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EFFECTS OF BENZYLADENINE AND HAND THINNING ON SIZE OF STARKRIMSON 'DELICIOUS' APPLES, AND PREDICTION OF HARVEST SIZE.

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Joseph G. Masabni

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Frank [signature]

Major professor

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EFFECTS OF BENZYLADENINE AND HAND THINNING ON SIZE OF STARKRIMSON 'DELICIOUS' APPLES, AND PREDICTION OF HARVEST SIZE

By

Joseph Gebran Masabni

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ABSTRACT

EFFECTS OF BENZYLADENINE AND HAND THINNING ON SIZE OF STARKRIMSON 'DELICIOUS' APPLES, AND PREDICTION OF HARVEST SIZE

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Joseph G. Masabni

Starkrimson 'Delicious' is notorious for bearing small fruits as the trees age. Cytokinin application before anthesis, and hand thinning on various dates and to various densities were tested. Neither time of application nor concentration of BA affected size, length/diameter ratio or weight of fruits measured at harvest. Final set was dramatically reduced at 50 ppm. Hand thinning to 20 fruits/100 flower clusters increased size in one orchard, with thinning effective in another orchard when limbs were thinned on June 6 but not thereafter.

Fruit diameters were monitored in 3 Michigan orchards over 3 years. The data were used to prepare a prediction table for comparison with the Washington chart. In general, Michigan fruits grew more slowly than would be predicted from the Washington chart, the difference increasing with fruit size. Use of the new table allows prediction of harvest size of 50% of the fruits within 3 mm at 50 days after full bloom.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BA	Benzyladenine
CHES	Clarksville Horticulture Experimental Station
citowett	Alkylarylpolyoxy-glycolether (a surfactant)
ctrl	Control
DAFB	Days after full bloom
DMRT	Duncan's multiple range test
DNOC	Dinitro-ortho-cresol
GA	Gibberellic acid
in.	Inch(es)
l	Liter
Lc	Leaf conductance
L/D	Length/Diameter
LSD	Least significant difference
Mc	Mesophyl conductance
MI	Michigan
min.	Minute
mm.	Millimeter
μmols/m^2	Micromols per meter squared
μl	Microliter
NAA	Naphthaleneacetic acid
NAD	Naphthaleneacetamide
n.s.	Not significant
PAR	Photosynthetically active radiation
PlotIt	Interactive Graphics and Statistics Program, Copyright, 1987, Scott P. Eisensmith. Michigan State University.
Pn	Net photosynthesis
ppm	Parts per million
r	Correlation coefficient
r^2	Determination coefficient
RH	Relative humidity
s	Second
Sc	Stomatal conductance
Sevin	1-naphthyl N-methylcarbamate
Tween-20	Polyoxyethylene sorbitan monolaurate
VPD	Vapor pressure deficit
WA	Washington
WUE	Water use efficiency

Literature review

Fruit size is critical in determining the economic value of an apple crop, for price generally increases with fruit size. Mature trees of Starkrimson 'Delicious' tend to produce small fruit, therefore methods to improve fruit size are needed (8).

In this review, I will focus on the importance of cell division in determining size, on the effects of fruit thinning and chemical treatment on cell division and size in apple flowers and fruits, and on predicting harvest size.

A. Importance of cell division in determining apple fruit size

Apple fruits undergo both cell division and cell enlargement in the course of their development. Most of the cell division occurs within the first 4 weeks after anthesis, whereas cell enlargement continues until harvest.

In a study of cell size gradients and changes in cell shape and packing during development of 'Granny Smith' apple, Bain and Robertson (2) confirmed that cell division ceased within 4 weeks of pollination. Final size of fruits was proportional to cell number, whereas cell size was less important. Cell enlargement continued as long as the fruit remained on the tree. Martin and Lewis (20), on the other hand, reported that the difference in fruit size between light and heavy-bearing trees was due to differences in cell size rather than cell number.

Denne (11) measured cell size and calculated cell number in large and small unthinned fruits of "Cox's Orange Pippin" apple on M7 rootstocks. Both cell number and size increased as both crop load and fruit weight declined. The diameter of fruits on light cropping trees increased more rapidly than did that of fruits on heavily cropping trees (significant at 12 weeks after full bloom). Denne concluded from her observations that harvest size variation within trees was related to both cell size and number.

Goffinet (15) studied the relation between final size of 'Empire' fruits and cell size and number. Fruit diameter was highly correlated with both pith and cortex thickness (r^2 of .982 and .998, respectively). Total flesh thickness (cortex and pith) increased linearly with time until the last month before harvest. However, total cell layers in the flesh tripled the first 3 weeks, then increased more slowly, with the cortex having more cell layers than the pith at all times. Cell volume, on the other hand, in the cortex and pith increased rapidly starting about 4 weeks post bloom. Although the cells of cortex and pith expanded in volume at the same rate, they did so in different planes. Cortex cells expanded vertically and tangentially 10% more than did pith cells, but their radial expansion was 16% less.

B. Influence of fruit thinning and growth regulators on cell division in apple flowers and fruits

Starkrimson 'Delicious' is notorious for bearing small fruits as trees age. Previous work in Michigan (8) showed that fruit size was not improved by hand thinning in July. Estimates of costs/returns indicated that growers lost money by thinning even when the cost of hand labor was not included.

Westwood, Batjer and Billingsley (22) conducted several experiments to determine the effects of fruit thinning on cell size, number and specific gravity. They found that fruits on light-cropping trees had as many or more cells than those on heavy-cropping trees. NAA application increased cell number in 'Golden Delicious' fruits, probably because of selective thinning by NAA rather than stimulation of cell division. 'Delicious' and 'Jonathan' fruits in Washington had more but smaller cells than Australian fruits of the same cultivars.

Their work also showed that: a) early hand thinning usually stimulated cell division and sometimes cell enlargement, particularly in heavy-setting varieties; and b) DNOC blossom sprays increased fruit size mainly by increasing cell number rather than cell size.

Westwood, et al. (22) listed various factors which tend to increase cell size, including few cells/fruit, adequate soil moisture, strong spurs, center-bloom fruits, excess N fertilizer, late season thinning, healthy leaves and excessive chemical thinning. They advised growers, however, that fruits with many cells of medium size are preferable to those with fewer cells of large size.

Recently, Iftikhar (17) evaluated the effect of hand thinning of Starkrimson 'Delicious' apple on cell number and size of flowers the following year. Thinning affected neither cell size nor number. Cell number in "king" flowers was similar to that in lateral flowers. Although cell volume in "king" flowers was larger ($p < 0.01$), inter space was smaller ($p < 0.01$). Finally, Iftikhar observed that lateral flowers from trees in a mature orchard contained approximately the same number of cells as did those from a young orchard. Cell size, however, was smaller.

Goffinet, et al. (16) thinned 'Empire' trees at pink, bloom, and 10-, 20- and 40-days post bloom and compared cell size and numbers of fruits from unthinned and hand thinned trees. Control fruits were significantly smaller than those in any other treatment, with bloom-thinned fruits the largest. The latter contained slightly larger and greater numbers of cells than did control fruits. Regression analysis showed that fruit size was better correlated with cell number than with cell size or interspace.

Stembridge and Morrell (21) found that benzyladenine (BA) applied during bloom markedly increased development of the calyx lobes of 'Delicious' apple fruits. This resulted in a larger length/diameter (L/D) ratio. BA and gibberellins 4+7 (GA_{4+7}), applied at either pink or full bloom, also increased L/D ratio.

Martin, et al. (19) showed that major elongation of apples occurred when BA was applied at petal fall. According to the authors, differences in L/D ratio between control and treated branches were dramatic, visually noticeable without measurement.

Williams and Stahly (24) conducted a similar experiment in Washington. They used several cytokinins (zeatin, BA and phenylglycine) on 'Delicious' blossom clusters 4 days after full bloom. All cytokinin treatments significantly increased the L/D ratio, the greatest elongation being observed when cytokinin and GA_{4+7} were combined. High concentrations (500 ppm) of cytokinin and gibberellin resulted in overly prominent lobes which gave the fruits a knobby appearance.

Ferree, et al. (12), on the other hand, did not observe a significant difference in fruit shape following Promalin application.

C. <u>Effects of fruit thinning on size</u>

Early fruit removal reduces competition for carbohydrates and other nutrients thereby increasing fruit size and improving fruit quality and color. Thinning is essential for some cultivars, for it prevents biennial bearing. Fruits can be thinned either chemically or by hand. The most commonly used chemicals include DNOC (dinitro-ortho-cresol), NAA (naphthaleneacetic acid), NAD (n

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(naphthalene acetamide); and Sevin (1-naphthyl N-methylcarbamate).

Early thinning experiments demonstrated that tar oil distillates were most effective in killing flower buds (1). Later DNOC was shown to prevent pollen germination when applied to stigmata (18), thus initiating extensive research to determine the optimal concentration and time of application. When NAA and NAD were found to reduce harvest drop of apples (14), they were evaluated to determine whether they also increased set if applied during bloom (6). Rather than increasing set, NAA reduced set by up to 77% at 50 ppm (6). This shifted attention from DNOC to growth regulators. Considerable attention was given to timing of NAA sprays. Davidson, et al. (9) obtained effective thinning when the sprays were applied as late as 2-3 weeks after bloom. In 1958, an insecticide (Sevin) was found to possess thinning qualities in 'Delicious' and 'Winesap' apples. Batjer and Westwood (4) later reported that Sevin was a safe and effective thinning agent, rarely over- or under-thinning.

DNOC thinned apples equally well at full bloom and at early petal fall. Many growers, however, prefer to assess the degree of fruit set before applying chemical thinners, thus chemicals which can be applied later were tested. Consistent results were achieved when NAA and NAD were applied 15 to 25 days after full bloom, with Sevin being effective over a wider time period.

Consistent thinning results are achieved with cultivars that tend to set heavy crops, such as 'Golden Delicious', 'Jonathan', and 'Rome Beauty'. 'Delicious' and 'Winesap', on the other hand, do not set heavily on a regular basis, and overthinning often occurs (7).

Chemical thinning also reduces the biennial bearing habit of apples so that yield is more consistent from year to year. Although yield is reduced with chemical thinning, total yield over a period of years is generally slightly increased.

Various systems have been tested and used by growers in hand thinning, including uniform space thinning, graduated space thinning and removal of small fruits after "June drop".

D. Predicting harvest size

Not only does predicting harvest size early in the season help the grower decide whether any thinning is needed, but also allows estimation of crop size and storage volume needed, whether the crop should be sold for processing or fresh market and, most importantly, what prices to expect.

In an 8-year study, Davis and Davis (10) obtained high correlation coefficients between early and final diameters of cling peaches in California. They measured fruits at the beginning of the second growth period and at harvest, and calculated the correlation coefficients for initial vs.

final diameter for individual fruits, means of groups of 25 fruits and means of all trees for the season combined. In all 3 cases they obtained significant r values, ranging from 0.462 to 0.995. Not only did size at the beginning of the second growth stage correlate well with that at harvest, but little variability in sizing ability was observed. Therefore they recommended that growers and the industry use fruit size measurements to monitor thinning and estimate total yield.

Batjer, et al. (3) reported similar work on 'Winesap' and 'Delicious' apples. They found that r values for initial vs. final diameter of individual fruits increased as harvest approached, and that the harvest size of 75-80% of the fruits could be accurately predicted as early as 50 days after full bloom, with greater accuracy for larger fruits. The work of both Davis and Davis and Batjer, et al. encouraged a shift from thinning by spacing fruits uniformly on a branch to thinning by removing only the smaller fruits.

Williams, Billingsley and Batjer (23) found that final diameter could be accurately predicted for 83% of pear fruits to within 1/8 in. (3 mm) at 60 days from full bloom. However, the r values calculated were consistently higher for pears than those reported for apples (Batjer, et al. 1957), suggesting that greater confidence could be achieved in early season prediction of harvest size with pear.

Forshey's work (13) with 'McIntosh' apples in New York's Hudson Valley suggested that, under optimal growing conditions, fruits tended to increase in size at a fairly uniform rate, which makes possible an accurate estimate of final size several weeks before harvest. However, r values calculated for 55 days after full bloom were lower than the values reported by Batjer, et al. (3) for the same time. Forshey concluded that the marked differences were due to the highly variable growing conditions in the Northeast. He confirmed that size of large fruits was more accurately predicted and suggested that smaller fruits are affected more by unfavorable growing conditions such as moisture stress. Hand thinning is not a common practice with 'McIntosh'. Thus early season estimates of harvest size are of little importance in determining when to thin, but can be very useful in planning the order in which orchards are harvested and how fruits are to be marketed.

Blanpied (5) measured the weights and volumes of 10 average-sized apple fruits of 7 varieties at weekly intervals over two years. He correlated weekly change-in-volume vs. weekly change-in-weight for each variety and obtained a constant r value of 0.99 for the period of cell enlargement.

Cook (8) measured Starkrimson 'Delicious' fruits in mature Michigan orchards and prepared a table to predict harvest size. Values differed considerably from those in the Washington chart, indicating much slower rates of fruit growth in Michigan. However, he based his predictions on a linear, rather than a curvilinear, increase in diameter. Subsequent comparison of actual vs. predicted values indicated considerable error (unpublished data).

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Section I: Evaluation of Cytokinin Application to Apple Flowers for Increasing Fruit Size.

Evaluation of Cytokinin Application to Apple Flowers for Increasing Fruit Size.

Abstract

Starkrimson 'Delicious' is notorious for bearing small fruits as the trees age. One possible method of improving size would be to stimulate cell division early in the season. The cytokinin benzyladenine (BA) was therefore tested to determine its effect on harvest size. Neither timing nor concentration of BA applied as a branch spray before anthesis affected size, length/diameter ratio or weight of fruits measured at harvest. However, final set was dramatically reduced at 25 and 50 ppm.

Michigan growers often use "Promalin" (benzyladenine + GA_{4+7} mixture) to increase the length/diameter (L/D) ratio and thereby achieve a more "typey" 'Delicious' fruit, which is more marketable. However, both Promalin and benzyladenine (BA) alone often reduce set of apple (2,3). In many cases, high concentrations (50 to 100 ppm) have been used (5).

My purpose was to evaluate the effects of relatively low concentrations of BA (12.5, 25 and 50 ppm) on set and fruit size in Starkrimson 'Delicious', when applied before full bloom. If cytokinins were to increase cell division in the treated flowers, then the fruits might become stronger sinks, hence increasing set and fruit size.

Materials and Methods

In 1987, five mature (25- to 30-year-old) Starkrimson 'Delicious' trees on seedling rootstocks were chosen in a commercial orchard at Leslie, MI. Trees were of uniform vigor and canopy size. Although the trees were not irrigated, they did not appear to be water stressed during the course of the study. Pruning had been minimal, therefore some of the branches were removed at bud swell to reduce competition.

A randomized complete block design was used with whole trees as blocks. Branches of good vigor and bloom were chosen for treatment. BA was applied (a) at pink (April 21) , (b) when king flowers were open (April 30), and (c) on both dates. Full bloom was approximately on May 5. The concentrations of BA used were 0, 12.5, 25 and 50 ppm, and all solutions contained a surfactant (Tween-20, polyoxyethylene sorbitan monolaurate, 0.1%). Controls included both non-treated limbs and limbs sprayed with surfactant alone. These treatments were arranged in a 3 (date) x 5 (BA) factorial, and each was applied to one randomly selected limb on each tree. The tagged limbs were sprayed on the designated dates using a 2-gallon knapsack sprayer and a plastic screen to reduce drift. Fruit diameter and number were recorded 29, 63, 73, 91, 105, and 141 days after full bloom (DAFB). Fruits on the tagged limbs were harvested and weighed on September 23 (141 DAFB). Analysis of variance was performed for initial set (May 28), final set (September 23), fruit diameter on each of 6 dates of measurement, and fruit weight at harvest.

On some limbs, all fruits abscised before harvest. Due to this loss of replicates, analysis of variance of all variables, except initial and final set, excluded values for Tween-20 and 50 ppm BA.

Results

Initial set on unsprayed controls was sufficiently heavy to warrant chemical thinning by the grower. However, the experimental trees were not spray thinned. Fruit set on May 28 varied from 16 to 33 fruits per 100 flower clusters among treatments and across dates of application. However, differences among means for treatment and date effects and the interaction of date and time of application were not significant at 5% (Table 1). 50 ppm appeared to reduce set, but differences were not significant at 5%.

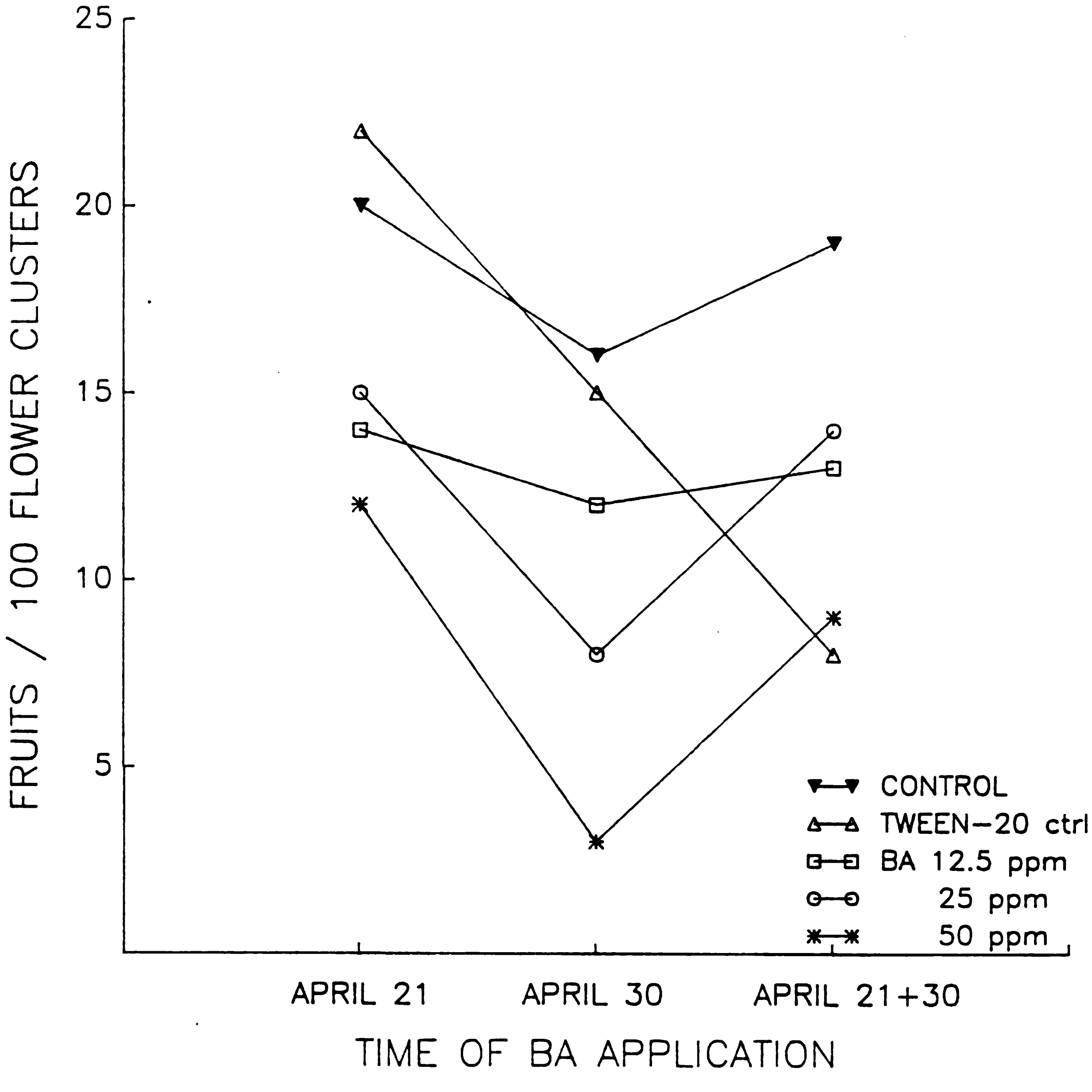
A heavy "June drop" occurred, approximately 40% of the fruits on the controls falling at this time (Table 1). Set on limbs sprayed with 12.5 ppm was not affected; that on limbs sprayed with 25 ppm was significantly reduced relative to unsprayed controls, but not in comparison with the Tween control. However, 50 ppm dramatically reduced set, an average of only 8 fruits per 100 flower clusters reaching maturity, with all the fruits abscising from approximately 25% of the branches by mid-season (data not shown). An average of 3 fruits per 100 clusters reached maturity following treatment with 50 ppm BA on April 30 (Table 1). In neither case was the interaction between BA concentration and date of application significant at the 5% level (Fig. 1). However, set was consistently lower for the April 30 treatment than for the April 21 or double application except for the treatment with Tween-20 alone. In this one case, set was lowest following the double application.

Table 1. Influence of BA on initial and final set of Starkrimson 'Delicious' apple, Leslie, MI. 1987.

Treatment	Time of application			BA mean
	4/21	4/30	4/21+4/30	
	Initial fruits/100 clusters, May 28			
Control	31	28	34	31
Tween-20	33	28	16	25
BA, 12.5 ppm	33	28	19	27
25 ppm	32	30	25	29
50 ppm	21	17	21	19 ns
Timing mean	30	26	23 ns	
	Final fruits/100 clusters, September 23			
Control	20	16	19	18 a[z]
Tween-20	22	15	8	15 a
BA, 12.5 ppm	14	12	13	13 ab
25 ppm	15	8	14	12 b
50 ppm	12	3	9	8 b
Timing mean	17 l	11 m	13 lm	

z-Mean separation within sets (abc, lmn), by DMRT, 5% level. Treatment X time of application interaction was non-significant in all cases.

FIG. 1. EFFECTS OF BA CONCENTRATION AND TIME OF APPLICATION IN AFFECTING FINAL FRUIT SET OF STARKRIMSON 'DELICIOUS' APPLE. SEPTEMBER 23, 1987



25
20
15
10
5
FRUITS / 100 FLOWER CLUSTERS
CONTROL
TWEEN-20 ctrl
BA 12.5 ppm
25 ppm
50 ppm
APRIL 21
APRIL 30
APRIL 21+30
TIME OF BA APPLICATION

Harvest diameter was small (about 67 mm or 2.50 in.), despite the light crop. BA did not affect fruit diameter significantly regardless of concentration or timing (Table 2). Data for only 3 representative dates (29, 91 and 141 DAFB) are presented in Table 2 for simplicity; results for the other 3 dates were similar. Although both Tween-20 alone and 50 ppm BA were not included in the statistical analysis because of loss of replicates, visual comparison of results across date and time show no consistent differences in fruit size.

Fruit weight at harvest was likewise not significantly affected by BA treatments (Table 3). 50 ppm appeared to increase fruit weight compared to other concentrations, but loss of replicates prevented statistical analysis.

Available data for fruit weight and diameter at harvest for 50 ppm and Tween-20 treatments were paired with appropriate control data and analysis of variance performed. Neither date of BA application nor concentration had any effect on weight of fruits at harvest (data not shown).

Time of BA application did not affect either fruit weight or L/D ratio (Table 3). No BA treatment increased L/D ratio. The largest values were 1.048 (control, 4/21) and 1.060 (Tween-20, 4/30).

Table 2. Influence of BA on fruit diameter (mm) of Starkrimson 'Delicious' apple, Leslie, MI. 1987.

Treatment	Time of application 4/21	4/30	4/21+4/30	BA mean
	Fruit diameter (mm), June 3			
Control	25	25	25	25
Tween-20	(26)[z]	(25)	(25)	(25)
BA, 12.5 ppm	25	25	25	25
25 ppm	25	24	25	25
50 ppm	(25)	(24)	(25)	(25) ns
Timing mean	25	25	25 ns	
	Fruit diameter (mm), August 4			
Control	58	58	58	58
Tween-20	(57)	(55)	(57)	(56)
BA, 12.5 ppm	58	56	56	57
25 ppm	56	59	58	58
50 ppm	(55)	(55)	(58)	(56) ns
Timing mean	57	57	57 ns	
	Fruit diameter (mm), Sept. 23			
Control	68	67	67	67
Tween-20	(65)	(64)	(67)	(65)
BA, 12.5 ppm	68	66	66	67
25 ppm	65	68	68	67
50 ppm	(63)	(66)	(67)	(65) ns
Timing mean	67	67	67 ns	

z- Data in parentheses were not included in statistical analysis and are excluded from the means for main effects because of loss of replicates.

No effects were significant at the 5% level by DMRT.

Treatment X time of application interaction was non-significant in all cases.

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Table 3. Influence of BA on fruit harvest weight (g) and length/diameter (L/D) ratio of Starkrimson 'Delicious' apple, Leslie, MI. 1987.

Treatment	Time of application 4/21	4/30	4/21+4/30	BA mean
	Fruit weight (g), Sept. 23			
Control	127	123	116	122
Tween-20	(131)[z]	(134)	(141)	(135)
BA, 12.5 ppm	121	131	107	120
25 ppm	120	118	144	127
50 ppm	(135)	(140)	(147)	(141) ns
Timing mean	123	124	122 ns	
	Fruit L/D ratio, Sept. 23			
Control	1.048	1.013	0.955	1.005
Tween-20	(0.980)	(1.060)	(0.990)	(1.013)
BA, 12.5 ppm	0.972	0.970	0.969	0.971
25 ppm	0.987	0.980	0.993	0.987
50 ppm	(0.980)	(1.020)	(1.000)	(1.000) ns
Timing mean	1.002	0.988	0.972 ns	

z- Data in parentheses were not included in statistical analysis and are excluded from the means for main effects because of loss of replicates.

No effects were significant at the 5% level by ANOVA.

Treatment X time of application interaction was non-significant in all cases.

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Discussion

My goal was to increase harvest size by enhancing cell division during the early stages of fruit development. BA was applied before full bloom in order to avoid a reduction in set. However, 25 ppm BA reduced final set. On the other hand, even the highest concentration of BA (50 ppm) did not affect fruit shape, size or harvest weight. The significant difference between means for April 21 and April 30 vs. no difference between April 21 and the double application is probably an artifact.

Although initial set was not reduced significantly, final set was drastically reduced by high concentrations of BA. The heavier "June drop" on sprayed limbs may have resulted from stress. BA-treated fruits may have been more susceptible to adverse conditions and thus abscised more readily.

The Tween-20 treatment applied at both pink and king bloom also reduced final set slightly (not significant at 5%). Noga and Bukovac (4) found that the surfactant Citowett an alkylarylpolyoxy-glycolether (0.1%) increased the abscission of young apple fruits; Tween-20 was also effective, but only at 10 times this concentration. Thus, Tween-20 may have had a detrimental effect on response to BA in my work. All BA solutions contained Tween-20 and therefore all double applications should have reduced set more than single applications.

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My results confirm those obtained by Ferree, et al. (2), although they used Promalin while I used BA. My data show that BA reduces set in apple, the effect increasing with concentration, with little or no effect on fruit shape or fruit size. Even low concentration (25 ppm) significantly reduced set (Table 1).

Finding chemicals which increase fruit size without reducing set could give the fruit grower a valuable tool to increase production and financial returns. This remains a goal in future research.

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Section II: Effect of Timing and Degree of Hand Thinning Starkrimson 'Delicious' Apple Fruits on Harvest Size

Effect of Timing and Degree of Hand Thinning Starkrimson 'Delicious' Apple Fruits on Harvest Size

Abstract

Hand thinning generally increases apple fruit size, the effect decreasing as thinning is delayed. In order to determine the effects of both time and degree of thinning in mature Starkrimson 'Delicious', experiments were conducted in two Michigan orchards. Moreover, photosynthesis was measured to evaluate the influence of thinning on net photosynthetic rates. Hand thinning increased size in one orchard, with a threshold of 20 fruits/100 flower clusters needed for significant effects. Thinning was effective in the second orchard when limbs were thinned on June 6, but not thereafter. Regression lines for other treatments/orchards were non-significant. Effects of thinning on net photosynthesis were inconsistent.

Thinning has been used for centuries to increase fruit size. As early as 1927, Chandler and Heinicke (3) proved through chemical analyses that fruiting is an exhaustive process. Flower and fruit production deplete the tree of carbohydrates, nitrogenous compounds and minerals. Heavy fruiting may prevent a weak tree from surviving the following winter, and increases its susceptibility to insect or disease injury. Other benefits of thinning include reduction of limb breakage due to over-loading and the removal of diseased and insect-injured fruits.

Probably the two most important benefits from thinning are the regulation of biennial bearing and the increase in size of the remaining fruits. Traditionally, apple fruits are thinned to a determined space, usually 6-8". However, Batjer et al. (2) showed that size thinning - -the removal of undersized fruits at any date- - gave better results. This method rests on the principle that "once a small fruit, always a small fruit". Hence early removal of smaller fruits will allow the remaining fruits to grow to a marketable size. Today, size prediction charts are available for Washington growers to help predict harvest size and determine whether or not thinning is necessary.

If 'Delicious' apples set a heavy crop one year, flower initiation may be reduced. Reducing the crop load early in the season allows fruiting spurs to flower the next year. About 30-40% of the spurs should flower in a given year in order to assure annual cropping (1,9). Three methods of thinning are practiced, namely hand, mechanical and chemical thinning. Chemical thinning using dinitro-ortho-cresol (DNOC), naphthalene-acetic-acid (NAA), naphthalene-acetamide (NAD) or 1-naphthyl N-methylcarbamate (Sevin) has proven to be the most convenient method. However, rates and times of application vary from one area to another. Mechanical thinning by shaking or "club-thinning" removes fruits effectively in peach, but cannot be used for apples because of mechanical injury. Finally, hand thinning is still practiced by many growers despite the high labor cost; it is normally performed as a supplement to chemical thinning.

Cook (4) reported that Starkrimson 'Delicious' fruit did not increase in size when thinned after June drop. Because reduction of yield was not balanced by increases in fruit size, thinning reduced income.

Hansen (6,7) has presented evidence that apple fruits acting as "sinks" accelerate the translocation out of nearby leaves of ^{14}C-labeled assimilates. The photosynthetic intensity of such leaves exceeds that of leaves on nonbearing spurs. Gucci (5) demonstrated that net photosynthesis (Pn) in sour cherry leaves dropped after fruit removal at the end of stage III.

The purpose of my study was to determine the effect on final fruit size of thinning Starkrimson 'Delicious' to various levels and at different dates early in the season. My goal was to determine when thinning was effective and what level of thinning was necessary. Moreover, in order to better understand what effect thinning has on "sink strength" and on CO_2 assimilation, photosynthetic rates were measured on thinned and nonthinned limbs.

Materials and Methods

Mature Starkrimson 'Delicious' trees were used in evaluating both degree and timing of thinning. Two orchards, one at Hartford (Dowd orchard, South-west Michigan), and another at Belding (Wittenbach orchard, West-central Michigan) were used.

The trees were 25-30 years old in 1987 and bore a good bloom (60% and 90% of the terminal buds flowering on shoots and spurs in the Dowd and Wittenbach orchards, respectively). Two separate experiments were conducted at each of the two locations in the spring of 1987. The density of thinning experiment, performed about 2 weeks after full bloom, consisted of adjusting fruit load to 3 levels (30, 20, or 10 fruits per 100 flower clusters) for comparison with non-thinned limbs. Actual fruit numbers after "June drop" are given in Table 1. The trees were thinned on May 21 (16 days after full bloom (DAFB)) in the Dowd orchard and on May 25 (15 DAFB) in the Wittenbach orchard. The same experimental design was adopted at both locations, the only difference being the use of 5 replicate trees in the Dowd orchard, 4 in the Wittenbach orchard. Uniform trees were chosen in one row and the treatments were randomly assigned to individual scaffold limbs. The limbs were large and extended back to the main trunk, hence were considered to be independent from one another. A randomized complete block design was used with whole trees as blocks, each tree containing the four treatments.

Table 1. Fruit density in September on limbs used for fruit thinning experiments. 1987.

Orchard	Experiment	Fruit density (fruits / 100 flower clusters)	
		Intended	Actual
Dowd	Timing	-	37
		30	23,32,29^{z}
	Density	-	59
		10,20,30	11,20,31
Wittenbach	Timing	-	73
		30	38,31,33^{z}
	Density	-	88
		10,20,30	15,24,34

^{z}- Values for 1st, 2nd, and 3rd dates of thinning, respectively.

Underlined value denotes the treatment not used in Pn measurements.

The same statistical design was used for the time of thinning experiment, with thinning on various dates as treatments. Fruits were thinned approximately 2, 4, and 8 weeks after full bloom in the Dowd orchard, and 2, 4, and 6 weeks after full bloom in the Wittenbach orchard. "June drop" occurred about 4 to 5 weeks after full bloom, therefore limbs were thinned before, during and after "June drop" in both locations.

Final fruit set on non-thinned limbs was 37 and 73 fruits per 100 clusters in the Dowd and Wittenbach orchards, respectively. Fruit load after hand thinning averaged 28 fruits per 100 flower clusters in the former and 34 fruits per 100 flower clusters in the latter.

Fruit diameters were measured using a hand caliper (Cranston Machinery Co., Oak Grove, OR) on various dates throughout the season. Statistical analysis (ANOVA and regression) was performed separately for each experiment and orchard.

In order to evaluate the effects of timing and severity of thinning on photosynthesis, readings were taken on two occasions (August 6 and September 3) in the Dowd orchard, and on one occasion (September 4) in the Wittenbach orchard. Because some treatments were located on the north side of the tree where light levels were not saturating (PAR < 1000 μmols/m2/s), Pn readings were not available for all treatments on all dates. Leaf area, ambient CO_2, relative humidity (RH) in the chamber, ambient RH, leaf temperature, differential CO_2 and photosynthetically active radiation (PAR) were recorded for each leaf, using a portable open gas exchange system equipped with a Parkinson broad leaf chamber (model ADC LCA-2, Analytical Development Co., Hoddesdon, England) operated at the following conditions: saturating light intensity, PAR > 1000 μmols/m2/s, ambient CO_2 of 330 to 340 μl/l, inlet relative humidity (RH) 6-11%, as by Gucci (5). A BASIC program (8) was used to convert the raw data to CO_2 assimilation, VPD, leaf conductance, stomatal conductance, transpiration and internal CO_2.

Table 1 lists the intended and actual fruit densities in all treatments.

Results

Effect of fruit density on fruit size: In the Dowd orchard, initial fruit set was only moderate (59 fruits/100 clusters) and thinning to 30 fruits/100 clusters had no effect on fruit diameter as measured on various dates throughout the season (Table 2). However, thinning to 20 and 11 fruits/100 clusters increased size significantly relative to the control treatment on all dates from 69 to 140 DAFB. Differences among thinning treatments were generally non-significant. Regression analysis performed for orchard 1 showed no significant correlation (r^2=0.22) at the 5% level between severity of thinning and fruit diameter at harvest (Fig. 1A).

Data for only 3 of the 4 replicates were available for regression analysis in the Wittenbach orchard. Hand thinning did not affect fruit size relative to controls at any date of measurement (Table 2). Regression analysis, in fact, showed an increasing trend in harvest size as fruit density increased (r^2=0.12, n.s. at 5%) (Fig. 1B).

Effect of time of thinning on fruit size: In the Dowd orchard, a heavy "June drop" reduced fruit density on control limbs to a level similar to that on thinned limbs (Table 1). Thinning to an average of 28 fruits/ 100 clusters did not affect fruit size regardless of timing (Table 3). Although average diameters recorded for fruits thinned on June 6 and July 2 (32 and 29 fruits/100

Table 2. The effects of hand thinning Starkrimson 'Delicious' apple to various levels 15 to 16 days after full bloom on fruit diameter (mm) at harvest. 1987.

Orchard	Fruits/100 flower clusters	Date of measurement (DAFB)				
		57	69	92	119	140[z]
Dowd	59 (control)	44 ns	51 a[y]	59 a	65 a	66 a
	31	45	52 ab	60 a	66 ab	68 ab
	20	47	54 b	63 b	69 b	71 b
	11	47	54 b	63 b	68 b	70 b
		19	49	105	140[z]	
Wittenbach	88 (control)	11 ns	35 ns	58 ns	65 ns	
	34	11	34	58	62	
	24	11	35	58	62	
	15	11	35	60	65	

[z]-Harvest date.
[y]- Mean separation within orchards and dates of measurement by LSD (5%).

FIG. 1a,b. REGRESSION OF FRUIT DIAMETER ON FRUIT DENSITY IN THE DOWD (A), AND THE WITTENBACH ORCHARD (B) MICHIGAN 1987. NUMBERS INDICATE FRUITS PER 100 FLOWER CLUSTERS FOR EACH TREATMENT

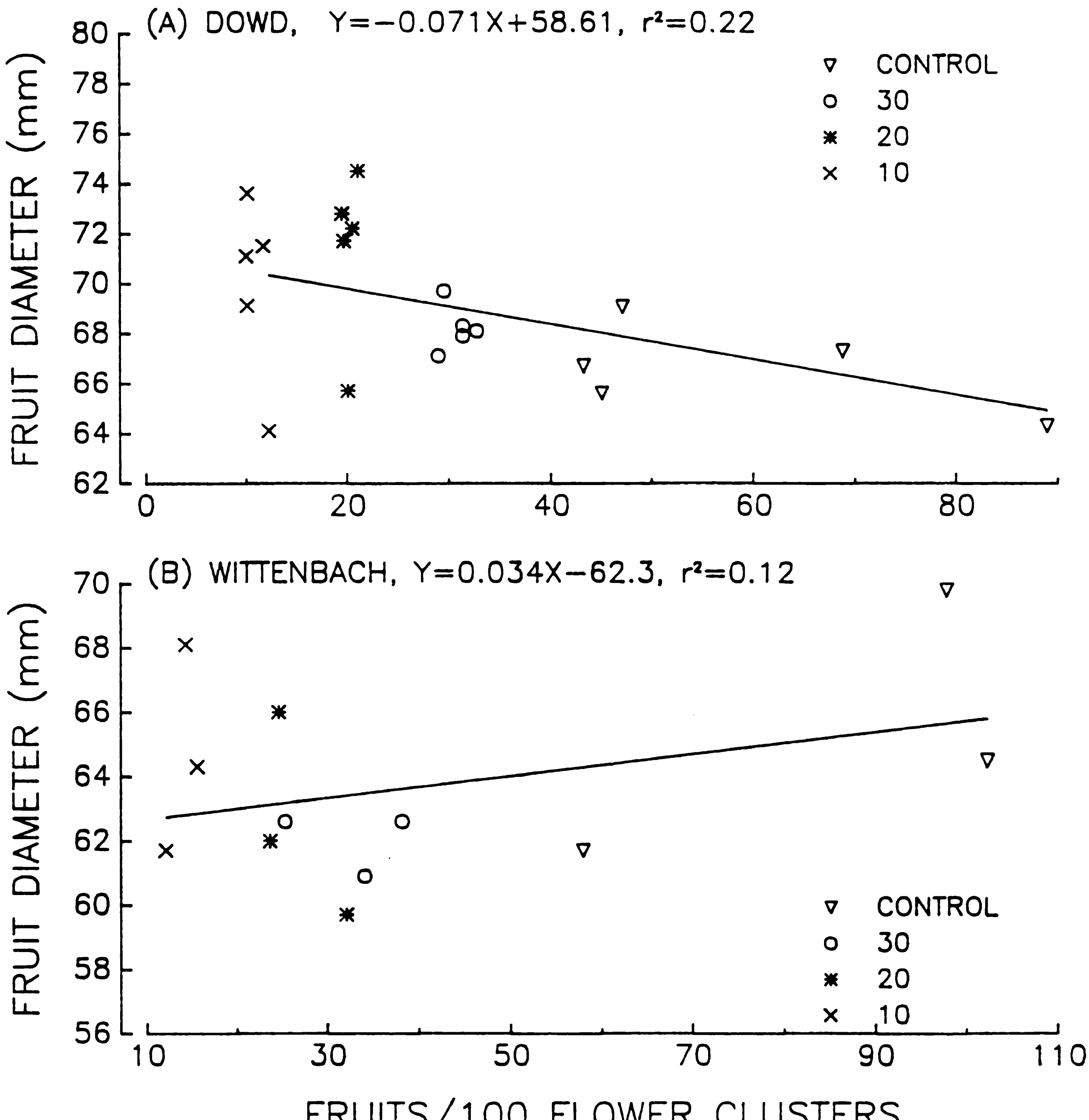
(A) DOWD, Y=-0.071X+58.61, r²=0.22
CONTROL
30
20
10
FRUIT DIAMETER (mm)
80
78
76
74
72
70
68
66
64
62
0
20
40
60
80
(B) WITTENBACH, Y=0.034X-62.3, r²=0.12
70
68
66
64
62
60
58
56
10
30
50
70
90
110
FRUITS/100 FLOWER CLUSTERS

Table 3. The effect of time of hand thinning[z] Starkrimson 'Delicious' apple to 30 fruits per 100 flower clusters on various dates on harvest diameter. 1987.

Orchard	Time of thinning (DAFB)	Date of measurement (DAFB)				
		57	92	119	140[y]	
Dowd	-	42 ns	56 ns	62 ns	64 ns	
	10	43	57	63	65	
	31	45	60	65	67	
	57	45	60	66	67	
		49	70	105	120	140[y]
Wittenbach	-	33 ns	43 a[w]	53 a	57 a	58 a
	16	35	46 ab	58 b	62 b	64 b
	31	34	46 ab	58 b	61 ab	64 b
	45	35	48 b	60 b	63 b	66 b

[z]-Limbs were thinned to an intended density of 30 fruits/100 flower clusters. See Table 1 for actual values.

[y]-Harvest date.

[w]- Mean separation within orchards and dates of measurement by LSD (5%).

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clusters, respectively), were larger than control values, the difference was non-significant at the 5% level. Regression analysis performed for measurements taken on September 24 (harvest date) was likewise non-significant (r^2=0.15) (Fig.2A).

In the Wittenbach orchard, where final set on control limbs was heavier, all treatments increased final size. Regression of harvest size on date of thinning gave an r^2 of 0.31, significant at 5% (Fig. 2B).

Effects of thinning on photosynthesis and water relations: In the Dowd orchard, thinning to 29 fruits per 100 flower clusters on July 2 (57 DAFB) significantly increased CO_2 assimilation rates, vapor pressure deficit (VPD), and water use efficiency (WUE) (Table 4). The apparent lower stomatal conductance in thinned branches may explain their higher WUE rates, since partial closing of the stomata would reduce the rate of transpiration.

CO_2 assimilation readings for the same treatments recorded on September 3 paralleled those for August 6 (Table 4). Thinning on May 16 (10 DAFB) also increased assimilation whereas thinning on June 6 (31 DAFB) did not. The only other significant effects of the May and July treatments on September 3 were increases in transpiration and mesophyll conductance.

FIG. 2a,b. REGRESSION OF FRUIT DIAMETER ON FRUIT DENSITY IN THE DOWD (A), AND THE WITTENBACH ORCHARD (B) FOLLOWING THINNING ON 3 DATES, MICHIGAN, 1987

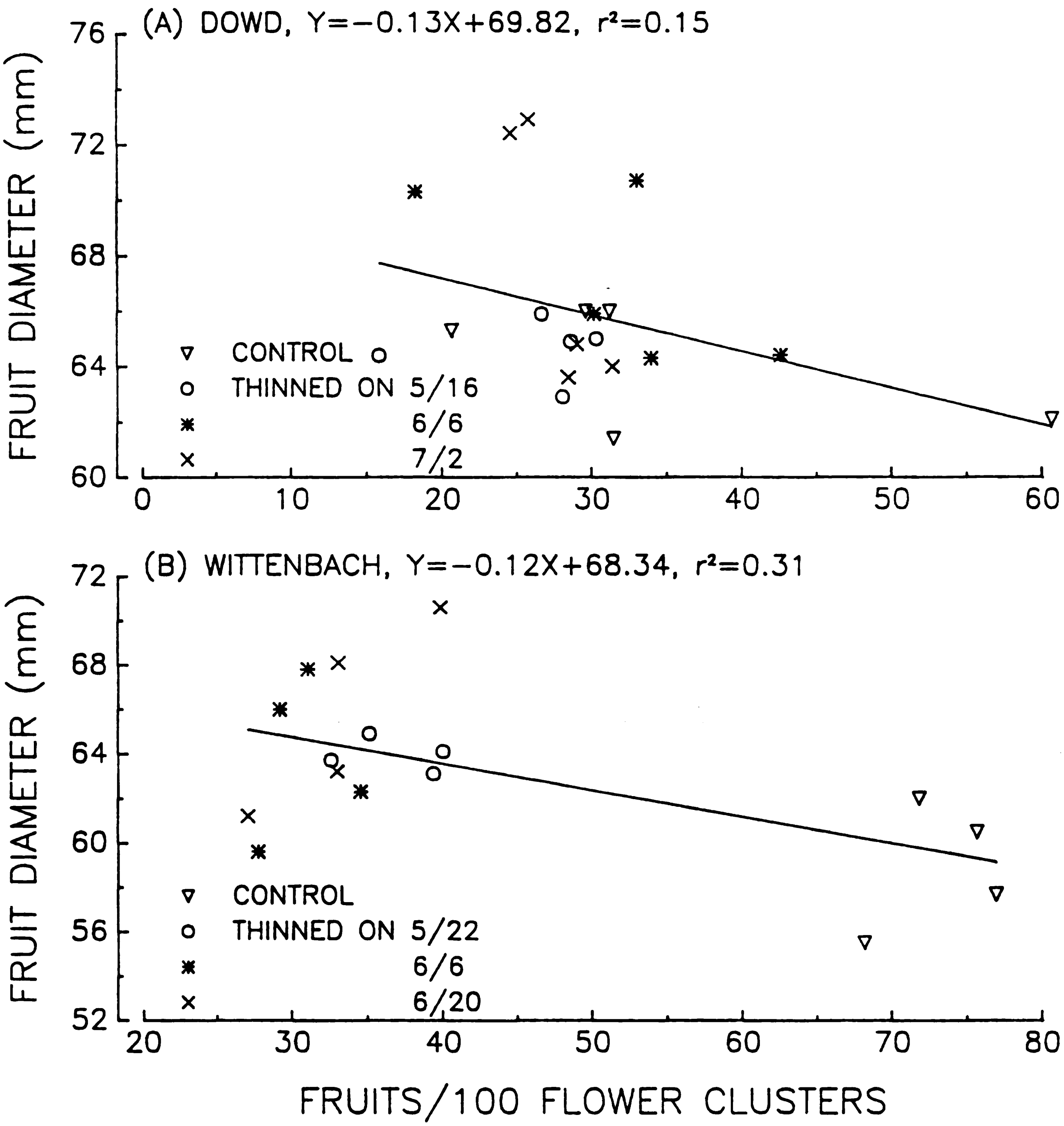
(A) DOWD, Y=−0.13X+69.82, r²=0.15
FRUIT DIAMETER (mm)
76
72
68
64
60
0
10
20
30
40
50
60
CONTROL
THINNED ON 5/16
6/6
7/2
(B) WITTENBACH, Y=−0.12X+68.34, r²=0.31
FRUIT DIAMETER (mm)
72
68
64
60
56
52
20
30
40
50
60
70
80
CONTROL
THINNED ON 5/22
6/6
6/20
FRUITS/100 FLOWER CLUSTERS

Table 4. Effects of hand thinning on Pn and related parameters in two Starkrimson 'Delicious' orchards in 1987.

Orchard	Date	Time thinned (DAFB)	Fruits per 100 clusters	Assimilation μmols/dm^2/hr	VPD KPa/m^2/s	L_c	S_c	Trans.	M_c	WUE μmol CO_2/mol H_2O
						millimols/dm^2/hr				
Dowd										
	8/6	-	37	8.9 b[z]	1.94 b	318.5	199.0	6.1	32.9	1.47 b
		57	29	13.4 a	2.12 a	251.6	157.3	5.3	38.5	2.37 a
	9/3	-	37	8.8 b	2.12	204.3	127.7	4.4 b	35.5 b	1.99
		10	23	13.2 a	2.15	232.1	145.1	5.1 a	57.5 a	2.66
		31	32	8.9 b	2.13	226.1	141.3	4.9 a	36.6 b	2.71
		57	29	11.9 a	2.15	225.5	140.9	4.9 a	52.3 a	2.40
	9/3	-	59	11.3 ab	2.91	189.9	118.7	5.6	50.3 ab	1.98 b
		16	20	10.5 b	2.80	206.9	129.3	5.9	45.4 b	1.77 b
		16	11	14.5 a	2.69	219.5	137.2	6.0	69.9 a	2.40 a
Wittenbach										
	9/4	-	73	13.9	2.13 b	247.3 a	154.6 a	5.4 ab	61.4	2.58 ab
		16	38	14.0	1.91 c	252.1 a	157.6 a	4.9 c	59.6	2.89 a
		31	31	13.5	2.23 b	225.7 b	141.1 b	5.1 bc	61.9	2.65 ab
		45	33	12.1	2.42 a	227.1 b	142.0 b	5.6 a	56.8	2.19 b
	9/4	-	88	13.0	2.33 c	231.3 a	144.5 a	5.5 b	62.2	2.36
		15	34	12.6	3.20 a	175.3 b	109.6 b	5.8 b	70.3	2.22
		15	24	12.5	2.91 b	219.2 a	137.0 a	6.6 a	61.8	1.87
		15	15	12.3	3.33 a	159.7 b	99.8 b	5.4 b	69.2	2.28

[z]- Mean separation within columns and dates by DMRT at $p < 0.05$.

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Although CO_2 assimilation was about 38% higher on September 3 in branches thinned to 11 fruits per 100 clusters than in those thinned to 20, neither treatment had a significant effect relative to the control.

Thinning did not affect CO_2 assimilation in September in the Wittenbach orchard regardless of timing or fruit density (Table 4). Thinning to 24 fruits per 100 clusters on May 22 significantly increased the transpiration rate on September 4, but all other differences were non-significant.

Thinning to 34 fruits per 100 clusters in May increased VPD and decreased both leaf and stomatal conductance in the fruit density experiment, whereas the same treatment reduced VPD and had no effect on leaf or stomatal conductance for the first date of thinning in the timing experiment. Thus the data for the two experiments are contradictory. Thinning consistently increased VPD regardless of fruit density, but effects upon leaf and stomatal conductances were inconsistent.

Discussion

In the Dowd orchard, hand thinning 16 DAFB significantly increased fruit size provided fruit density was reduced to 20 fruits per 100 clusters or less. Significant differences were observed as early as 69 days after full bloom (Table 2). The same treatments were ineffective in the Wittenbach orchard, despite considerably heavier fruit set on control limbs (final fruit density 88 per 100 clusters vs. 59 in the Dowd orchard).

The goal of the severity of thinning experiment was to reduce fruit density to 30, 20, and 10 fruits/ 100 clusters. The actual densities were 34, 24, and 15 fruits/ 100 clusters, respectively (Table 1). Because thinning was applied to individual limbs rather than whole trees, fruit load on the rest of the tree may have influenced fruit size on the thinned limbs.

Thinning to 28 fruits per 100 clusters had no effect on fruit size in the Dowd orchard regardless of timing (Table 3). This was probably due to a moderate "June drop" which reduced density of fruits on control limbs to a value lower than that observed in the Wittenbach orchard.

A notable "June drop" did not occur in the Wittenbach orchard, and thinning increased fruit size (Table 3). Unexpectedly, thinning on June 20 (45 DAFB and about 2 weeks after "June drop") was as effective as earlier treatment. The significant effects of hand thinning on size in this experiment may have been anomalous, for the control fruits on these trees were smaller than those on trees used in the density experiment (compare diameters of control fruits in Table 2 vs. Table 3). This could have resulted from errors in sampling.

No Pn readings were taken within 30 days of thinning. Effects on Pn in August and September were inconsistent. Thinning to 10 fruits/ 100 clusters on or soon after "June drop" increased CO_2 assimilation in one orchard but not in the second. Although Hansen (6) obtained a negative correlation between leaf/fruit ratio and percent ^{14}C assimilated, a positive correlation was observed in the Dowd orchard in both August and September.

Pn rates could have declined soon after thinning, then returned to rates comparable to controls as the season progressed. Considering that limb rather than whole tree treatments were used in my studies, any thinning effect could have been masked by the presence of fruits on the rest of the tree. This idea is supported by lack of consistent effects of thinning on fruit size.

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<u>Section III</u>: Predicting Fruit Size of Starkrimson 'Delicious' Apple in Michigan

Predicting Harvest Size of Starkrimson 'Delicious' Apple in Michigan

Abstract

Charts are currently used to predict harvest diameters and box sizes of fruits of 'Delicious' and other apple cultivars in Washington State. To determine if these data were applicable to Starkrimson 'Delicious' under Michigan conditions, fruits were measured at intervals from July 1 to harvest in 3-4 mature orchards over a 3-year period. Growth curves were constructed for fruits with harvest diameters of 2.25, 2.50, 2.75, and 3.00 inches (57, 64, 70 and 76 mm, respectively) by using regression analysis. In general, Michigan fruits grew more slowly than would be predicted from the Washington charts, and the difference was greater for large than for small fruits. However, considerable variability was evident from orchard to orchard, and no single curve was applicable to all orchards. Comparison of prediction curves for fruits borne by young vs. mature trees indicated little difference in one case, anomalous results in another. A fruit size prediction table has been prepared for use by Michigan growers.

Starkrimson 'Delicious' is notorious for bearing small fruits as trees age. Cook (2) reported that fruit size was not improved by hand thinning in July. This work prompted me to develop harvest size prediction curves to assist growers in decision making.

Earlier work by Davis and Davis (4) demonstrated high correlation coefficients between early and final diameters of cling peaches in California. Therefore, accurate prediction of size early in the season is possible.

Similar results were reported by Batjer, et al. (1) for 'Delicious' and 'Winesap' apples. R values increased as the season progressed, allowing size for 75-80% of the fruits to be accurately predicted as early as 50 days after full bloom (DAFB). Although accuracy was less for 'Delicious' than for 'Winesap', diameters of 40% of the fruits could be predicted within ± 3 mm at 50 DAFB; this value increased to 80% by 100 DAFB. Other researchers have confirmed the possibility of predicting harvest size of pear (8) and of 'McIntosh' apple (5). The Washington chart is currently used by Michigan apple growers to predict harvest diameter of 'Delicious' and 'Winesap' fruits. The purpose of my work was to determine whether the Washington chart is applicable to Starkrimson 'Delicious' under Michigan conditions, and, if not, to develop a new chart to meet the needs of Michigan growers .

Materials and Methods

Diameters of Starkrimson 'Delicious' were measured in several commercial Michigan orchards during 1986 and 1987. R.L. Cook provided 1985 data for some of the same orchards. The orchards were located near Leslie in South Central Michigan and Belding in Western Michigan. Table 1 lists location and age of the orchards used in this study in 1985-1987. Young Starkrimson 'Delicious' trees at the Clarksville Horticultural Experiment Station (CHES) and mature trees in the Kraft and Wardowski orchards were used in 1987 only. Data from orchards in the same general area were recorded on the same dates.

The mature trees used were 17 to 29 years old, of good vigor and bearing moderate to heavy crops. Management systems and cultural practices differed from one orchard to another. Five to eight trees were chosen in each orchard. Two branches per tree were chosen, one on the north, the other on the south side. The branches selected were well exposed to light and 4 to 10 feet from the ground. Because the south side intercepts more light than the north, fruits on the former side were expected to be the larger. Hence, combining data for the two branches was expected to provide a more representative sample than use of either branch alone. The first 10 fruits from the tip of each branch were tagged and numbered so that their sizes could be monitored throughout the season. When a tagged fruit was lost, a replacement fruit on the same branch was used in order to

Table 1. Location and age of Starkrimson 'Delicious' apple trees used in the study of harvest size prediction in 1985-1987, Michigan.

Orchard	Location	Age in years[z]
Steffens[y]	Comstock Park	26
Wittenbach[y]	Belding	26
Rasch[y]	Lowell	16
Kraft[x]	Sparta	28
CHES[w]	Clarksville	7
Wardowski[w]	Leslie	28
Klein[u]	Sparta	25

z- Approximate age in 1987.
y- Orchards used in calculating the prediction chart for MI.
x- Same as (y). Data used only in 1985, 1986.
w- Orchards used in comparing growth curves of old and young trees, in 1987 only.
u- 1987 data for this orchard are used only in comparing prediction curves with other orchards.

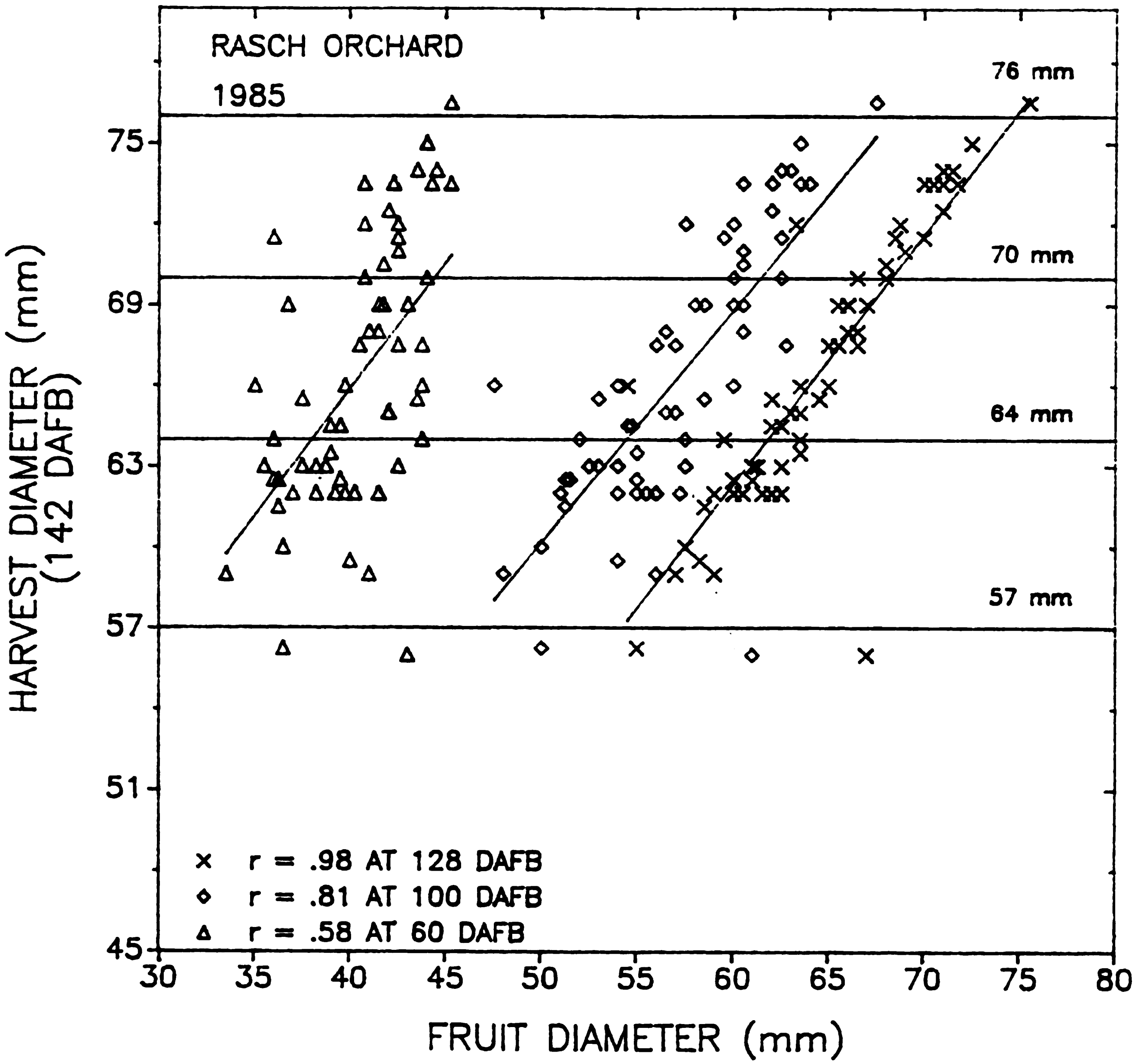
maintain a sample of 10 fruits/branch. A replacement fruit was chosen close to the fallen one and, most importantly, of similar size. Fruits less than 20 mm in diameter were measured with calipers and the largest diameter recorded. Once the diameter reached 20 mm, a tape device (Cranston Machinery Co., Oak Grove, OR) was used to record average diameter, based upon circumference.

Fruit diameters were recorded beginning 48, 59, and 18 days after full bloom (DAFB) in 1985, 1986 and 1987, respectively. The fruits were measured between 3 and 9 times from then until harvest, depending upon orchard and year.

Individual fruit diameters at various dates of measurement were plotted against their diameters at harvest, and regression lines drawn for each sampling date, using a statistical package. Different groupings of data were tested - -the north side alone, the south side alone and the combined data for both- - in the regression analysis. Due to a high incidence of fruit drop on the north sides of the trees, only measurements from the south limb were used in the regression analysis.

The regression lines were used to develop growth curves for fruits of selected diameter at harvest. The diameters of fruits which were 2.50 in. (64 mm) in diameter at harvest, for example, were obtained by preparing a graph of all regression lines for one orchard/year (Fig. 1). A horizontal line intersecting the vertical axis (diameter at

FIG. 1. REGRESSION OF STARKRIMSON 'DELICIOUS' FRUIT DIAMETERS (5 TREES) AT HARVEST ON DIAMETERS OF SAME FRUITS ON 3 SAMPLING DATES IN 1985


RASCH ORCHARD
1985
76 mm
70 mm
64 mm
57 mm
HARVEST DIAMETER (mm)
(142 DAFB)
75
69
63
57
51
45
30
35
40
45
50
55
60
65
70
75
80
FRUIT DIAMETER (mm)
× r = .98 AT 128 DAFB
◇ r = .81 AT 100 DAFB
△ r = .58 AT 60 DAFB

harvest) at 2.50 in. (64 mm) provided an estimate of the diameters of these fruits at each sampling date (i.e., points of intersection with regression lines). These values were then plotted to give the growth curve (Fig. 2). Interpolation was used to provide an estimate of fruit size at 10 day intervals for the final graphs (Fig. 3).

Regression analysis was performed for each orchard/year separately. In addition, the data were combined for different orchards for a given year. The Washington fruit growth chart presents average diameters of 'Winesap' and 'Delicious' apples in various box-size groups at 5-day intervals beginning 35 DAFB (Table 2). To compare my data with those of the Washington chart, diameters at 10-day intervals of 'Delicious' fruits whose diameters were 2.50 in. (64 mm), 2.75 in. (70 mm) and 3.00 in. (76 mm) at 140 DAFB were selected from the Washington chart. The values were then converted to mm and stored in "PlotIt" format for further use (Fig. 4).

Using these data as a base, graphs were generated to check for uniformity, divergence or goodness of fit. The three main comparisons were comparisons among orchards within years, comparisons within orchards among years, and comparison across orchards among years. Two additional comparisons were performed to test for differences between old and young trees. Data for old trees in one orchard at Belding were compared with those for young trees (planted 1980) at the Clarksville Horticultural Experiment Station

Fig. 2. Growth curves of fruits of 4 different harvest diameters, based upon regression of final diameter on diameter at various dates

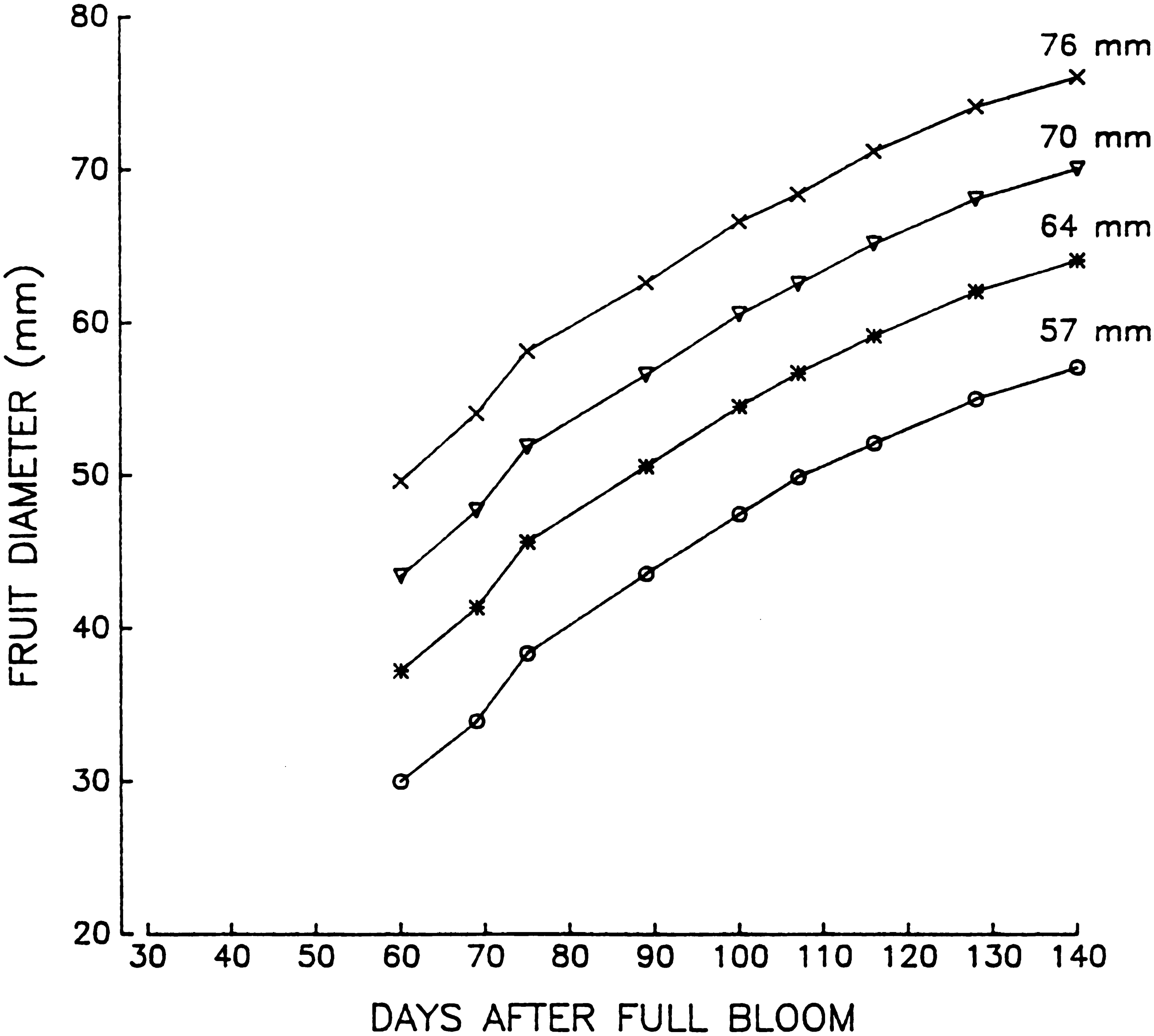

76 mm
70 mm
64 mm
57 mm
FRUIT DIAMETER (mm)
80
70
60
50
40
30
20
30
40
50
60
70
80
90
100
110
120
130
140
DAYS AFTER FULL BLOOM

Fig. 3. Growth curves of fruits of 4 different harvest diameters, based upon regression of final diameter on diameter at various dates. Values adjusted to 10 day interval

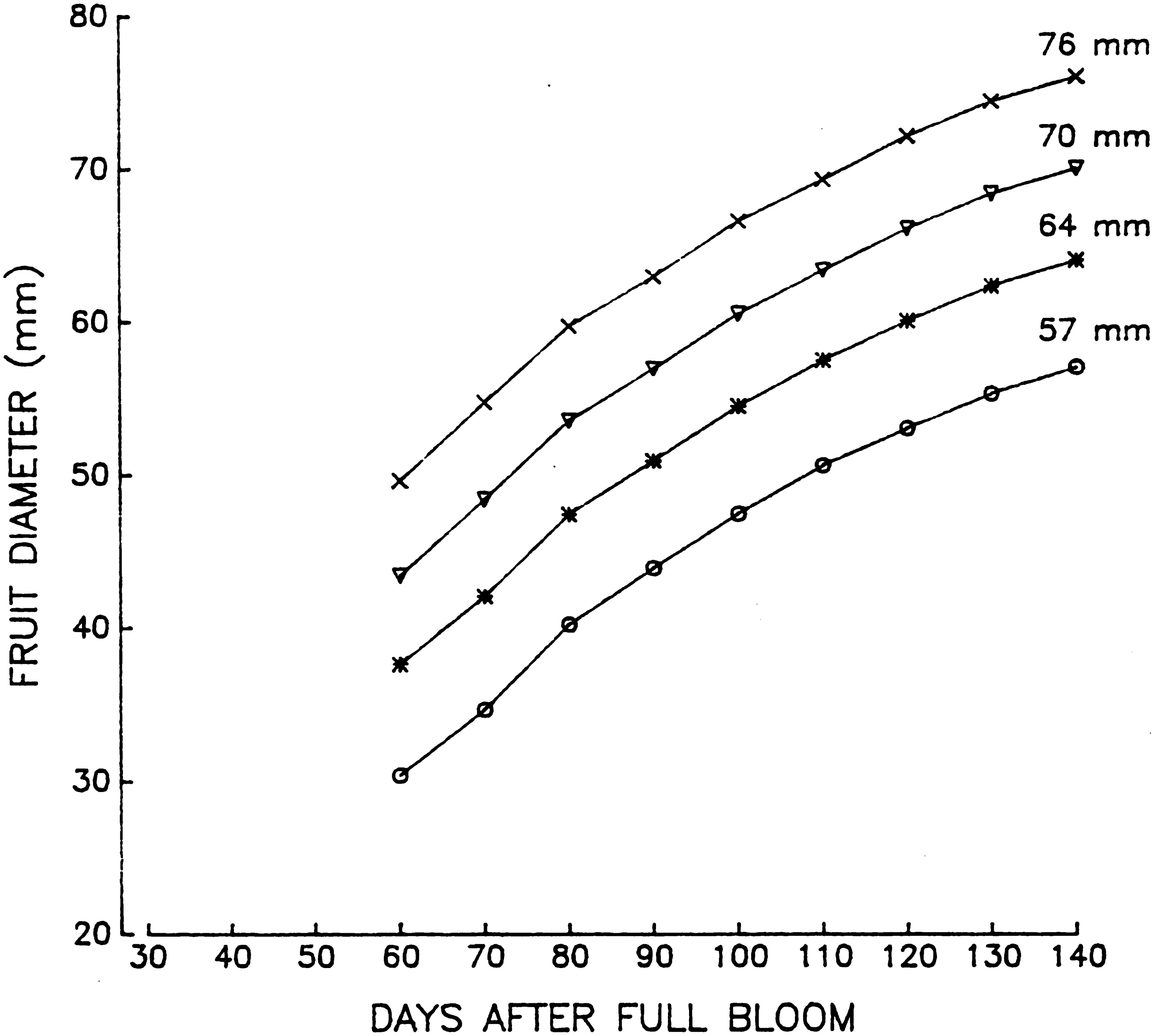
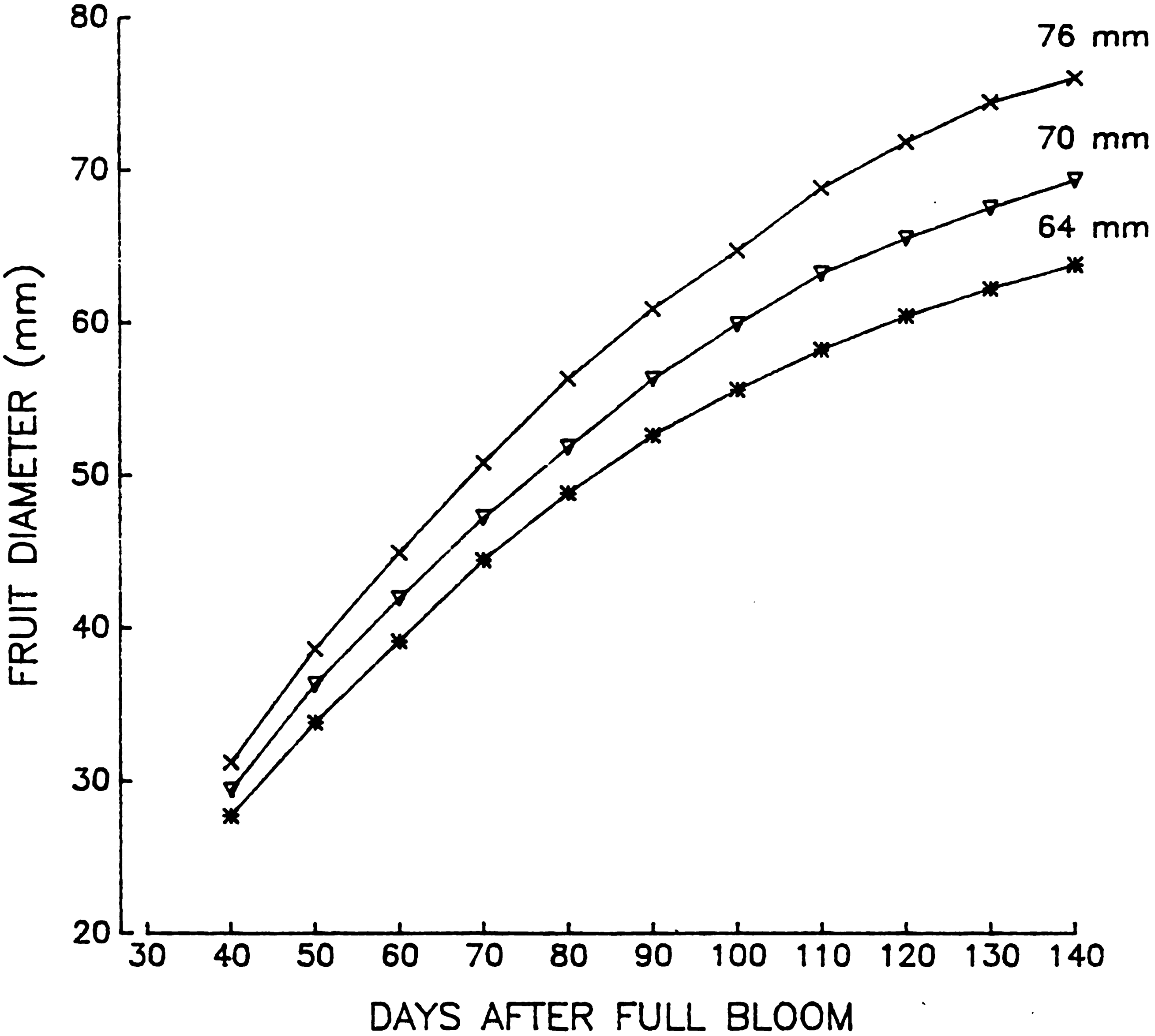

FRUIT DIAMETER (mm)
DAYS AFTER FULL BLOOM
76 mm
70 mm
64 mm
57 mm
80
70
60
50
40
30
20
30 40 50 60 70 80 90 100 110 120 130 140

Table 2. 'Standard' Washington chart established by Batjer, et al. in 1957, for predicting harvest size of 'Delicious' and 'Golden Delicious' for fruits of various size class at harvest.

DAFB	Projected box size								
	163	150	138	125	113	100	88	80	72
	present size, inches in diameter								
35	.90	.93	.95	.98	1.00	1.03	1.05	1.08	1.10
40	1.06	1.09	1.12	1.14	1.16	1.19	1.22	1.25	1.29
45	1.19	1.22	1.24	1.26	1.29	1.34	1.36	1.40	1.42
50	1.30	1.33	1.35	1.39	1.43	1.47	1.50	1.54	1.57
55	1.40	1.43	1.45	1.49	1.54	1.59	1.63	1.67	1.70
60	1.51	1.54	1.56	1.60	1.65	1.69	1.74	1.79	1.83
65	1.62	1.64	1.67	1.70	1.75	1.80	1.85	1.90	1.95
70	1.71	1.75	1.78	1.81	1.86	1.92	1.97	2.03	2.09
75	1.80	1.84	1.88	1.92	1.95	2.02	2.08	2.14	2.20
80	1.88	1.92	1.95	1.99	2.04	2.10	2.18	2.26	2.32
85	1.95	1.99	2.03	2.08	2.13	2.19	2.27	2.34	2.42
90	2.02	2.07	2.10	2.16	2.22	2.28	2.36	2.43	2.51
95	2.08	2.13	2.17	2.23	2.29	2.36	2.43	2.52	2.59
100	2.13	2.19	2.23	2.29	2.36	2.43	2.51	2.60	2.68
105	2.18	2.24	2.29	2.36	2.42	2.51	2.58	2.68	2.77
110	2.23	2.29	2.35	2.41	2.49	2.58	2.66	2.75	2.84
115	2.28	2.34	2.39	2.46	2.54	2.63	2.72	2.82	2.92
120	2.32	2.38	2.44	2.51	2.58	2.68	2.78	2.88	2.98
125	2.36	2.42	2.48	2.54	2.62	2.72	2.83	2.93	3.04
130	2.38	2.45	2.52	2.58	2.66	2.77	2.87	2.98	3.09
135	2.42	2.48	2.54	2.62	2.69	2.80	2.91	3.02	3.13
140	2.44	2.51	2.57	2.64	2.73	2.84	2.94	3.06	3.17
145	2.47	2.53	2.59	2.67	2.77	2.88	2.98	3.08	3.20
150	2.48	2.56	2.62	2.69	2.79	2.91	3.01	3.11	3.22

Fig. 4. Growth curves, based upon the Washington chart, for fruits of 3 different diameters at harvest


76 mm
70 mm
64 mm
FRUIT DIAMETER (mm)
80
70
60
50
40
30
20
30
40
50
60
70
80
90
100
110
120
130
140
DAYS AFTER FULL BLOOM

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(CHES), with the data for old and young trees in the same orchard at Leslie constituting the second comparison. The Washington curves were included as a reference in some graphs.

To determine how the accuracy of prediction compared with Washington values, three ranges of accuracy were adopted, namely ± 1/8" (~ 3 mm), ± 1/16" (~ 1.6 mm) and ± 1/32" (~ 0.8 mm). As an example, the percentage of fruits falling within each range was determined by calculating the difference between the actual harvest diameters measured and the harvest diameters predicted from measurements taken on 50, 100, and 125 DAFB. In addition, harvest diameter was predicted based on the regression coefficients of the Michigan chart and on actual diameter measurements at various dates after full bloom, in 3 orchards.

Fruit diameter in 4 Washington orchards in 1983 were supplied by Dr. Eric Curry of USDA, Wenatchee, WA. These were graphed for comparison with the data of Batjer, et al. (1) to determine if any differences were evident.

To determine whether tree age affected photosynthetic activity, the trees used for fruit size measurement in the Wardowski orchard were also used to measure CO_2 assimilation. Two trees of each age (old & young) were used and photosynthesis was measured in eight spur leaves per tree on September 1987, about 2 weeks before harvest. Non-fruiting spurs were chosen in order to avoid any influence of adjacent fruits . The fully expanded leaves were well exposed to light and showed no visual symptoms of insect or physical damage. Leaf area, ambient CO_2, relative humidity (RH) in the chamber, ambient RH, leaf temperature, differential CO_2 and photosynthetically active radiation (PAR) were recorded for each leaf, using a portable open gas exchange system equipped with a Parkinson broad leaf chamber (model ADC LCA-2, Analytical Development Co., Hoddesdon, England) operated at the following conditions: saturating light intensity (photosyntheticallly active radiation 1000 $\mu mols/m^2/s$), ambient CO_2 of 330-340 $\mu l/l$, flow rate of 0.4 l/min, inlet relative humidity (RH) of 6-11%, as described by Gucci (6). A BASIC program (7) was used to convert the raw data to CO_2 assimilation, VPD, leaf conductance, stomatal conductance, transpiration and internal CO_2. Data were analyzed by ANOVA and LSD.

Results

As expected, r values for fruit diameters at date of measurement vs. diameter at harvest improved in accuracy as harvest approached (Table 3). In 1985, r values increased from an average of 0.63 at 48 DAFB to 0.95 at 126 DAFB. Similar trends were observed in other years (Table 3). All the tabulated correlation coefficients were significant at 1% beginning 66 DAFB. Regression curves (see example in Fig. 1) were significant at 5% for 50 DAFB, and at 1% for the remaining two dates of measurement. As expected, deviation from the regression line declined with time. The analysis was repeated with data from another orchard in 1985 and comparable results were obtained (Fig. 5).

When the prediction curves of an individual orchard were plotted against similar curves for Washington fruits, two differences were noteworthy (Fig. 6). Firstly, diameters of Michigan fruits for a given date were greater than those of Washington fruits of similar harvest size. Secondly, for early season measurements particularly, the difference in diameter increased with increasing harvest size. These data indicate that Washington fruits grow at a faster rate than do Michigan fruits in the early part of the season. A Michigan grower using the Washington chart early in the season would therefore be likely to overestimate in predicting harvest size. The necessity of a Michigan chart to serve local growers is clearly evident.

Table 3. The coefficients of correlation (r) of the regression lines of fruit size at various days after full bloom (DAFB) vs. harvest size for various orchards and years. The r values are significant at $p < 0.05$ for 18 to 66 DAFB, and at $p < 0.01$ for 67 DAFB and after.

Year/ Orchard	Date of measurement (DAFB)								Harvest date (DAFB)	No. of observations (Trees X fruit/tree)
1985	48-50	58-60	67-69	75-77	89-90	100-102	115-119	125-126		
Kraft	.666	.716	.783	.737	.790	.866	.956	.976	139	8 X 15
Steffens	.627	.661	.737	.797	.815	.877	.937	.973	139	8 X 15
Wittenbach	.623	-	.668	.642	.775	.890	.907	.917	142	8 X 15
Rasch	-	.581	.521	.529	.663	.810	.886	.979	142	12 X 15(z)
1986	59-66	72-75	87	101	131					
Steffens	-	.847	-	.852	-				134	7 X 10
Wittenbach	.880	.869	-	.930	-				134	8 X 10
Rasch	-	.866	-	.928	.933				144	8 X 10
1987	18	30-32	49-51	70-72	105-107	113				
Rasch	.639	.831	.950	-	.943	-			143	3 X 10
Klein	-	.806	-	.902	-	.923			143	4 X 10
Steffens	-	.702	-	.912	-	.889			143	5 X 10

(z)-Less 19 missing values for fruits which abscised.

FIG. 5. REGRESSION OF STARKRIMSON 'DELICIOUS' FRUIT DIAMETERS (DATA FOR 4 TREES) AT HARVEST ON DIAMETERS OF SAME FRUITS ON 3 SAMPLING DATES IN 1985

HARVEST DIAMETER (mm)
(142 DAFB)

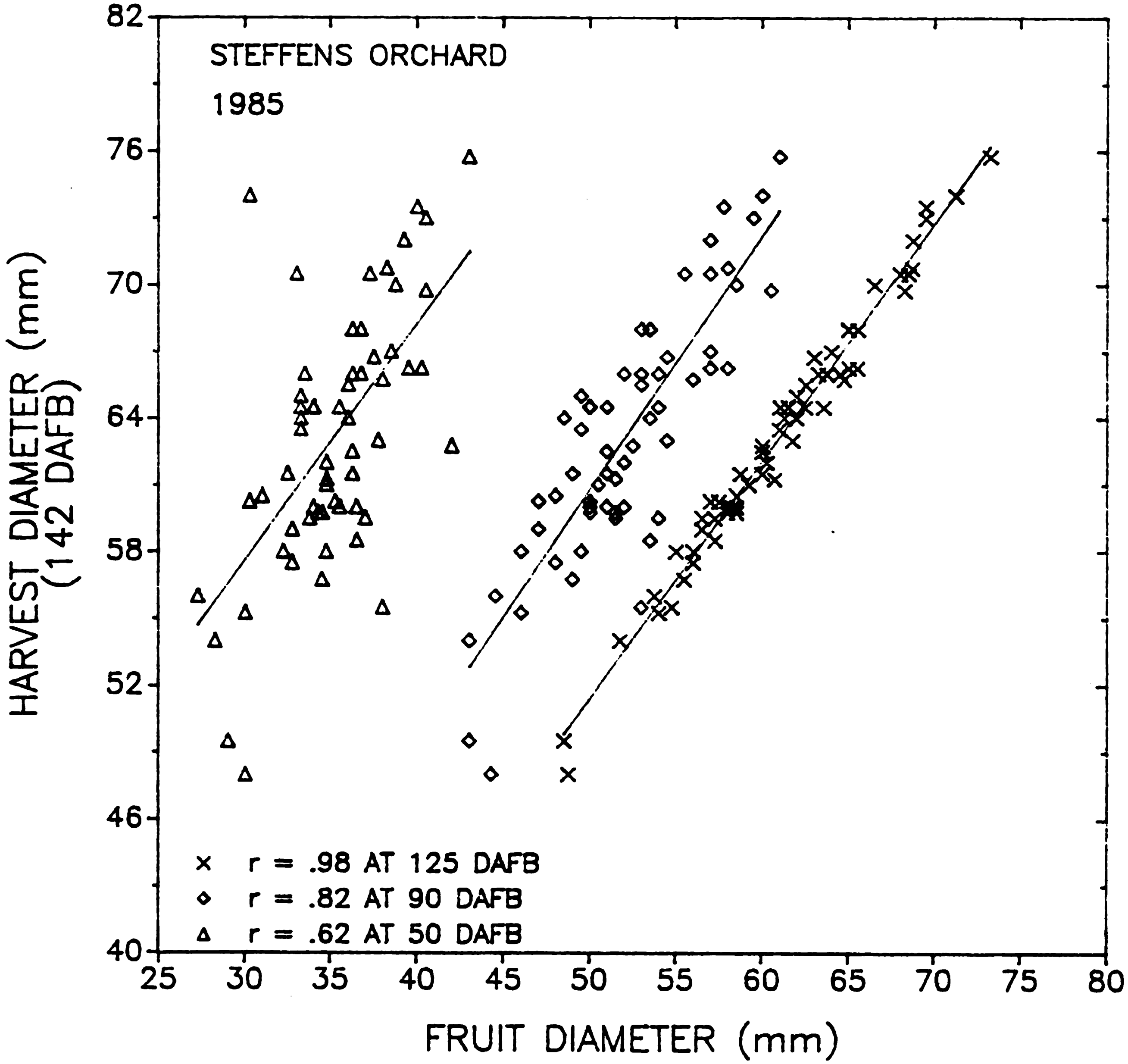
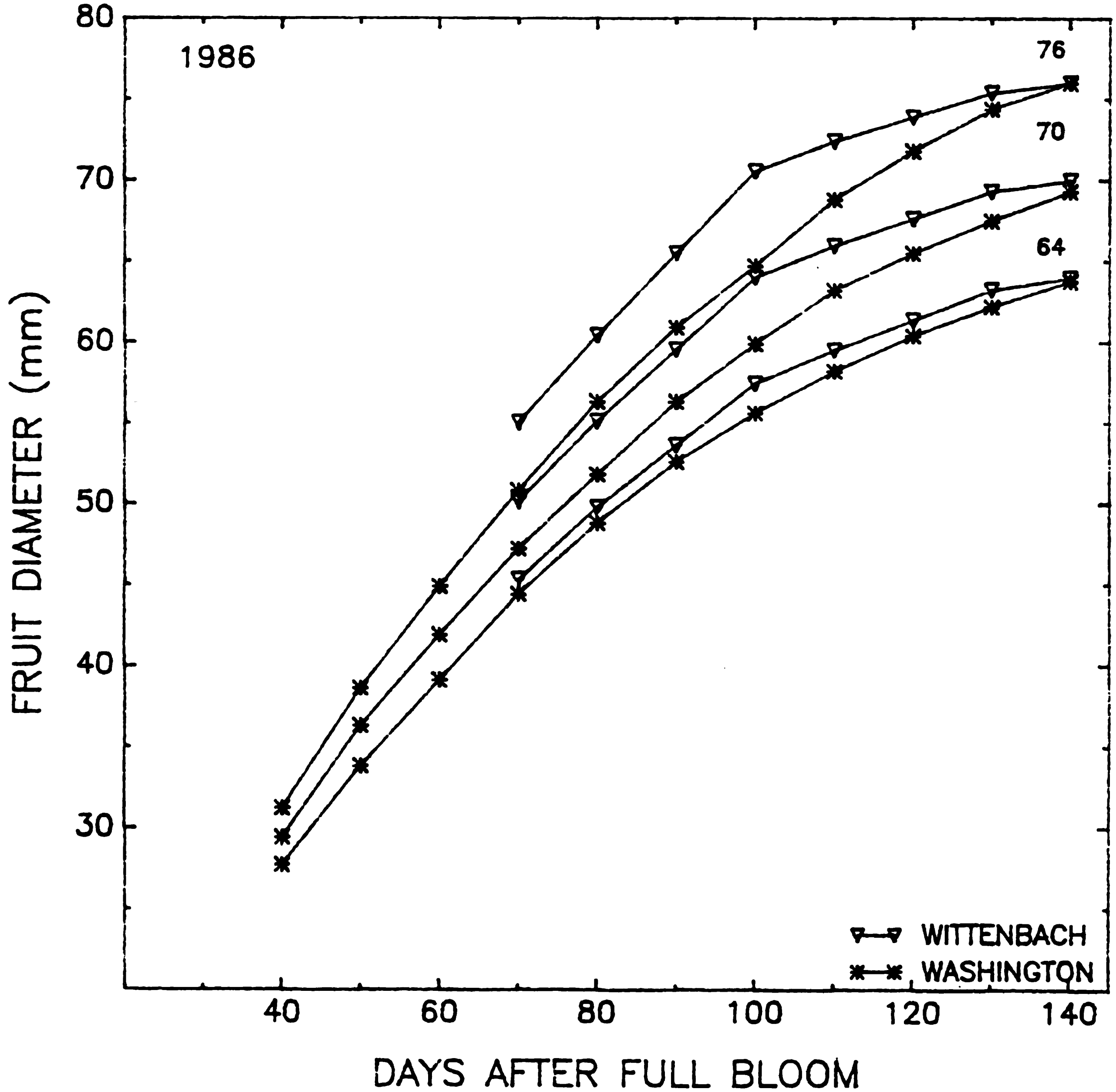

STEFFENS ORCHARD
1985
HARVEST DIAMETER (mm)
(142 DAFB)
FRUIT DIAMETER (mm)
82
76
70
64
58
52
46
40
25
30
35
40
45
50
55
60
65
70
75
80
× r = .98 AT 125 DAFB
◇ r = .82 AT 90 DAFB
△ r = .62 AT 50 DAFB

FIG. 6. FRUIT DIAMETER PREDICTION CURVES FOR STARKRIMSON 'DELICIOUS' FRUITS IN ONE MICHIGAN ORCHARD IN 1986 VS. SIMILAR CURVES FOR WASHINGTON 'DELICIOUS'



1986
76
70
64
FRUIT DIAMETER (mm)
80
70
60
50
40
30
40
60
80
100
120
140
DAYS AFTER FULL BLOOM
WITTENBACH
WASHINGTON

To be of value, however, the data must be reliable. Therefore two comparisons were made:

- a comparison of growth curves among years within orchards.
- a comparison of growth curves among orchards within years.

Growth curves for small (64 mm) and large (76 mm) fruits from one Michigan orchard, compared over the three years of study, clearly show some variability from year to year (Fig. 7). Similar variability was noted for other orchards (Fig 8a, b). The available data show that the MI growth curves differed in slope from the WA curves throughout the season. Major differences were evident early in the season, whereas differences late in the season were small. Data for a single year therefore cannot be used to predict harvest size in other years. The data in Figure 7 were used to calculate fruit volume, assuming fruit shape to be spherical. Small differences in fruit diameter become much larger when converted to volume (Fig. 9).

Comparison of growth curves of medium sized (70 mm harvest diameter) fruits in Michigan orchards in 1986 indicated that fruits in the Wittenbach orchard grew more slowly than fruits of similar harvest size in the other two orchards (Fig. 10). Variability among orchards in 1986 resembles that among years within a single orchard (compare Fig. 7, 8 and 10). Thus variability within orchards and years appears to rule out the use of any growth curve based upon a single orchard or year as a reference for Michigan growers.

FIG. 7. FRUIT DIAMETER PREDICTION CURVES FOR STARKRIMSON 'DELICIOUS' FRUITS IN ONE ORCHARD IN MICHIGAN OVER 3 YEARS

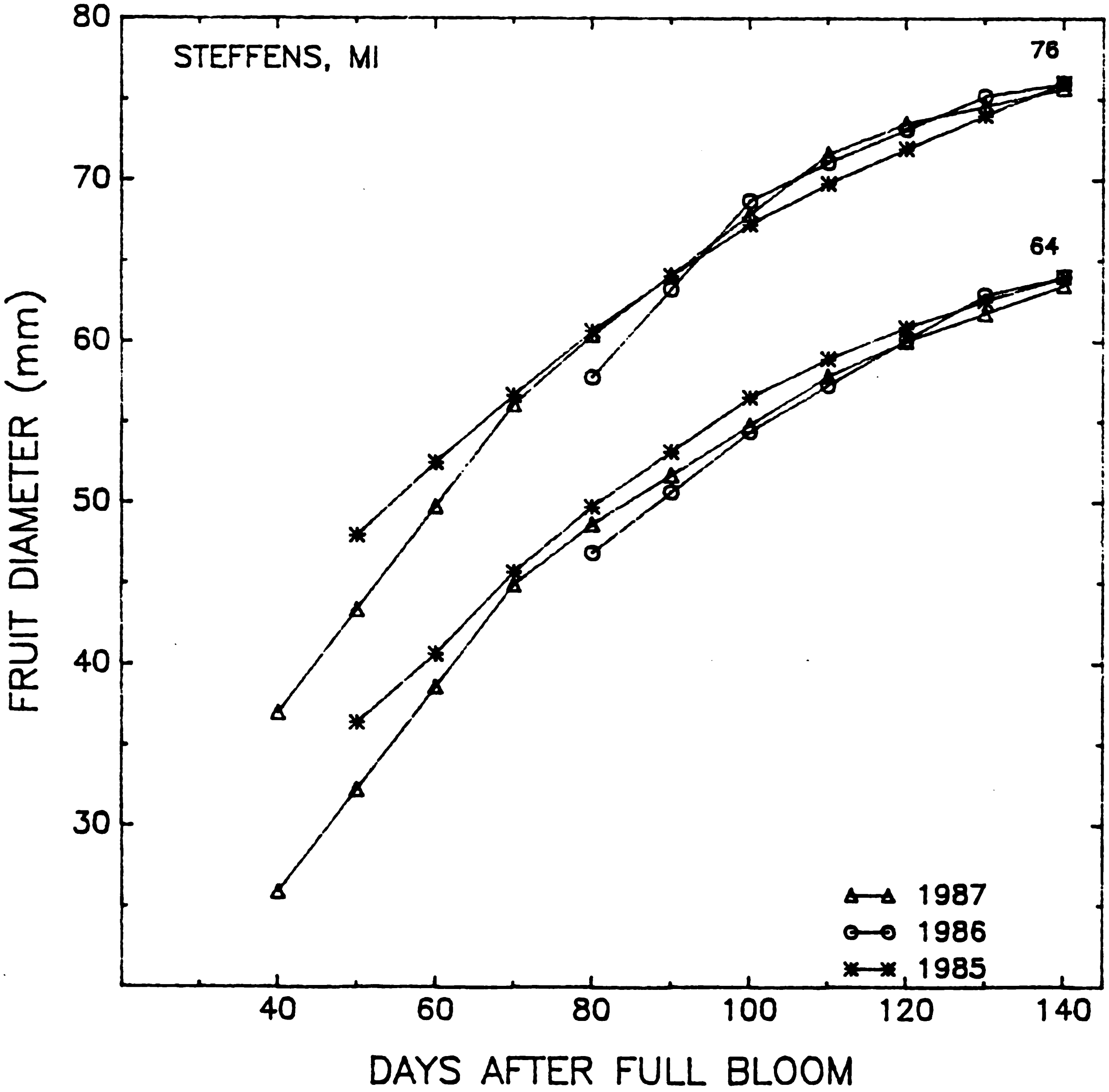

STEFFENS, MI
76
64
FRUIT DIAMETER (mm)
DAYS AFTER FULL BLOOM
1987
1986
1985
80
70
60
50
40
30
40
60
80
100
120
140

FIG. 8a,b. FRUIT DIAMETER PREDICTION CURVES FOR STARKRIMSON 'DELICIOUS' FRUITS IN TWO MICHIGAN ORCHARDS OVER 3 YEARS.

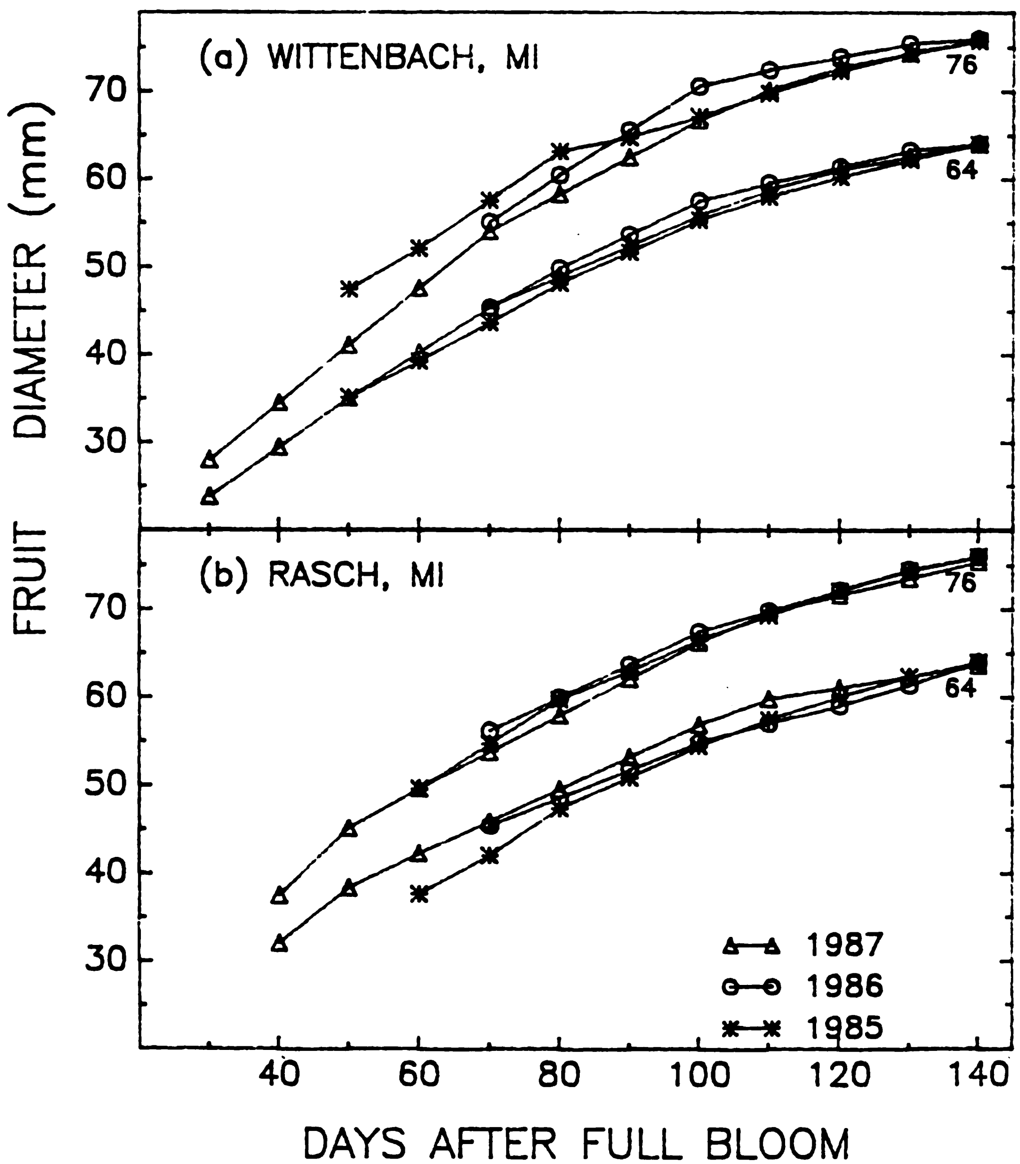

(a) WITTENBACH, MI
(b) RASCH, MI
FRUIT DIAMETER (mm)
DAYS AFTER FULL BLOOM
76
64
76
64
1987
1986
1985
30
40
50
60
70
40
60
80
100
120
140

FIG. 9. PREDICTION CURVES FOR LARGE (76 mm. DIAMETER AT HARVEST) VS. SMALL (64 mm. AT HARVEST) STARKRIMSON 'DELICIOUS' FRUITS IN ONE MICHIGAN ORCHARD OVER 3 YEARS EXPRESSED AS FRUIT VOLUME

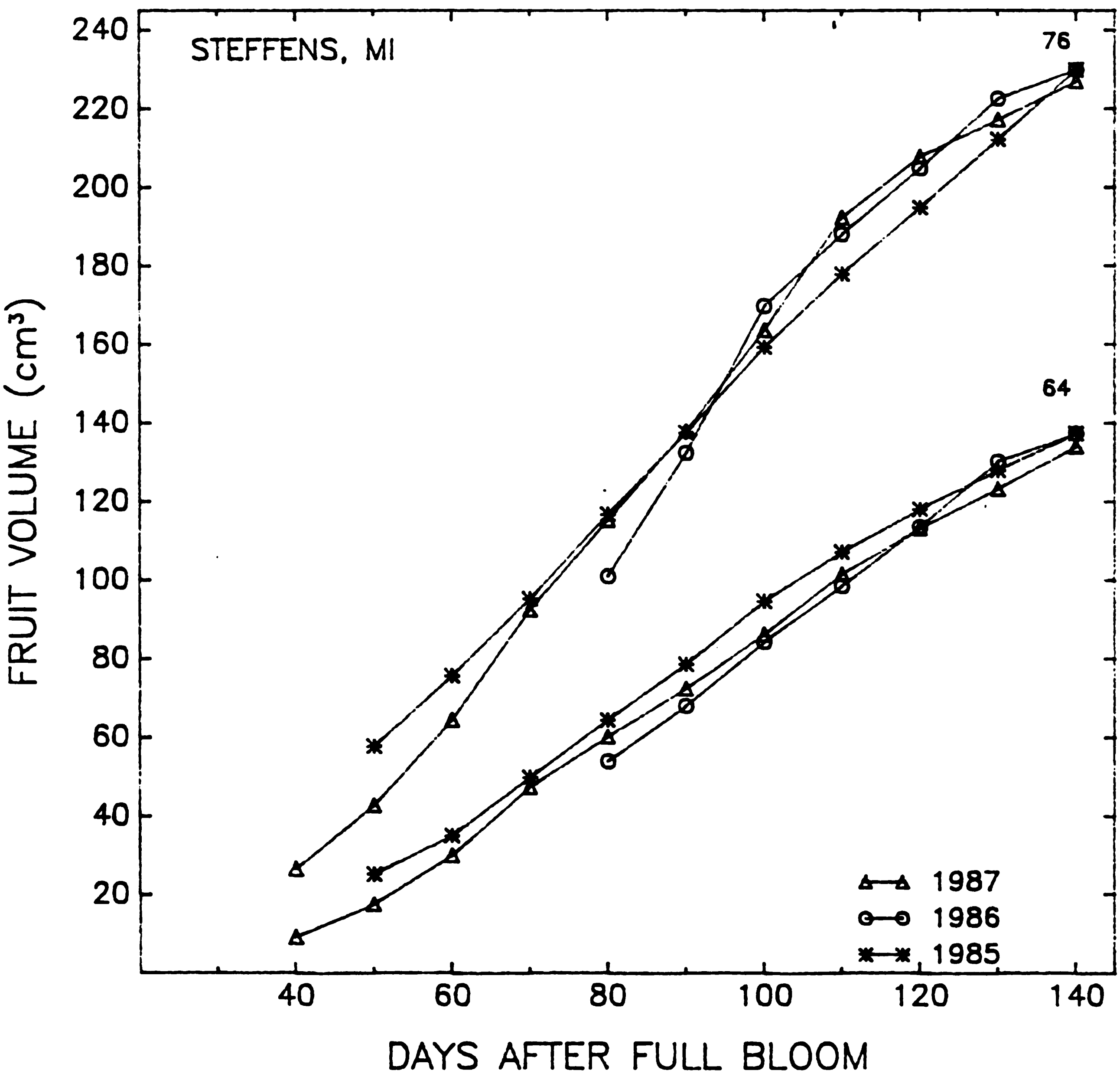
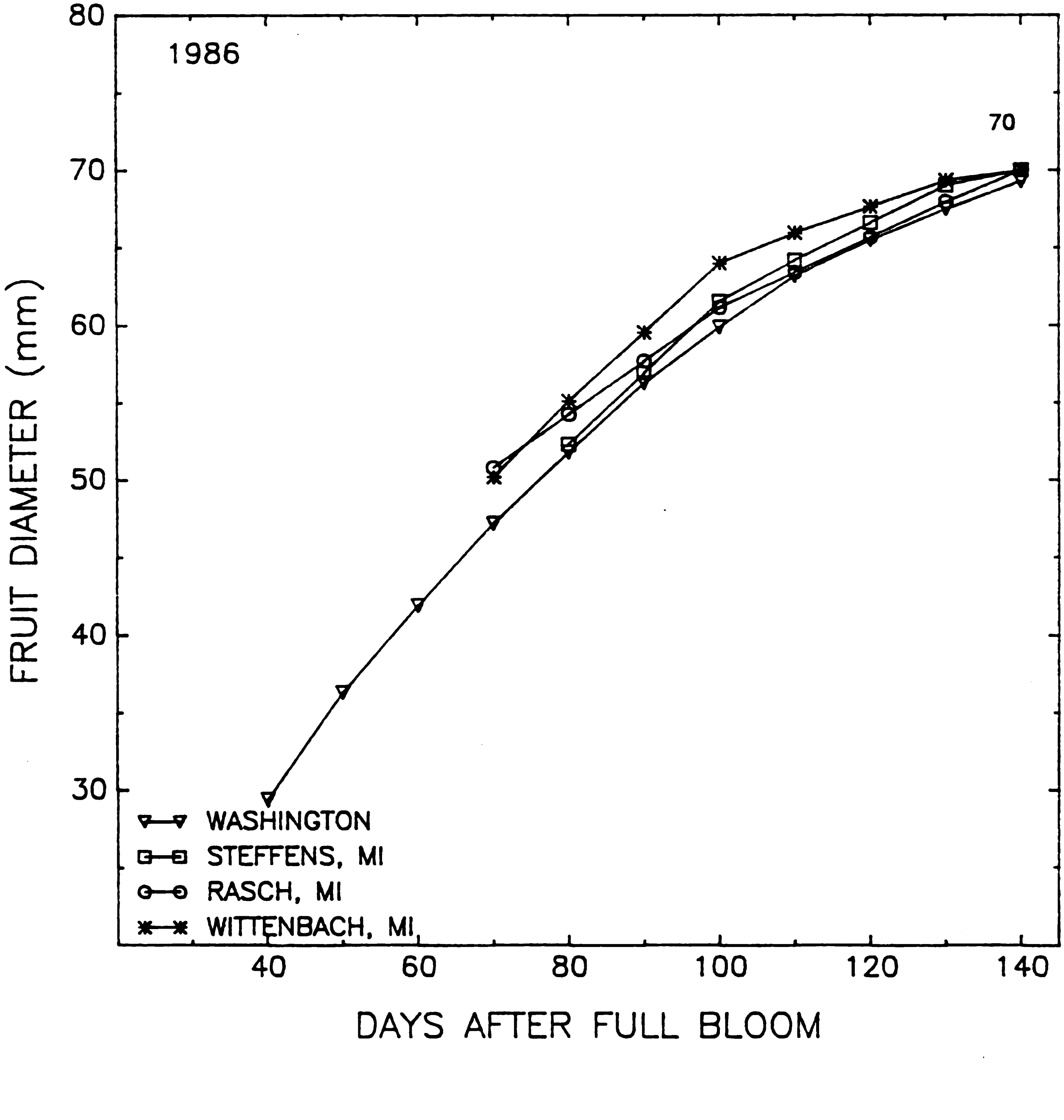

STEFFENS, MI
76
64
FRUIT VOLUME (cm³)
DAYS AFTER FULL BLOOM
1987
1986
1985
240
220
200
180
160
140
120
100
80
60
40
20
40
60
80
100
120
140

FIG. 10. FRUIT DIAMETER PREDICTION CURVES FOR MEDIUM SIZED FRUITS IN 3 MICHIGAN ORCHARDS IN 1986 VS. SIMILAR CURVE FOR WASHINGTON


80
70
60
50
40
30
1986
70
WASHINGTON
STEFFENS, MI
RASCH, MI
WITTENBACH, MI
40
60
80
100
120
140
FRUIT DIAMETER (mm)
DAYS AFTER FULL BLOOM

Two comparisons were made in 1987 to determine if the growth curves of fruits varied with tree age. Data from the Wittenbach orchard at Belding (mature) were first compared with those from trees planted at the Clarksville Horticultural Experiment Station (CHES) in 1980. The fruits from the young trees were larger at harvest than those in the Wittenbach orchard. Nevertheless, growth curves constructed from regression data (Fig. 11) indicated that fruits of similar harvest size grew at approximately the same rate regardless of tree age from 100 DAFB to harvest. Note also that the predicted growth curves for 76 mm fruits were similar in both orchards, despite the fact that the mature trees bore few (7%) fruits of this size whereas the young trees bore many (33%).

The second comparison involved trees of differing age within one orchard (Wardowski). Average diameter was consistently larger on young than on old trees (significant at 5% on each date) (Fig. 12). However, except for some differences early in the season, the two size prediction curves were very similar (Fig. 13). Differences early in the season reflect low r values presented in Table 3.

The data from the Rasch, Steffens and Wittenbach orchards for the 3 years of study were combined to obtain composite curves for comparison with similar data from the Washington chart (Fig. 14). The Michigan growth curves were compared with growth curves for fruits of similar harvest

FIG. 11. SIZE PREDICTION CURVES FOR A YOUNG VS. A MATURE ORCHARD, 1987

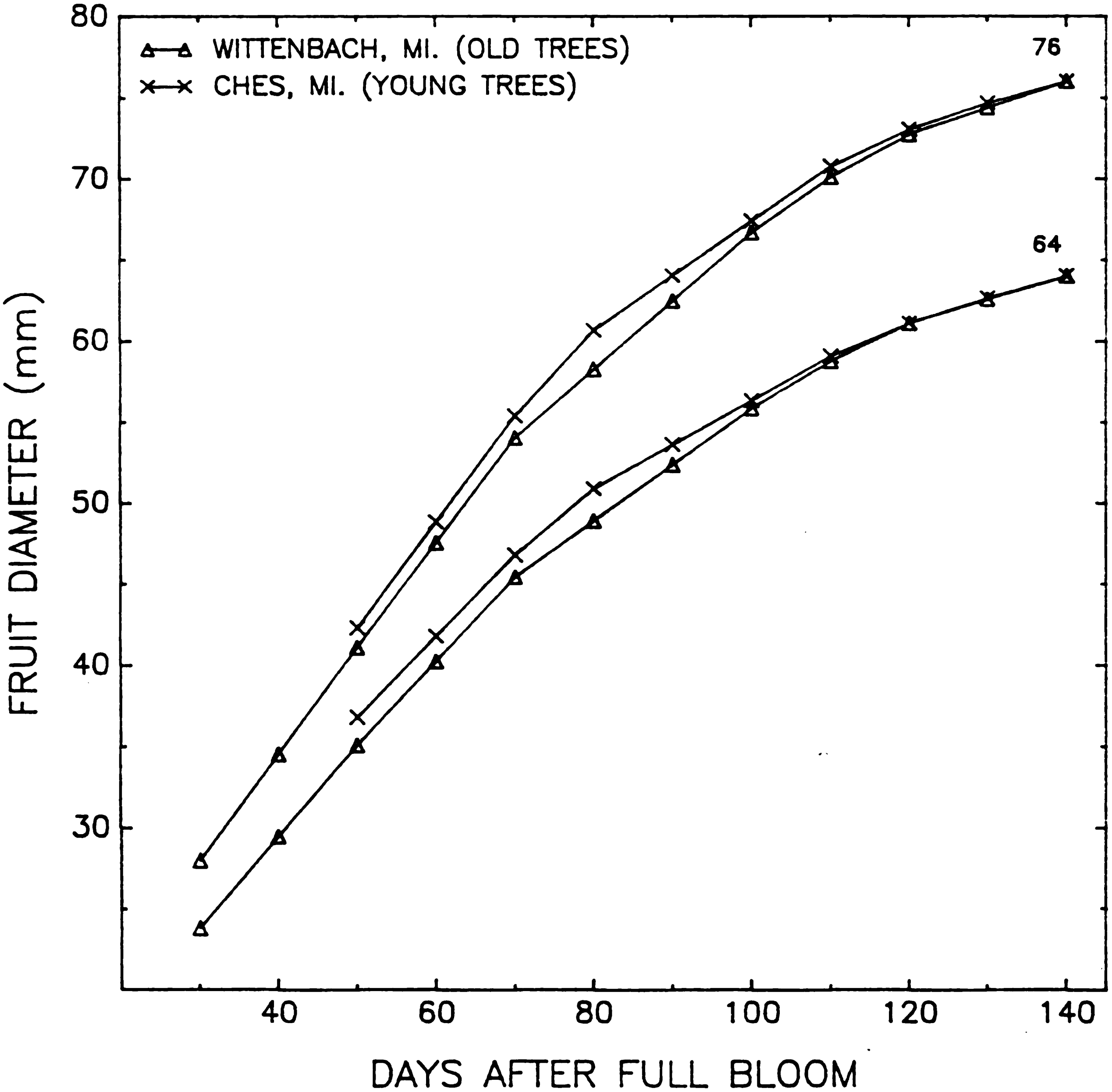
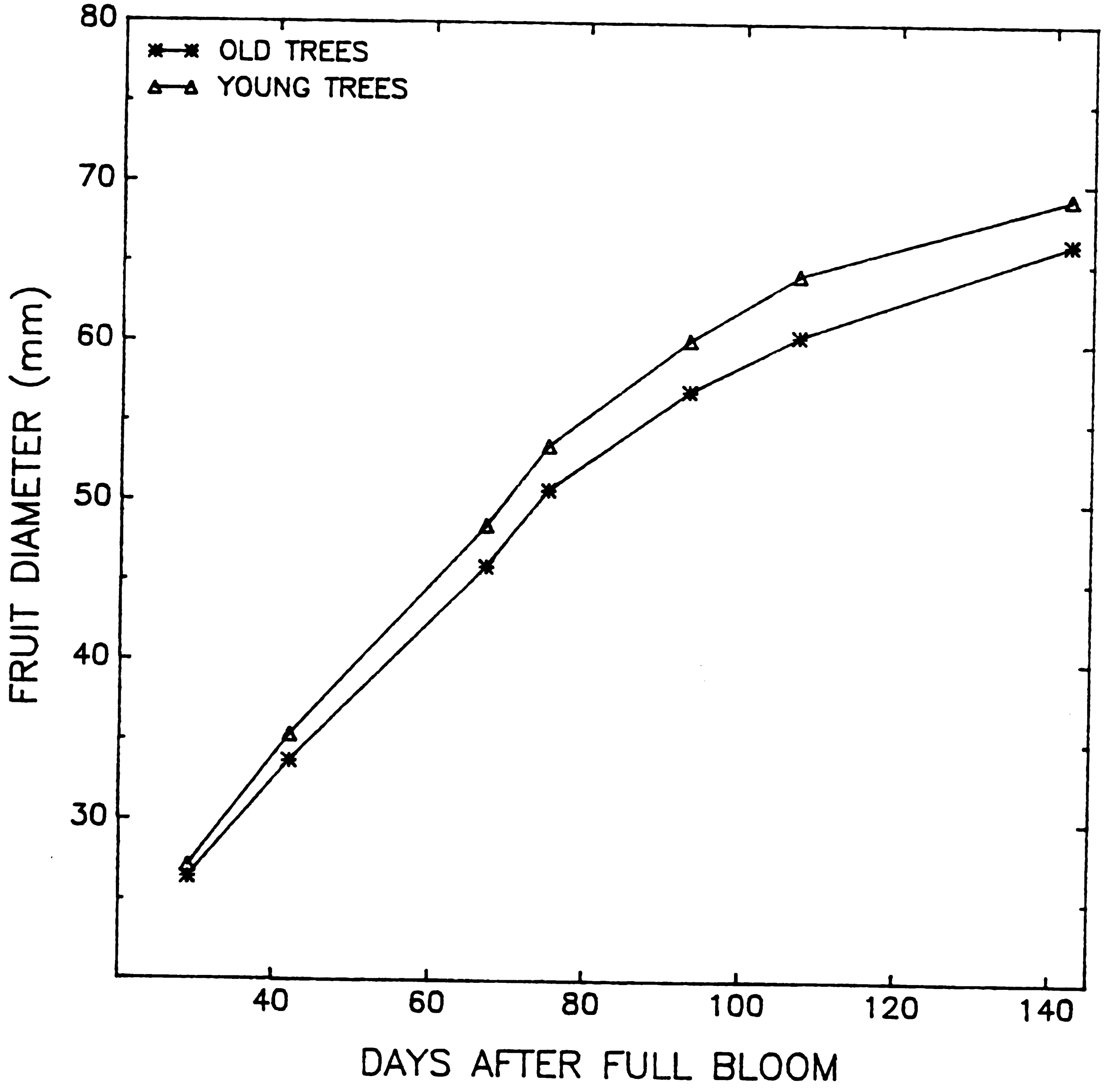

WITTENBACH, MI. (OLD TREES)
CHES, MI. (YOUNG TREES)
76
64
FRUIT DIAMETER (mm)
DAYS AFTER FULL BLOOM
30
40
50
60
70
80
40
60
80
100
120
140

FIG. 12. EFFECT OF TREE AGE ON GROWTH OF STARKRIMSON 'DELICIOUS' APPLE FRUITS, WARDOWSKI ORCHARD, LESLIE, MI. 1987



OLD TREES
YOUNG TREES
80
70
60
50
40
30
FRUIT DIAMETER (mm)
40
60
80
100
120
140
DAYS AFTER FULL BLOOM

FIG. 13. SIZE PREDICTION CURVES FOR YOUNG VS. MATURE TREES IN THE SAME ORCHARD, LESLIE, MI. 1987

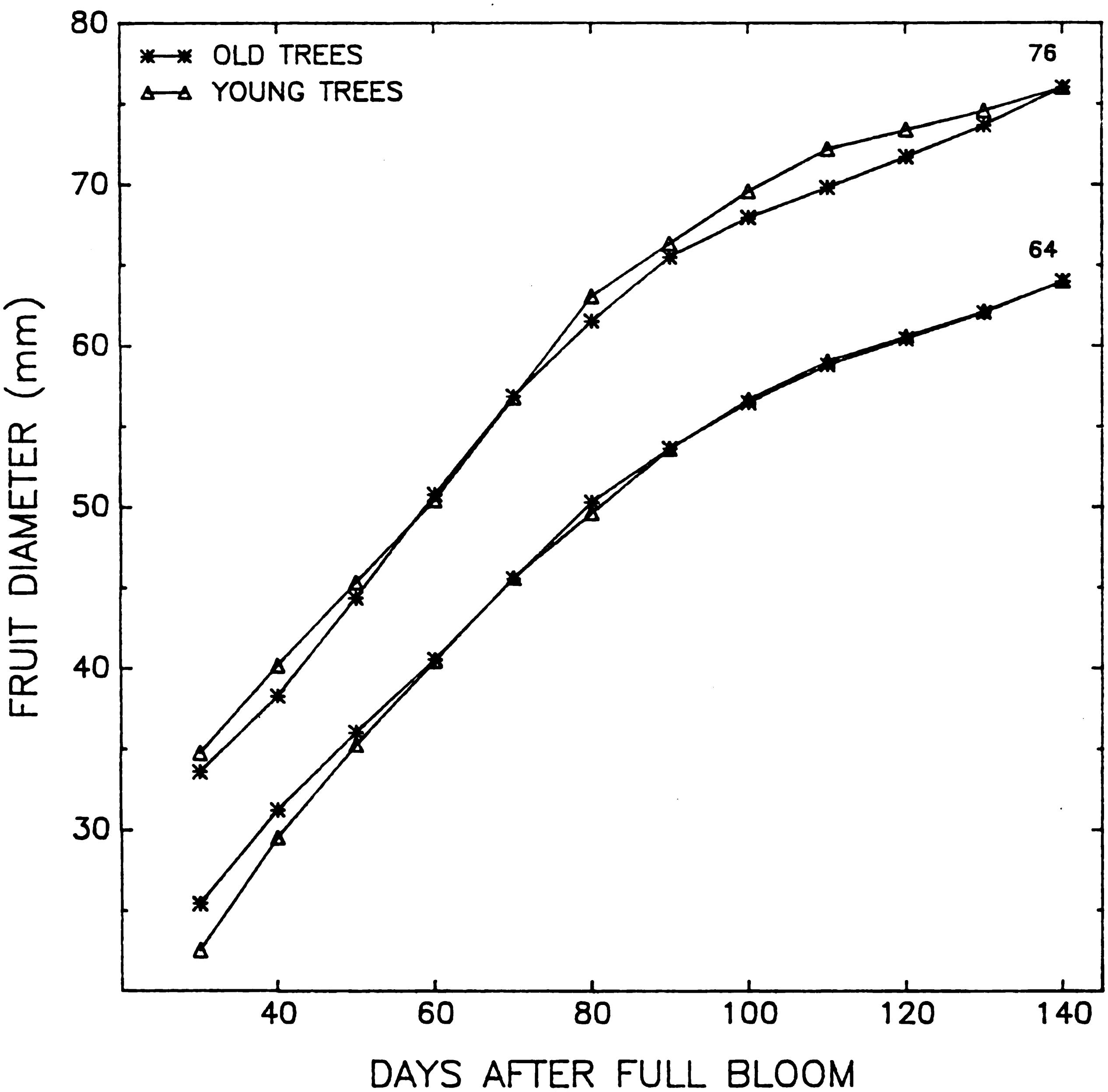
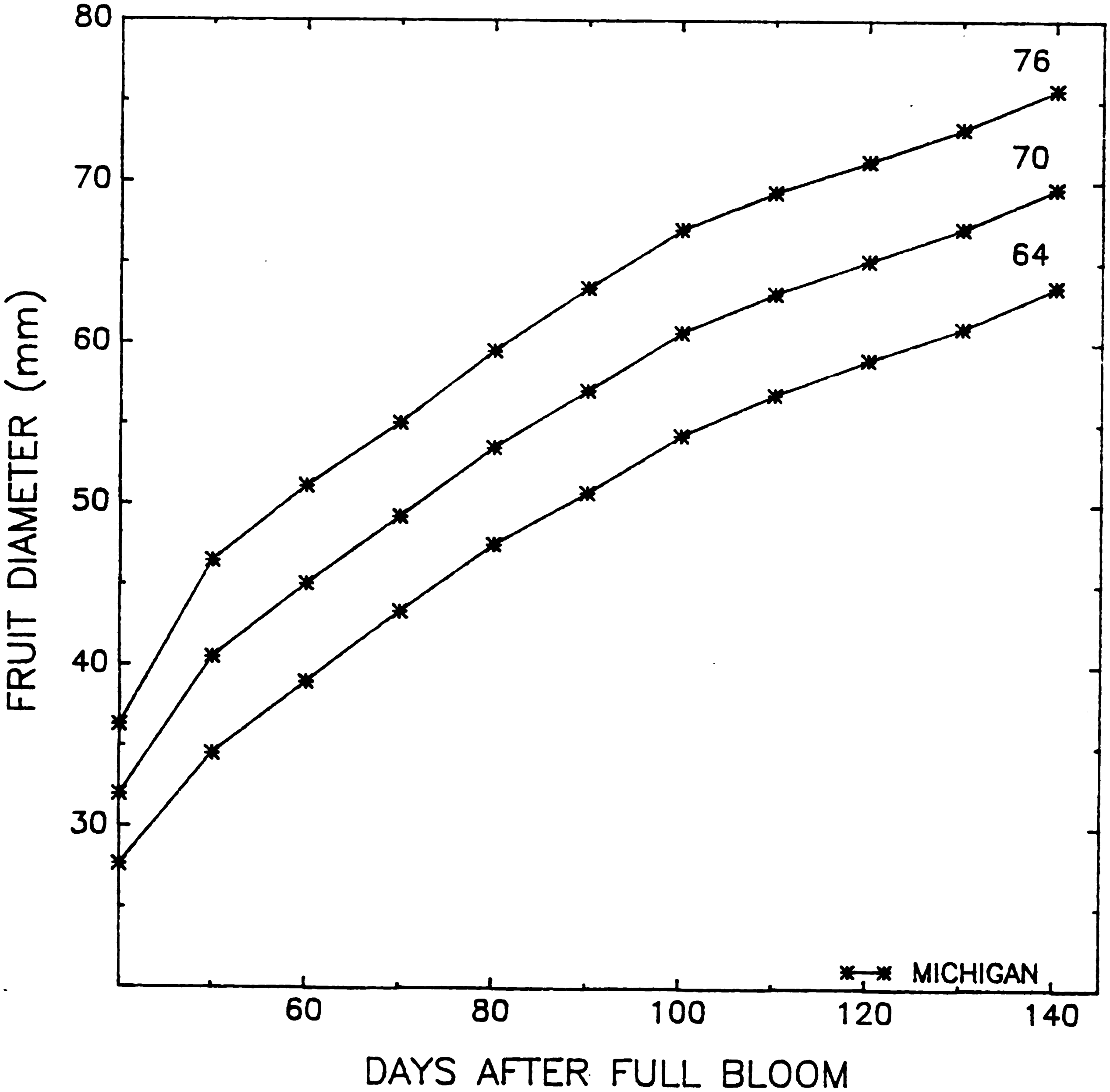

OLD TREES
YOUNG TREES
76
64
80
70
60
50
40
30
FRUIT DIAMETER (mm)
40
60
80
100
120
140
DAYS AFTER FULL BLOOM

Fig. 14. Growth curves of fruits of 3 different harvest diameters as predicted in Table 4


80
70
60
50
40
30
FRUIT DIAMETER (mm)
76
70
64
MICHIGAN
60
80
100
120
140
DAYS AFTER FULL BLOOM

diameter taken from the Washington chart (Fig. 15). Here again the differences between Washington and Michigan curves early in the season increase with increasing harvest size. However, the Michigan values on certain DAFB closely resemble those of Washington fruits for the first time. The largest fruits grew at comparable rates only after 100 DAFB, those of 70 mm fruits after 90 DAFB. In both cases final fruit size would have been overestimated by using the Washington data prior to these dates. In contrast, data from the Washington curve for small fruits (64 mm) between 70 and 130 DAFB slightly underestimated Michigan fruit size, whereas earlier data were very similar for the two states.

Fig. 16 compares the growth curves of small and medium sized fruits (64 and 70 mm, respectively) for the Steffens orchard in 1987 with similar curves from the Michigan prediction chart. Using the Michigan chart for medium sized fruits allows for accurate prediction of harvest size as early as 70 DAFB, but it overestimates harvest size for small fruits. The same comparison was repeated for 1985 and comparable results were obtained (see example in Fig. 17). Although a slight difference exists between actual and predicted growth curves of 70 mm fruits, the difference is negligible when compared to that of 64 mm fruits in either year.

FIG. 15. AVERAGED FRUIT DIAMETER PREDICTION CURVES FOR STARKRIMSON 'DELICIOUS' DATA FOR 1985-1987 VS. SIMILAR WASHINGTON GROWTH CURVES

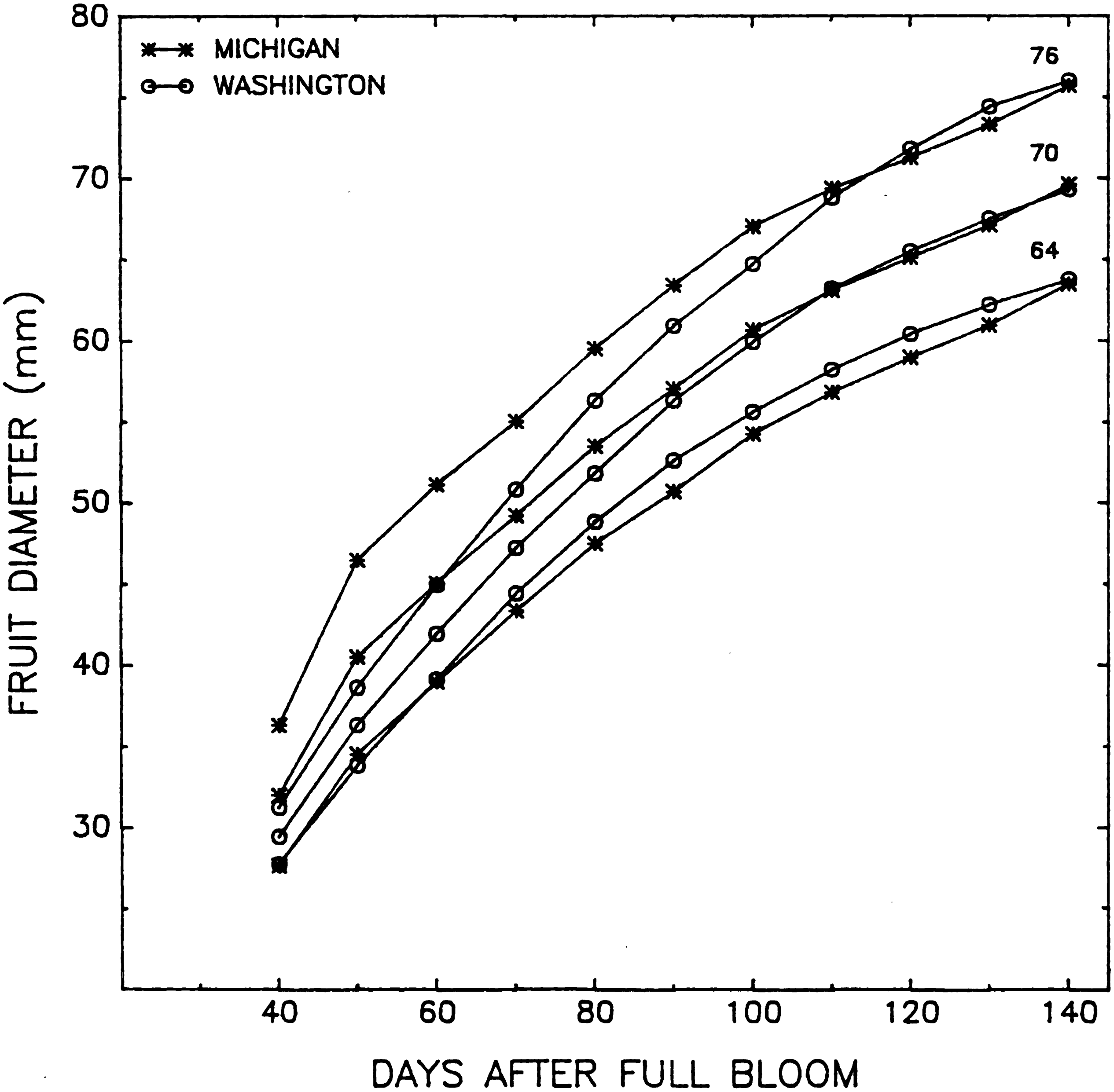

MICHIGAN
WASHINGTON
76
70
64
80
70
60
50
40
30
FRUIT DIAMETER (mm)
40
60
80
100
120
140
DAYS AFTER FULL BLOOM

FIG. 16. ACTUAL DIAMETER IN ONE ORCHARD VS. AVERAGED MICHIGAN PREDICTION CURVES FOR 64, 70 mm HARVEST SIZE. 1987

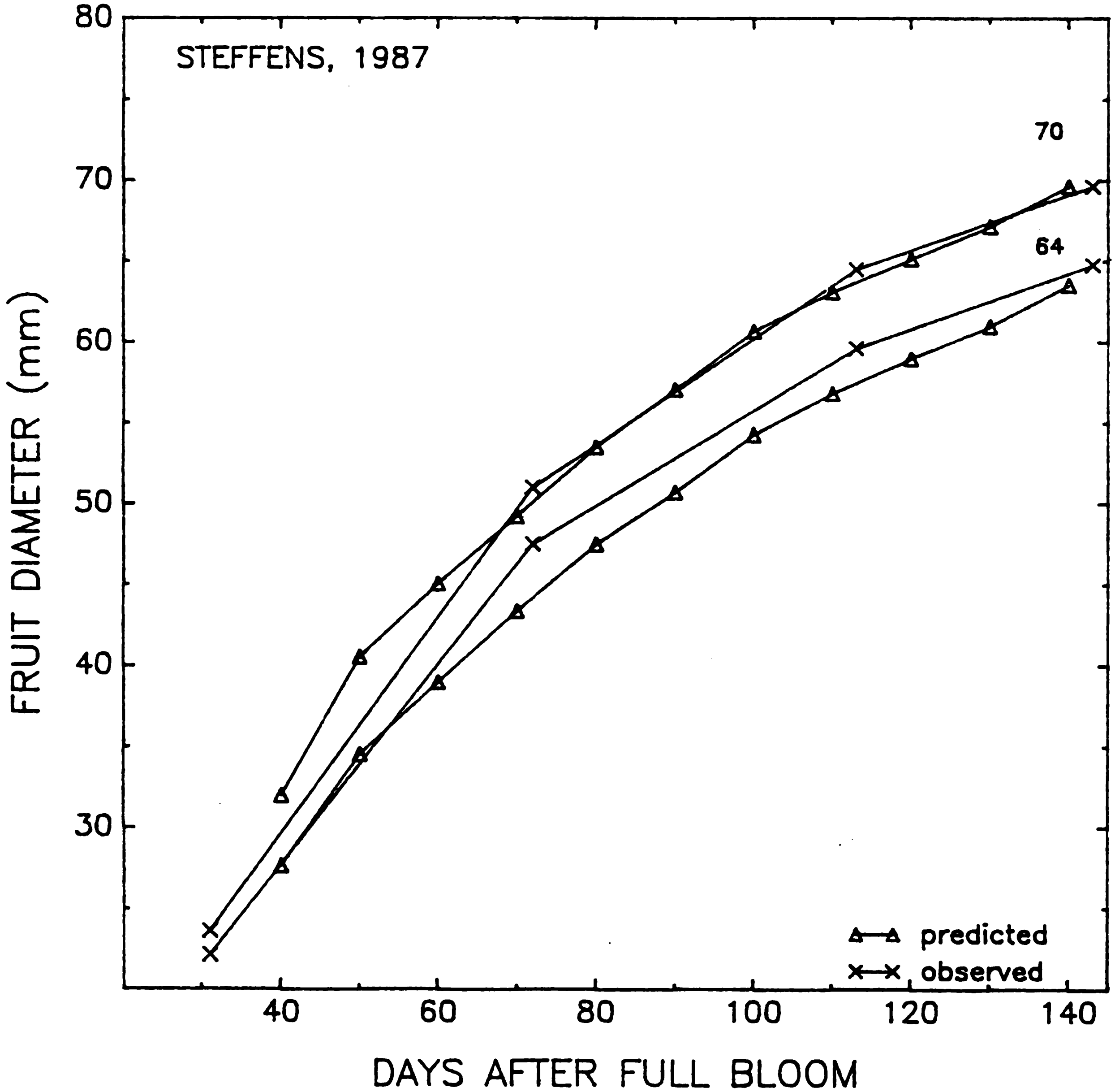
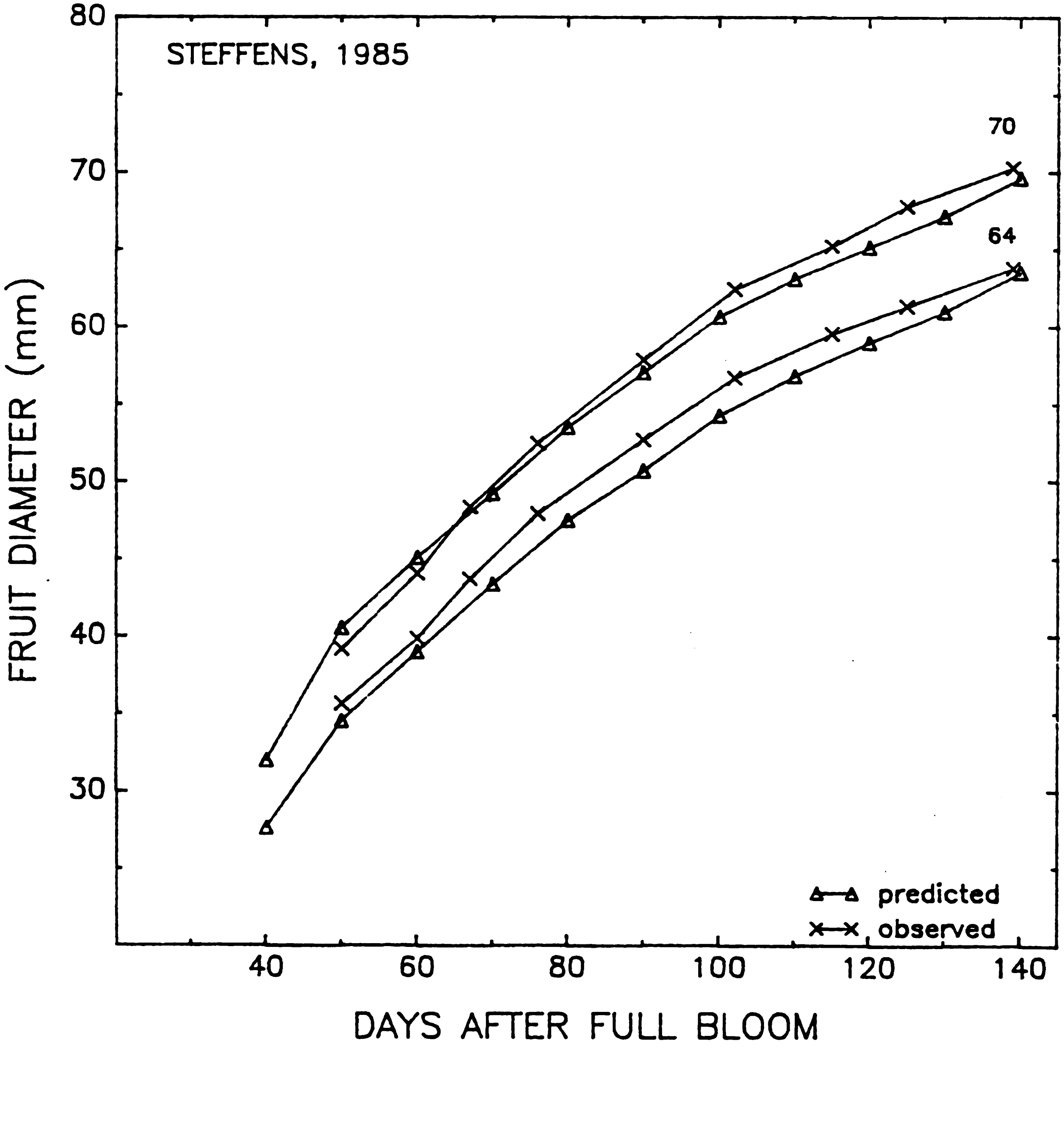

STEFFENS, 1987
FRUIT DIAMETER (mm)
DAYS AFTER FULL BLOOM
80
70
60
50
40
30
40
60
80
100
120
140
70
64
predicted
observed

FIG. 17. ACTUAL DIAMETER IN ONE ORCHARD VS. AVERAGED MICHIGAN PREDICTION CURVES FOR 64, 70 mm HARVEST SIZE, 1985


STEFFENS, 1985
FRUIT DIAMETER (mm)
DAYS AFTER FULL BLOOM
70
64
predicted
observed
80
70
60
50
40
30
40
60
80
100
120
140

The combined data for all three Michigan orchards were used to prepare tables for predicting harvest size, based upon diameters at 5 day intervals from 40 to 140 DAFB (Tables 4 and 5).

In order to test the accuracy of the prediction curves for 1985-1987 in Michigan, the averaged regression equations on various dates of measurement were used to predict average harvest size in one orchard; these values were then compared with actual size at harvest (Table 6). Predicting harvest size of fruit on old trees in another orchard gave similar results (Table 7). Use of the averaged prediction equations for Michigan allowed estimates of actual size within 2-3 mm. Similar results were obtained when harvest size was calculated for fruits on young trees (Table 8). Prediction based on measurements taken at 48 DAFB was less accurate than predictions based on measurements for other dates.

Another necessary test to determine the validity of using the calculated Michigan chart consisted of comparing the predicted percentages of fruits in various size classes vs. the observed percentages (Table 9). Differences between predicted and observed values were 10% or less in comparisons 2, 4, 8, and 9, and 13% or less in comparisons 1, 5, & 7 (Table 9). Only in comparisons 3 and 6 did differences reach 20% or greater; in both cases predicted values were larger than observed ones.

Table 4. Predicted diameters in mm. for Starkrimson 'Delicious'apples at various days after full bloom (DAFB), based upon data from 3 orchards over 3 years.

DAFB	Fruit diameter at harvest (mm)					
	51	57	64	70	76	83
40	23.3	26.2	27.6	32.0	36.3	37.9
45	26.4	29.7	31.1	36.2	41.4	42.9
50	29.6	33.2	34.5	40.5	46.5	48.0
55	31.2	35.1	36.7	42.8	48.8	50.7
60	32.9	37.0	38.9	45.0	51.1	53.4
65	34.4	38.7	41.1	47.1	53.1	55.8
70	35.9	40.4	43.3	49.2	55.0	58.3
75	37.5	42.2	45.4	51.3	57.3	60.9
80	39.0	43.9	47.5	53.5	59.5	63.4
85	40.3	45.4	49.1	55.3	61.5	65.5
90	41.6	46.8	50.7	57.0	63.4	67.6
95	42.9	48.3	52.5	58.9	65.2	69.8
100	44.3	49.8	54.3	60.7	67.0	71.9
105	45.2	50.8	55.5	61.9	68.2	73.4
110	46.1	51.8	56.8	63.1	69.4	74.8
115	46.8	52.6	57.9	64.1	70.3	76.0
120	47.5	53.5	59.0	65.1	71.3	77.2
125	48.3	54.3	60.0	66.1	72.3	78.4
130	49.0	55.1	61.0	67.1	73.3	79.6
135	49.9	56.1	62.2	68.4	74.5	81.1
140	50.8	57.2	63.5	69.6	75.7	82.6

Table 5. Predicted diameters in in. for Starkrimson 'Delicious' apples at various days after full bloom (DAFB), based upon data from 3 orchards over 3 years

DAFB	Fruit diameter at harvest (inches)					
	2.00	2.25	2.50	2.75	3.00	3.25
40	0.92	1.03	1.09	1.26	1.43	1.49
45	1.04	1.17	1.22	1.43	1.63	1.69
50	1.16	1.31	1.36	1.59	1.83	1.89
55	1.23	1.38	1.45	1.68	1.92	2.00
60	1.29	1.46	1.53	1.77	2.01	2.10
65	1.35	1.52	1.62	1.85	2.09	2.20
70	1.41	1.59	1.70	1.94	2.17	2.30
75	1.47	1.66	1.79	2.02	2.25	2.40
80	1.54	1.73	1.87	2.11	2.34	2.50
85	1.59	1.79	1.93	2.18	2.42	2.58
90	1.64	1.84	1.99	2.25	2.49	2.66
95	1.69	1.90	2.06	2.32	2.57	2.75
100	1.74	1.96	2.14	2.39	2.64	2.83
105	1.78	2.00	2.19	2.44	2.69	2.89
110	1.81	2.04	2.24	2.48	2.73	2.95
115	1.84	2.07	2.28	2.52	2.77	2.99
120	1.87	2.10	2.32	2.56	2.81	3.04
125	1.90	2.14	2.36	2.60	2.85	3.09
130	1.93	2.17	2.39	2.64	2.89	3.13
135	1.96	2.21	2.45	2.69	2.93	3.19
140	2.00	2.25	2.50	2.75	3.00	3.25

Table 6. Actual fruit diameter at harvest and diameter predicted by using regression equation, based on average diameter at various times prior to harvest over a 3-year period. Wittenbach orchard, Belding MI, 1985-1987.

Year	DAFB	Intercept a	Slope b	Actual size (mm) X	Predicted harvest size (mm) Y=a+(b*X)	Actual harvest size (mm)
1985						
	48	35.03	0.815	36.5	64.7	
	67	22.76	0.973	44.7	66.2	
	75	16.26	1.016	49.1	66.1	
	90	15.61	0.898	54.2	64.2	
	101	8.19	0.998	58.0	66.1	
	119	-1.06	1.087	63.2	67.6	
	126	0.54	1.023	63.2	65.2	
	140					66.3
1986						
	67	22.76	0.973	41.4	63.1	
	75	16.26	1.016	45.5	62.5	
	101	8.19	0.998	54.7	62.7	
	134					61.1
1987						
	48	35.03	0.815	34.4	63.0	
	67	22.76	0.973	44.3	65.8	
	101	8.19	0.998	55.6	63.7	
	119	-1.06	1.087	60.4	64.6	
	140					65.3

Table 7. Actual fruit diameter at harvest and diameter predicted by using regression equation, based on average diameter at various times prior to harvest. Mature trees at the Wardowski orchard, Leslie, MI. 1987.

DAFB	Intercept a	Slope b	Actual size (mm) X	Predicted harvest size (mm) Y=a+(b*X)	Actual harvest size (mm)
48	35.03	0.815	36.4	64.7	
67	22.76	0.973	46.5	67.9	
75	16.26	1.016	49.9	66.9	
90	15.61	0.898	54.8	64.8	
140					64.8

Table 8. Actual fruit diameter at harvest and diameter predicted by using regression equation, based on average diameter at various times prior to harvest. Young trees at the Clarksville Horticultural Experimental Station. 1987.

DAFB	Intercept a	Slope b	Actual size (mm) X	Predicted harvest size (mm) Y=a+(b*X)	Actual harvest size (mm)
48	35.03	0.815	39.3	67.1	
75	16.26	1.016	55.7	72.8	
101	8.19	0.998	64.8	74.0	
119	-1.06	1.087	69.8	70.4	
140					72.9

Table 9. Predicted percentages of fruits in various size classes vs. observed percentages based upon combined data for 3 Michigan orchards over 3 years. Prediction based on fruit diameter at 100-102 DAFB.

Comparison	Orchard	Year		Diameter (mm) <57	57+	64+	70+	76+
1	Rasch	1985	Predicted	2	30	48	20	0
			Observed	3	24	37	33	3
			Diff.	-1	6	11	-13	-3
2		1986	Predicted	11	64	22	3	0
			Observed	9	54	31	6	0
			Diff.	2	10	-9	-3	0
3		1987	Predicted	0	30	53	17	0
			Observed	10	70	20	0	0
			Diff.	-10	-40	33	17	0
4	Steffens	1985	Predicted	8	42	39	11	0
			Observed	15	39	35	11	0
			Diff.	-7	3	4	0	0
5		1986	Predicted	0	7	34	38	21
			Observed	1	9	23	50	17
			Diff.	-1	-2	11	-12	3
6		1987	Predicted	0	4	30	54	12
			Observed	0	12	50	38	0
			Diff.	0	-8	-20	16	12
7	Wittenbach	1985	Predicted	1	31	54	13	1
			Observed	3	30	43	19	5
			Diff.	-2	1	11	-6	-4
8		1986	Predicted	7	56	36	1	0
			Observed	13	61	26	0	0
			Diff.	-6	-5	10	1	0
9		1987	Predicted	0	37	36	20	7
			Observed	3	40	30	20	7
			Diff.	-3	-3	6	0	0

Accuracy in harvest size prediction was similar to that obtained by Batjer, et al. in 1957. By 50 DAFB, predicted harvest size of about 50% of the fruits fell within 3 mm of actual harvest diameter; this increased to 87% by 100 DAFB (Fig. 18). Percentages of fruits falling within 0.8 mm were 14% and 53% at 50 and 125 DAFB, respectively.

Data supplied by Curry for 2 of the 4 Washington orchards are compared with those from the Washington chart in Fig. 19. Average fruit diameters for individual orchards agreed well with those in the Washington chart. The other 2 curves for individual orchards varied, but their harvest diameter fell within the 70-76 mm range (data not shown). The average curve for all 4 orchards also fell within the same range (Fig. 20). Although sample size differed between Batjer, et al. and Curry's work - - 8 orchards x 5 years and 4 orchards x 1 year, respectively - - agreement was close. Thus, the Washington chart appears to be valid for Washington growers despite the passage of 26 years.

CO_2 assimilation did not differ significantly between old and young trees when measured on September 12, 1987, nor did leaf or stomatal conductance (Table 10). However, vapor pressure deficit, transpiration rate, and transpiration ratio were significantly higher, and internal CO_2 and water use efficiency lower, in leaves on young trees. Thus, although the leaves on young trees transpired more, assimilation was similar to that in old trees.

FIG. 18. PERCENTAGE OF FRUITS WHOSE ACTUAL HARVEST HARVEST SIZE FELL WITHIN INDICATED RANGES OF PREDICTED SIZE AT 50, 100, AND 125 DAFB. STEFFENS ORCHARD, 1985

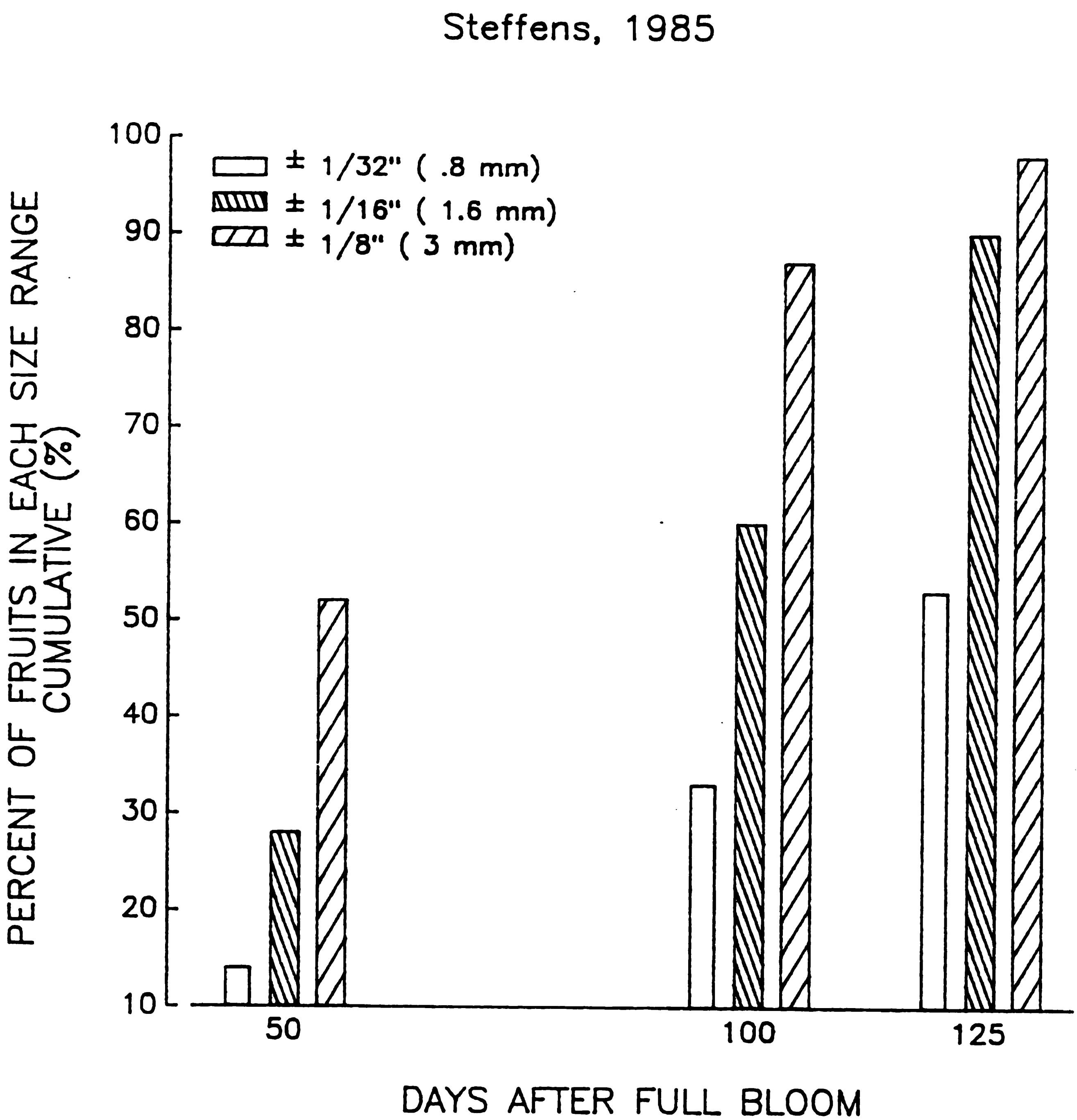

Steffens, 1985
± 1/32" (.8 mm)
± 1/16" (1.6 mm)
± 1/8" (3 mm)
PERCENT OF FRUITS IN EACH SIZE RANGE
CUMULATIVE (%)
100
90
80
70
60
50
40
30
20
10
50
100
125
DAYS AFTER FULL BLOOM

FIG. 19a,b. COMPARISON BETWEEN GROWTH CURVES OF FRUITS AS MEASURED BY CURRY (WASHINGTON, 1983) AND "STANDARD" WASHINGTON CURVE OF BATJER, ET AL. (1957)

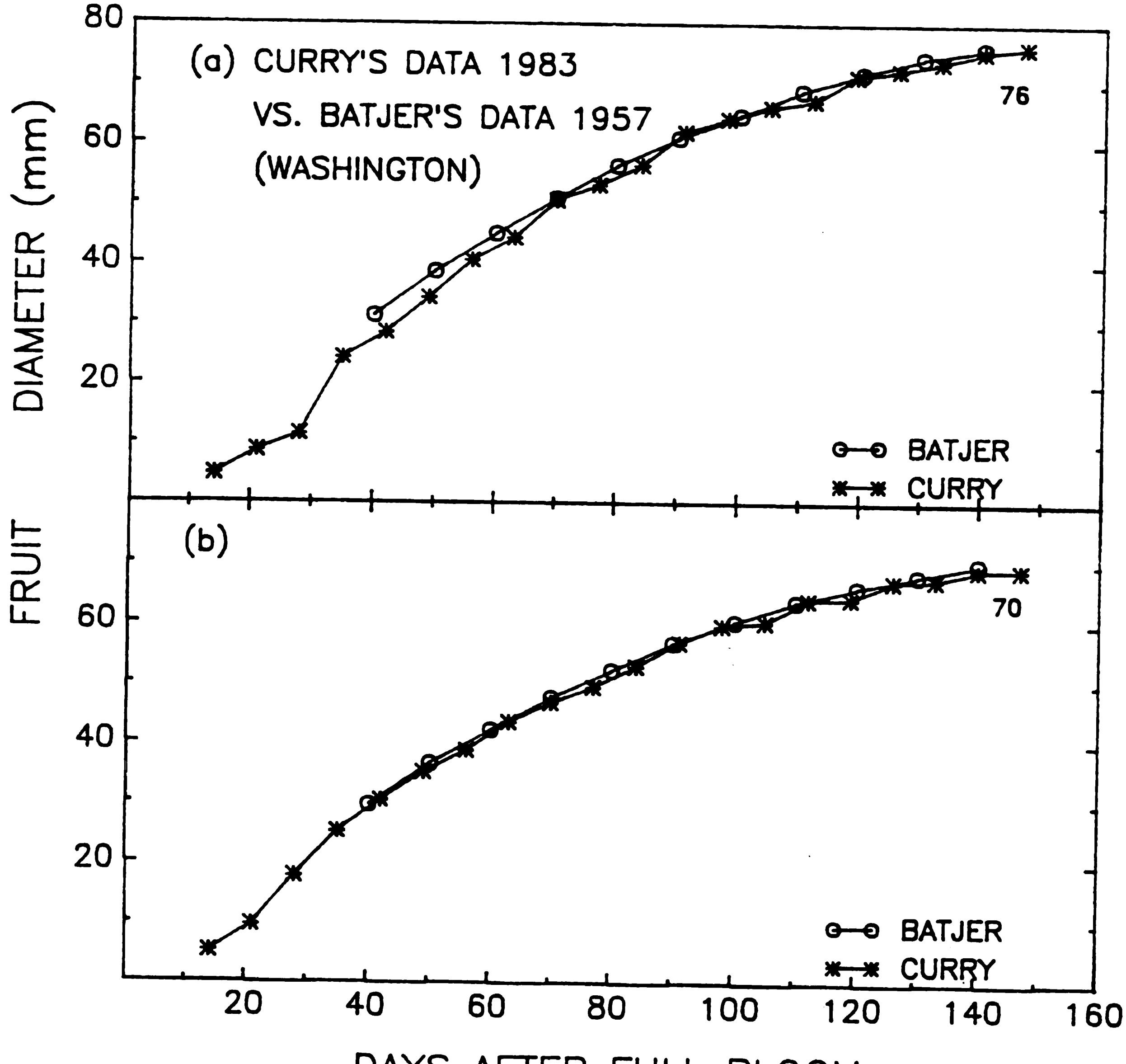

(a) CURRY'S DATA 1983
VS. BATJER'S DATA 1957
(WASHINGTON)
76
BATJER
CURRY
(b)
70
BATJER
CURRY
FRUIT DIAMETER (mm)
80
60
40
20
60
40
20
20
40
60
80
100
120
140
160
DAYS AFTER FULL BLOOM

FIG. 20. AVERAGE DIAMETER FOR DELICIOUS FRUITS MEASURED BY CURRY IN WASHINGTON IN 1983 VS. CURVES FOR 70 AND 76 mm. FRUITS BASED UPON DATA OF BATJER, ET AL. (1957)

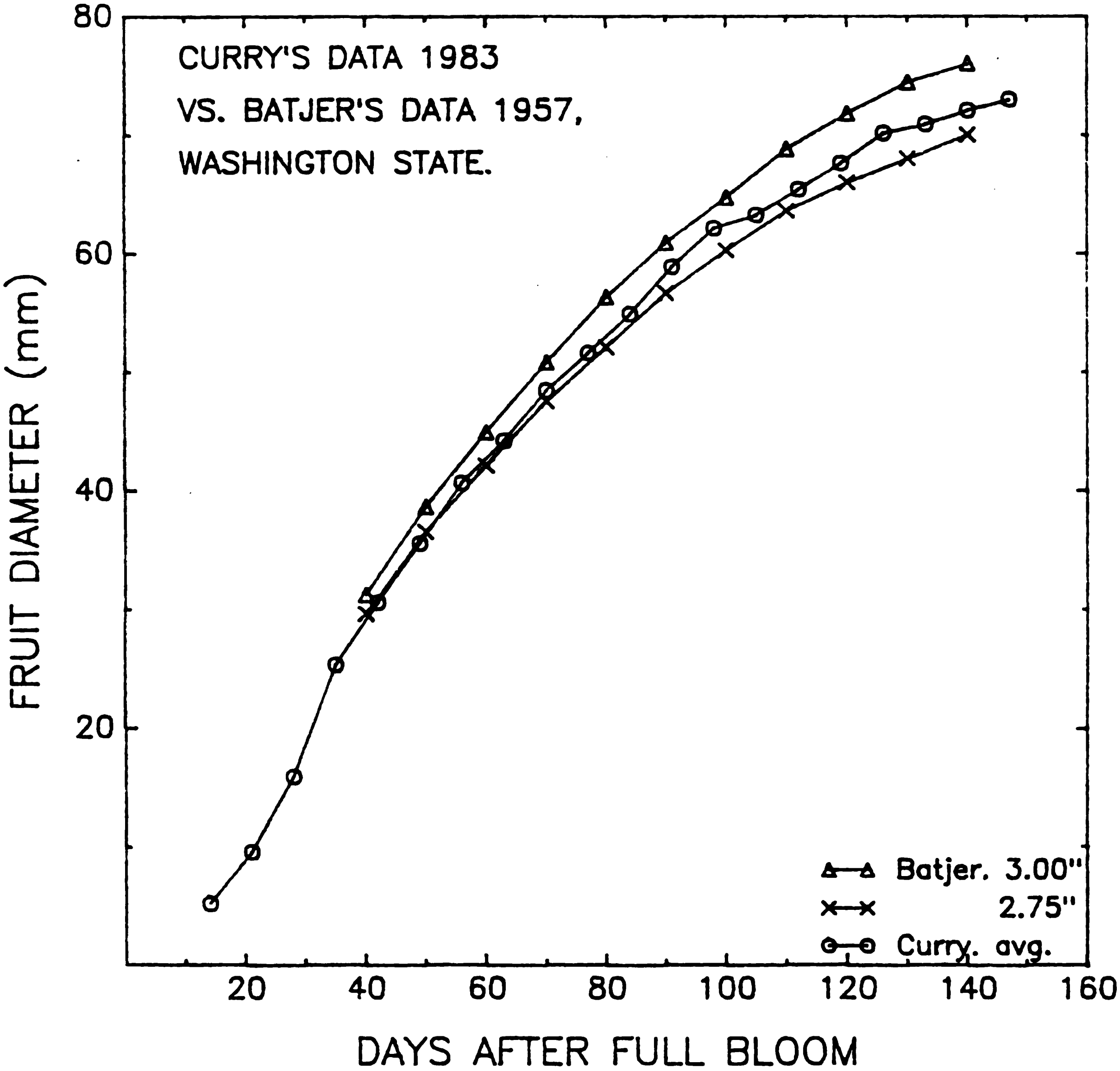

CURRY'S DATA 1983
VS. BATJER'S DATA 1957,
WASHINGTON STATE.
FRUIT DIAMETER (mm)
80
60
40
20
20
40
60
80
100
120
140
160
DAYS AFTER FULL BLOOM
Batjer. 3.00"
2.75"
Curry. avg.

Table 10. Photosynthesis measurements on old vs. young Starkrimson 'Delicious' trees in Wardowski orchard, Leslie, MI. September 12, 1987.

Observation	Tree age: Old	Young
Vapor pressure deficit ($KPa/m^2/s$)	2.02	2.96 *
CO_2 assimilation ($\mu mols/dm^2/hr$)	9.03	9.24 ns
Leaf conductance ($millimols/m^2/s$)	220.54	205.14 ns
Stomatal conductance ($millimols/m^2/s$)	137.84	128.21 ns
Internal CO_2 ($\mu mol/mol$)	252	241 *
Transpiration ($millimols/m^2/s$)	4.49	6.24 *
Transpiration ratio (mol H_2O/mol CO_2)	514	707 *
Water use efficiency (μmol CO_2/mol H_2O)	2.07	1.46 *

* Significant effect of tree age at 5% level (LSD)

Discussion

Forshey (5) suggested that major differences in climatic conditions between Washington and New York's Hudson Valley were reflected in differences in fruit growth curves in the two areas. Forshey worked with 'McIntosh' to determine whether harvest size could be predicted. Although no comparison between his and Washington charts was intended, Forshey realized that varietal differences between 'McIntosh' and 'Delicious', and, more importantly, differences in growing conditions between the two areas, prevented the use of the Washington chart for predicting harvest size of 'McIntosh' in New York.

The sunny days and cool nights in the apple producing areas of Washington might explain the more rapid growth rates of fruits there. In the Hudson Valley, suboptimal growing conditions such as cloudy and cool days were considered by Forshey to be responsible for the variability in growth rates. Conditions in Michigan resemble those in New York, therefore the observed inconsistencies might be attributed to weather conditions. Weather conditions alone, however, could not account for the variability among orchards in any given year. Cultural and management practices, such as crop load, tree vigor, irrigation and fertilizer regimes, and insect control, obviously affect harvest size. Only the Wittenbach orchard was irrigated. Although no visual evidence of water stress was noticeable in any of the orchards, moderate water stress may have occurred. Neither soil water potential nor leaf water content was measured at any time, therefore no concrete conclusions can be drawn. Another cause of variability may be the method used in calculating the predicted growth curves. Since the measurements were not taken at regular 10-day intervals, interpolation may have been a source of error. However, unless measurement is too infrequent, interpolated data should be just as accurate as actual data. They might even be more accurate because unusual and irregular data are averaged out.

Another potential cause of inconsistencies in the results is the volume of data used in preparing the size prediction tables. Batjer, et al. (1) used more data in preparing their growth curves (8 years x 4-6 orchards in Washington vs. 3 years x 3-5 orchards in Michigan). However, they do not provide information as to orchard-to-orchard and year-to-year variability, for they present only one table for 8 years x 4-6 orchards. Therefore one cannot determine whether data for any one orchard and year fit the curve. In addition, Batjer et al. do not specify what strain of 'Delicious' was used, although 'Starking' was probably the most abundant strain at that time. Thus strain differences could be responsible for the observed differences in growth curves. However, the fact that the data supplied by Curry closely parallel those in the table prepared by Batjer, et al. suggests that the differences in growth rates observed are related to climatic, rather than strain differences.

Young trees bear larger fruits than do old trees, yet growth rates of fruits of similar harvest size on young and old trees were parallel from mid-summer to harvest. Thus fruit size potential is established very early in the season. CO_2 assimilation in September did not differ appreciably in leaves on old vs. young trees in one orchard, although earlier measurements might have revealed significant differences. Transpiration rate was higher in young trees, resulting in lower water use efficiency. However, this is unlikely to have affected fruit size.

Accuracy in predicting harvest size was comparable to, if not better than, to those obtained by Batjer, et al. Thus, although many variables can affect harvest size of Starkrimson 'Delicious' fruits in Michigan, the use of the Michigan chart allows reasonably accurate prediction of harvest size.

Conclusions

1- In accordance with the findings of Batjer, et al. and of Forshey, final fruit size of Starkrimson 'Delicious' can be predicted reasonably accurately by measuring fruit diameters beginning in mid-summer.

2- Final size is determined early in the season. Therefore fruits of the same harvest size on young vs. old trees grow at similar rates during the final half of the growing season.

3- In general, Starkrimson 'Delicious' fruits in Michigan grow more slowly than would be indicated by the Washington chart. Therefore predicted values based on this chart generally overestimate actual size at harvest.

4- The available data suggest that harvest size can be predicted reasonably accurately when the data are averaged for several orchards over several years. The earliest time for reliable prediction is 90 to 100 DAFB (mid-August).

5- A size prediction chart has been prepared based upon data for Starkrimson 'Delicious' in Michigan (Table 4, 5). This chart is only partially reliable because of variation within orchards and within years. Environmental and/or cultural effects may be responsible for some of these differences.

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