand harvested and machine harvested samples, the latter both before and after soaking for 4 hours in cold water--a standard industry practice. Soft cherries were found only rarely, even in machine harvested fruit. In some orchards considerable fruit flesh was evident in the soak tanks-- an indication that a significant proportion of the fruits had been crushed during harvesting. Even in these orchards, however, the number of soft fruit was insignificant.

In additional experiments (Brown, et al., unpublished data) fruits were dropped from various heights to a hard surface to simulate mechanical harvest, and the firmness measured before and after dropping. Several cushioning materials were also evaluated. Some data on firmness before and after treatment are given in Table A1. These data indicate that: a) damage increased with height of fall and with number of drops; b) fruits of the Ufehertoi Furtos cultivar are much more resistant to injury than are 'Montmorency' fruits; and c) injury can be reduced by using padding materials. Cultivar replacement is a long-term solution to the problem, but growers should evaluate the padding materials on shaker arms, etc., as well as the materials used for catching frames, in order to limit bruising.

B. Factors evaluated in 1993-94

a. Environmental effects: Light intensity (shading); leaf:fruit ratio (although leaf-fruit ratio is not a true environmental variable, it determines the amount of photosynthate per fruit, and therefore is included with environmental effects); water supply during the critical stage of fruit development; temperature.

b. Cultural practices: Mineral nutrition (N, K, Ca); growth regulators, including ethephon and gibberellin (GA3).

The information obtained is discussed below.

1. Shading.

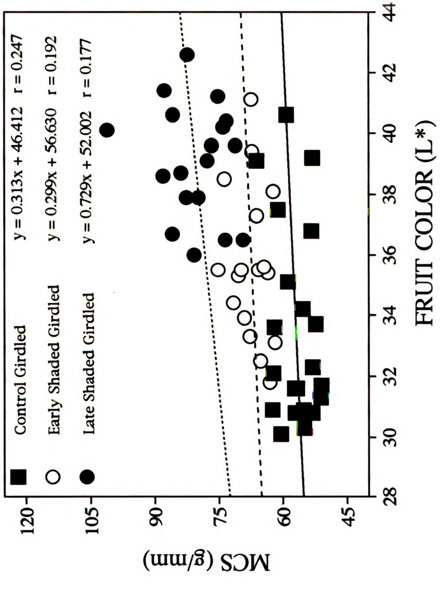
Shading can have a profound effect on the yield and growth of cherry trees (Flore and Lane, 1990) and on fruit maturation, as indicated by color and fruit retention force (Flore, et al., 1990). Flore, et al. (1990) also determined that light is a major factor associated with uniformity of ripening, and fruit quality, soluble solids and fruit size in particular. Patten and Proebsting (1986) had previously established that shading cherry trees delayed fruit maturation and red color development; shaded fruits were softer (durometer test) at maturity and lower in soluble solids than unshaded fruits. In my work with 'Montmorency' sour cherry at East Lansing in 1993 shading delayed fruit ripening by three weeks when treatment was applied early in the season, but firmness of mature fruit was not affected significantly. Shading at this time reduced fruit growth, coloration and soluble solids content. Later shading produced similar, but less pronounced results. Shading appears to have maximum effect in term of delaying fruit development and fruit ripening when applied at the beginning of pit hardening. However, my firmness data differ from these obtained by Patten and Proebsting (1986) with sweet cherries. They reported that shading increased firmness at every sampling date, early shading being more effective than late shading. This effect on firmness can be at least partially explained by the immaturity of shaded fruits. Patten and Proebsting (1986) compared firmness at the same fruit color. To determine if firmness paralleled color change in shaded vs. non-shaded samples, my 1993 data for fruits with similar color ratings were plotted (Fig. 33). Shaded fruits were consistently firmer than the controls at the same stage of coloration. Thus, my firmness data parallel those of Patten and Proebsting when corrected for fruit color.

The fruits were not mechanically harvested in 1993 nor were fruits dropped to a hard surface as was done in 1994; had this been done, different results might have been obtained. Shading clearly delays maturation, but its effects on firmness after mechanical harvest remains to be determined.

2. Leaf:fruit ratio.

The most obvious conclusion gleaned from previous research regarding leaf:fruit ratio in tree fruits is that quality parameters are

Figure 33. Effects of shading on the relationship between firmness and fruit color. Horticultural Teaching and Research Center, East Lansing, MI, 1993.


Control Girdled
y = 0.313x + 46.412 r = 0.247
Early Shaded Girdled
y = 0.299x + 56.630 r = 0.192
Late Shaded Girdled
y = 0.729x + 52.002 r = 0.177
MCS (g/mm)
120
105
90
75
60
45
28
30
32
34
36
38
40
42
44
FRUIT COLOR (L*)

affected (Teryl, et al., 1987; Facteau, et al., 1983). Spayd, et al. (1986) showed that trees with heavy crops produced cherries that were softer, greener and lower in sugar than those from trees with light crops. Teryl and Loescher (1987) also reported positive correlations between leaf:fruit ratio and both fruit firmness and soluble solids.

Flore (1985) reported that leaf to fruit ratios less than 2.0 resulted in a limited carbohydrate supply and delayed ripening of sour cherry for several days. Unfortunately many of the trees that I used in 1993 were partially defoliated by a fungal infection. I did not record the final leaf:fruit ratio, but low ratios were associated with delayed fruit ripening, and reduced fruit size, soluble solids and fruit color. Heavy cropping of sweet cherries results in soft fruit and low soluble solids (see above). My data with sour cherries confirms the effect on soluble solids but not on firmness.

3. Nitrogen and potassium.

In 1950 Stanberry and Clore determined that soil application of nitrogen to unproductive 'Bing' cherry trees greatly increased yield and fruit size. Nitrogen alone usually increased firmness, whereas potassium alone reduced it (firmness was measured by surface pitting). Combinations of nitrogen and potassium in medium amounts improved firmness, but heavy applications resulted in soft fruit. At Traverse City, Michigan, in 1993-1994, the higher rates of nitrogen application increased firmness of 'Montmorency' sour cherries. The trees given no nitrogen produced somewhat larger fruits with higher soluble solids. Trees with medium and high nitrogen yielded between 60 and 75 kg/tree vs. 30 to 40 kg/tree for trees receiving no nitrogen. Thus fruit size and soluble solids content were inversely related to both yield and firmness. The relationship between nutrition and firmness was therefore confounded by differences in cropload. Nitrogen application could have increased cropload, which in turn delayed maturation, leading to firmer fruit. However, the fruits on high nitrogen trees remained firmer well after the time of optimum harvest (Fig. 7).

In 1994, mechanical harvest reduced firmness of fruit from both nitrogen treatments and no differences were apparent in recovery on soaking in cold water for 4 hours. Although nitrogen delayed fruit maturation it did not affect the other parameters measured, with one exception; fruit removal force was reduced.

Research in 1993 showed no consistent effects on firmness when potassium sprays were applied, although potassium appeared to accelerate maturation of the fruit, reduce fruit removal force and increase soluble solids. However, the treatments were not replicated, thus conclusions must remain tentative.

4. Calcium.

In 1976 Cooper and Bangerth determined that calcium application increased apple firmness by stabilizing cell membranes and helping to maintain the internal integrity of the fruit. Anderson (1992) concluded that the role of calcium in cherry firmness was not certain, but that it clearly caused condensation of water on membrane surfaces and decreased permeability of the fruit to water. In my experiment, foliar applications of calcium in 1993 and 1994 did not affect fruit firmness. However, both soluble solids and fruit removal force were increased. There was no interaction between calcium treatment and time of harvest, nor were correlations significant between fruit firmness and fruit color, diameter, soluble solids, pull force, or fruit weight. In 1994 calcium treatments had no effect on firmness during mechanical harvest or gain in firmness on soaking in cold water for 4 hr.

Bedford and Robertson (1957) observed that adding calcium during soaking increased sour cherry firmness (tenderometer) in comparison with those soaked in cold water. Anderson (1992) reported that soaking sour cherries for extended time periods in calcium solutions reduced the percentage of split fruit. In 1993 I soaked cherries in solutions of $CaCl_2$ for 30 minutes before transfer to running water. Fruit firmness was not affected when measured after 4 hours of soaking (data not reported). Although soaking in water increased firmness, $CaCl_2$ had no effect.

Calcium is very important in fruit growth and development. It is involved directly in the cell wall and the middle lamella in which it binds to pectin groups (polygalacturonic acids). The degradation of pectates is mediated by polygalacturonase, which is drastically inhibited by high Ca^{2+} concentrations. Cassells and Barlass (1976) reported that a large proportion of the pectic material exists as calcium pectate, making the tissue highly resistant to degradation by polygalacturonase. As shown by Rigney and Wills (1981) in experiments with tomato pericarp tissue during fruit development, the calcium content of the cell walls increases to the fully grown immature stage, then drops just before the onset of ripening and tissue softening. In future research the role of Ca^{2+} and pectins in cherry fruit softening may be a profitable area of study.

5. Ethephon.

The biological activity of ethylene in growth and development, e.g., fruit abscission, coloration, and maturation, is well established. Ethephon, an ethylene-releasing chemical, is used to promote cherry abscission and to minimize damage from harvesting procedures. Both Anderson (1969) and Olien and Bukovac (1978) reported that exceeding optimum ethephon dosage led to excessive leaf abscission and gummosis. The optimum level of 300-500 ppm was established by Anderson (1969) who noted that treated fruit was darker red in color, and more mature in appearance. Also, a critical factor in ethephon application is temperature. Olien and Bukovac (1983b) recognized that the major effect of temperature is to increase or decrease the rate of ethylene generation from ethephon.

As yet, no one has reported a direct relationship between ethephon treatment and fruit firmness. In 1993 I found that the firmness of treated cherries was significantly reduced 5 to 7 days after ethephon application (300 ppm and 150 ppm). In 1994, the orchards (Plamondon and HRC, East Lansing) in which untreated controls were available showed similar results (see Fig. 23 and 26), but time of ethephon application did not affect firmness significantly. Although ethephon reduces firmness by hastening maturation, these softer fruit are more easily removed during mechanical harvest, and therefore exhibit less bruising (Bukovac, et al. 1979).

6. Gibberellic acid (GA_3).

Limited studies involving gibberellic acid in the 1960s suggested that it tended to delay fruit ripening, allowing harvesting of firmer fruit (Dostal and Leopold, 1967; Russo, et al., 1968; Dilley, 1969). Additional work in the 1970s and 1980s demonstrated that an application of 10 to 30 ppm at stage III of fruit growth would increase size and firmness of sweet cherries. Both Proebsting, et al. (1973) and Facteau, et al. (1985a) found that the difference in firmness was due to the presence of more soluble solids in the treated fruits. Facteau, et al. (1985b) also discovered that multiple applications of gibberellic acid not only increased fruit firmness and weight, but also delayed harvest time. GA3 is used extensively in Washington State on 'Bing' cherries destined for fresh market.

In 1993 GA_3 was applied to 'Montmorency' sour cherries at Belding, Michigan, at 10 and 20 ppm, resulting in increased fruit weight, delayed maturity, slower color development and increased fruit removal force. However, firmness, fruit diameter and soluble solids were not affected. In a second experiment at Northport, Michigan, GA_3 at 20 and 40 ppm increased fruit size and soluble solids, and delayed color development, but again did not affect fruit firmness. At present GA_3 can not be recommended for improving fruit quality in sour cherries , although it is used to reduce flower bud initiation (Hull, et al., 1959; Stang and Weidman, 1986; Bukovac, et al., 1987).

7. Irrigation.

Poor distribution of rainfall has been suggested as an environmental factor that may favor soft sour cherries (Bedford, et al., 1955). Too much or too little water, particularly during the 3 week period of fruit development immediately prior to harvest, may result in soft cherries. The effect of irrigation was studied in 1993 and 1994 at the NWM Experimental Station, Traverse City. Cherries from the irrigated trees were softer and larger than those from non-irrigated trees, but fruit color, soluble solids and fruit removal force were not affected. In 1994, irrigation had no effect on fruit characteristics at the normal time of harvest, but, when harvest was delayed about one week, fruits from irrigated trees were again softer. In both years, rainfall was not limiting; irrigation may have more pronounced effects in dry years.

8. Temperature.

Mechanical harvesting of sour cherries by shaking results in additional bruising. Cherry farmers always are concerned about fruit temperature both during harvest and in the cooling tanks. Lowering water temperature from 24 to 13 °C increased the product yield of the fruit, but temperatures lower than 13 °C did not further increase yield (Tennes, et al., 1967). Also, Tennes, et al. (1967) reported that soluble solids and fruit firmness reached maximum values at midnight, with minimum values at noon. The effects on firmness of air and fruit temperatures at harvest and after harvest were measured over a 24-hr period in 1994. Initial firmness was lowest at 17:00 and highest at 20:00 p.m. (difference not significant with three replicates). Soaking had no consistent effect upon firmness of harvested fruit, but fruits held at 3.3 °C were significantly firmer than those held at 23 °C. The lack of effect of soaking may indicate that non-bruised, hand-harvested fruits will not respond, whereas bruised fruits will. Burton (1979) observed that soaking affected firmness of sour cherries only after several drops to a hard surface (Table A1).

Although not a part of this thesis, two experiments were performed at Traverse City in 1994 to test the effects of fruit temperature on resistance to bruising. Limbs were enclosed in plastic bags for 4-5 hr to raise fruit temperature on a sunny day. Subsequently the fruits were dropped from several heights. The trials were performed in the NWM Experimental Station (no ethephon used) and Gregory's Cherri-ke Orchard (with ethephon) at Traverse City in 1994. The firmness of fruits enclosed in bags was lower than that of controls before bruising, but higher after bruising, resulting in a noticeable reduction in total loss of firmness in bruising (Table A2). These data, though limited, did not support the view that high temperatures increase the problem of soft fruit. In the same orchard, adjacent trees were harvested at 9:00 a.m. (20 °C) or at 3:00 p.m. (26 °C), but firmness was not affected by time of harvest. The data for bagged fruit support the observations of Crisosto, et al. (1994) who reported that sweet cherries that were cold at the time of impact were more susceptible to bruising and pitting than were warm cherries; thus internal and external bruising damage decreased as temperature increased.

9. <u>Bruising.</u>

Whittenberger, et al. (1964) observed that in some years cherries were better able to withstand rough treatment during harvesting and handling operations than in other years (Table A3). Bedford and Robertson (1962) evaluated cherries from the same orchard and trees for three consecutive years. Using identical handling methods they observed that in 2 of the 3 years the fruits were firm and bruise-resistant, but in the other year (1961) the cherries were relatively soft. My studies indicated that some orchards have softer cherries than others (Table A4). But, soft cherries, as defined by the USDA, were rarely observed even after mechanical harvesting. Soft cherries appear to be caused by excessive bruising; they were always found in association with split fruits.

No cultural practice was identified that would prevent the occurrence of soft cherries, but immaturity or over maturity, heavy crops, mineral nutrition, excessive rainfall, etc., seem to pre-dispose the cherries to greater bruise damage (Brown, et al., 1994). Correlations between the firmness of hand harvested fruits in 1993 and other fruit characteristics, summarized in Table 20, indicated a preponderance of negative correlations with color and fruit removal force. Thus firmness was high when fruit were small and low in soluble solids (immature), and low when values for color and fruit removal force were low (mature). As noted before, such correlations were usually not significant when early samples were omitted. In 1994, when only mature fruits were sampled, firmness was best correlated (Table 21) with color (negative) and with soluble solids and fruit removal force (both positive). Except for soluble solids, therefore, the relationships were similar in both years. Marshall, et al. (1951) reported that following hand harvest immature fruits exhibited higher losses in cull fruit, pit loss and juice loss (33.8%) than mature fruits (20.4%) when not soaked; during 6 hours of soaking in water immature fruits lost 46.7% of juice vs. 26.4% for mature fruits (Table A5). Soft cherries were a problem even when all sour cherries for processing were hand picked; the adoption of mechanical harvesting did not create this problem, but it can make it worse (Whittenberger, et al., 1965).

Cherries are initially bruised during mechanical harvesting, and additional bruising occurs during handling and processing (Tables A6, A7, A8). Fruits withstand one serious bruise, but two serious bruises spaced a few hours apart resulted in a rapid deterioration of cherry quality (Whittenberger, et al., 1964). Kenworthy and Silsby (1974) reported that firmness prior to harvest varied between seasons and that as the harvest season progressed fruit firmness decreased (Tables A3 & A7).

Bruising and the loss of fruit firmness are problems that growers face every year. Since mechanical harvesters were introduced different ways of evaluating the effects of bruising and the loss of firmness have been used. Dropping is a common practice to compare and measure the deterioration (firmness-bruise) of the fruit. Hand-harvested fruits were dropped onto different surfaces from several heights to simulate mechanical harvest. Whittenberger, et al. (1965) and Burton, et al. (1979) reported that the number of drops was directly related to bruising and loss of firmness (Table A1). Also Brown, et al. (1994) found that a single drop from 3 ft onto a hard surface softened the fruit and dropping three times caused splitting. A drop from 12 ft onto a hard surface caused splitting, whereas the use of different fabrics used for harvester catching frames reduced or prevented injury (Appendix A9). Accumulated data on bruising indicate the importance of controlling bruising during all harvesting and handling operations to maintain maximum quality and pitted yield of cherries.

In 1994 studies, fruit firmness was evaluated on the tree just before mechanical harvesting, after mechanical harvesting and four hours after soaking. Soft cherries could not be identified on the tree, and initial firmness was reduced by harvesting and handling operations. Cherry farmers are probably tired of hearing the same recommendations with regard to the soft cherry problem. Nevertheless, experience has shown repeatedly that mechanical harvesters, when operated by competent personnel and under proper conditions, can harvest cherries with a minimum of bruising. Most of the initial injury occurs in harvesting; this can vary from 8 to 32 percent (Whittenberger, et al., 1964). Brown, et al. (1994) indicated some of the problems in mechanical harvesting, and suggested that growers, harvester dealers, and harvester manufacturers have some management decisions to make in relation to the soft fruit problem. Harvesting, handling and holding conditions which are acceptable one year may not be acceptable in another year. Developing and adopting new methods that will reduce both harvest and post-harvest bruising will be very beneficial for the cherry industry.

APPENDICES

Figure A1. Schematic drawing of firmness measuring device

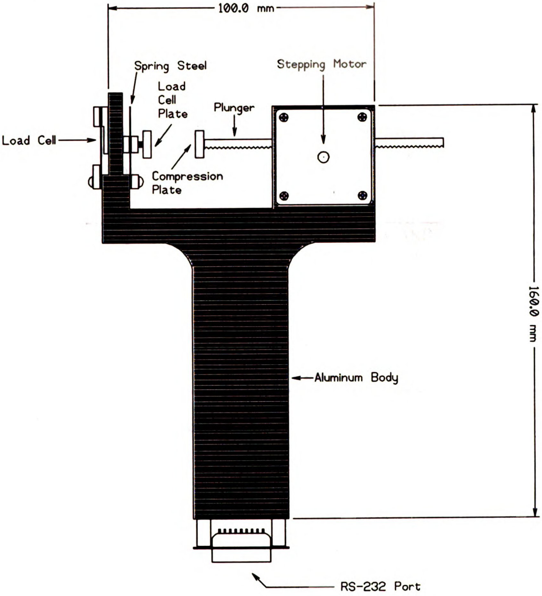

100.0 mm
Spring Steel
Load
Cell
Plate
Stepping Motor
Plunger
Load Cell
Compression
Plate
160.0 mm
Aluminum Body
RS-232 Port

Table A1. Effects of bruising on recovery of firmness (durometer units) of 'Montmorency' sour cherries on soaking in water for 5 hr at 12 °C (Burton, 1979).

No. of drops z	SOAKING	
	Before	After
0	43.6	42.4
1	38.3	39.7
2	34.9	33.9
3	26.7	29.5

z Dropped 3 ft to hard surface

Table A2. The effects of raising fruit temperature on the tree by enclosing limbs in plastic bags on firmness of 'Montmorency' cherry fruits before and after dropping onto a hard surface.

Orchard		TEMPERATURE	FIRMNESS (MCS units)		
	Ethephon	(°C)	Initial	Dropped	Δ
NWMS	-	39.5	50.2	41.7	8.5
		24	54.4	38.6	15.9
Cherry-Ki	+	41	45.2	34.2	11
		25.5	52.1	31.4	20.7

Table A3. Comparison of effects of hand vs. machine harvest on bruising (%) of 'Montmorency' sour cherry (Whittenberger, et al. 1964).

	BRUISING (%)	
Year	Hand	Machine
1962	4.8	8.3
1963	4.4	6.7
1964	17.0	19.4
Mean	8.7	11.5

Table A4. Firmness of hand harvested 'Montmorency' cherry fruits (MCS Units). Control fruits only (see Figs. 17,1,5) at three different locations (1993).

WEEK	BELDING (Ethephon)	HTRC (Shading)	NWMES (Irrigation)
1	65.7	56.2	57.9
2	62.8	53.7	59.7
3	54.3	58.1	59.8
4	54.3	55.5	53.4
5	55.7	62.3	57.3

Table A5. Effects of soaking treatments on percentage of cull fruit, pit loss and juice loss in 'Montmorency' cherries (Marshall, 1951).

TREATMENT	IMMATURE FRUIT				MATURE FRUIT			
Soaking(hr)	Cull fruit (%)	Pit loss (%)	Juice loss (%)	Total loss (%)	Cull fruit (%)	Pit loss (%)	Juice loss (%)	Total loss (%)
0	7.1	9.9	16.8	33.8	4.8	9.7	5.9	20.4
3	---	---	---	---	6.3	9.7	7.3	23.3
6	18.3	12.5	15.9	46.7	9.2	9.9	7.3	26.4

Table A6. Effects of mechanical harvesting and soaking in cold water for 6 hours on firmness (durometer units) of 'Montmorency' cherry fruit (Kenworthy, 1974).

Week	On Tree	Mech Harv	Soaked
Orchard 1			
1	51.4	43.2	53.9
2	45.0	37.0	47.4
Orchard 2			
1	50.4	37.6	47.2
2	52.9	39.5	44.6
MEAN	49.9	39.3	48.3

Table A7. Comparison of sour cherry fruit firmness (durometer units) at 3 dates over 4 years (Kenworthy, 1974).

		TIME OF HARVEST (week)		
YEAR	1	2	3	MEAN
1966	49.9	48.7	47.1	48.6 b [z]
1967	53.7	48.2	47.7	49.9 ab
1968	52.2	50.9	46.9	50.0 ab
1969	54.4	52.1	51.4	52.6 a
MEAN	52.6 A	50.0 AB	48.3 B	

[z] Mean separation (Tukey's test) following reanalysis of published data, using years and times of harvest as main effects.

Table A8. Range in firmness as affected by method of harvest and soaking in water for 4 hour (1994).

TREATMENT	MCS (g/mm)
Hand harvest	45-65
Mechanical harvest	
Before soaking	33-45
After soaking	37-52

Table A9. Effects of dropping hand-harvested sour cherry fruits on firmness (MCS units). Traverse City, 1994.

	Cultivar	
Treatment	Montmorency	Ujfehertoi furtos
Initial	55	78
After dropping		
3ft to hard surface	35-40	-
Same, then soaked 4 hr	40-50	-
3 ft, 3 times	Split	-
12 ft to hard surface	Split	42
12 ft to MW foam [z]	54	-
12 ft to "No Bruze" [y]	45	-

[z] Merryweather. 1-inch charcoal polyester foam, 2-pound density with a black skin.

[y] 1/2-inch "Softer No Bruze".

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