HILGARDIA

A JOURNAL OF AGRICULTURAL SCIENCE PUBLISHED BY
THE CALIFORNIA AGRICULTURAL EXPERIMENT STATION

Volume 42, Number 12 • July, 1974

Effect of Time and Amount of Fruit Thinning on Leaf Carbohydrates and Fruit Set in Valencia Oranges

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HILGA 4 441–450 (1974)
USA ISSN 0073–2230

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Starting in 1970, an "on" year for fruit set, young Valencia orange fruit were thinned in July, September, and November. Degrees of thinning were 0, 33, 66, and 100 per cent. Leaf samples were taken in 1971 for carbohydrate analysis.

The fruiting cycle was almost completely reversed when all of the young fruit were removed in July. Less fruit removal or removal at a later date was progressively less effective. Thinning had no effect on the size of the fruit remaining on the tree. In the year after thinning, fruit size was inversely related to number of fruit on the tree. The amount of fall growth in 1970 was increased by fruit removal. Likewise, the spring growth in 1971 was earlier and more extensive on the trees that were 100 per cent thinned in July, 1970.

Carbohydrates in the leaves were mainly starch, sucrose and one unidentified compound. Also present were small amounts of fructose, glucose, malic acid, myo-inositol, and one other unidentified soluble carbohydrate. There was a positive correlation between the fruit set in the spring of 1971 and the concentration of starch in the leaves before the beginning of 1971 spring growth. During the June drop period, there was an increase in leaf starch, but not in sugar, associated with an increase in degree of thinning. At the end of the June drop period, there were no significant differences in starch or sugar content. Data presented in this study indicate that carbohydrates, in the amounts present, were not limiting for fruit set.

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INTRODUCTION

ALTERNATE BEARING is characteristic of the Valencia orange, especially in coastal areas of California. where the flowering-to-harvest cycle frequently spans 18 months. The basis of alternate bearing is not understood, but the degree of alternate bearing is influenced by both the amount of fruit on the tree and the length of time of on-tree storage of mature fruit. It is clear that large amounts of carbohydrates are utilized in the process of flowering, in fruit growth and development, and during on-tree storage. It therefore seemed reasonable to test the hypothesis that a carbohydrate deficit limits flowering, set, and retention of young fruit, and thus is the cause of alternate bearing in Valencia orange. If this were the case, the critical period would be from the time of flowering through the June drop period. This paper describes a thinning experiment, and presents the effects of degree and time of thinning on fruiting in the year after thinning, and on carbohydrate levels during the June drop period. Thinning was done in order to compare trees with various fruit loads under equal environmental conditions in the same year.

LITERATURE REVIEW

Studies on the thinning of Valencia oranges go back at least to Waynick's (1929) report that the removal of about half of the crop at the beginning of the harvest season did not increase the amount of relative growth subsequently made by the rest of the fruit. In the following year all trees set a heavy crop. Shamel and Pomeroy (1932) found an increase in fruit size in current-crop fruit as a result of heavy thinning, but did not report the effect on the following crop. Parker (1934), in an extensive study on thinning, reported that yields were increased in the year following thinning, but concluded, in a cost analysis, that the practice was not feasible. Since Parker's work, no additional studies on thinning of Valencia oranges in California have been reported. In Australia, West, Barnard, and Allen (1937) found that thinning the fruit by 30 to 40 per cent in the "on" year caused a slight increase in the ultimate size of the fruit left on the tree and a considerable increase in the number of flowers formed and fruit set during the following season.

A number of studies have been reported on alternate bearing as influenced by time of effective fruit removal. After a severe freeze in Tulare County

Submitted for publication December 4, 1973.

in the winter of 1937, yields were larger in 1938 in unprotected orchards than in protected ones, and Johnston (1939) attributed this to the early removal of frozen fruit. Hodgson, Cameron, and Eggers (1941) reported that the heavy crop in the on year depressed tree growth during the current season and yield in the following season, and that the depressing effects could be reduced by early harvesting. Jennings (1947), in comparing early- and late-picked orchards, reported that late picking decreased yields the following year and increased the severity of alternate bearing. Jones and Cree (1954), in a 14-year study on effects of early, midseason, and late harvesting of Valencia oranges, concluded that late harvest reduced yield and grade and increased the alternate bearing habit. Jones *et al.* (1964) showed a curvilinear relation between harvest date and yield in the following year and suggested that Valencia orange trees fruit to the limit of available carbohydrates.

In late winter or early spring, axillary buds begin to grow as vegetative shoots (Schneider, 1968), and flowers form on these new shoots. In coastal California, fruit set from these flowers require more than 12 months to mature, and are still on the tree during the next spring flowering period. Thus, for a period of time, two sets of fruit are on the tree. The amount of fruit in the first set apparently has a marked effect on the second set—hence, alternate bearing. Carbohydrate changes appear to be associated with the spring flush of growth. Before that growth flush, carbohydrates accumulate in leaves and twigs (Jones and Steinacker, 1951; Dugger and Palmer, 1969), and during growth the carbohydrate supply, at least in leaves, declines (Hilgeman, Dunlap, and Sharples, 1967; Martin, 1942; Sharples and Burkhart, 1954; Smith, Reuther, and Specht, 1952). Jones *et al.* (1970) and Jones and Embleton (1971) reported that carbohydrate accumulation in Valencia orange leaves, sampled in February, was inversely related to the fruit load on the tree at the time of sampling, but that the amount of fruit produced from the flowering that followed the time of leaf sample was directly related to the carbohydrate level. They also reported that late harvest reduced fruit production in the following year but did not significantly alter carbohydrate accumulation in leaves sampled in February. These findings suggest that carbohydrates may not be the controlling factor in alternate bearing. Lewis, Coggins, and Hield (1964) reported the same general relations between carbohydrates and fruiting in 'Wilking' mandarin (*Citrus reticulata* Blanco) as has been reported for Valencia oranges, but they found that naphthaleneacetic acid thinning treatment changed the production cycle without significantly affecting carbohydrate accumulation. From this, they concluded that the mechanism controlling alternate bearing appeared not to be carbohydrates. Jones *et al.* (1973) found that total carbohydrates in the leaves of 'Kinnow' mandarins apparently were not related to fruit load, but carbohydrates in the feeder roots were drastically depleted by an on crop. Rosedale, Miller, and Platt (1968) reported that 'Kinnow' mandarin trees failed to recover, in some instances, following an extreme on year. Stewart, Wheaton, and Reese (1968) reported that 'Murcott' mandarins are subject to the same extreme alternate bearing, and that trees bearing heavy crops may collapse and die during the time of fruit maturation. They concluded that the trouble may be caused by nitrogen and potassium starvation. Jones *et al.* (1973) and Jones and Embleton (1968) found that with both the 'Kinnow' mandarin and the Valencia orange a heavy crop load depressed nitrogen, phosphorus, and potassium, but not to levels normally considered deficient.

MATERIALS AND METHODS

This study was started in 1970 in Ventura County, on 12-year-old Olinda Valencia [*Citrus sinensis* (L.) Osbeck] trees with sweet orange [*C. sinensis* (L.) Osbeck] rootstock, planted in Sorrento silty clay loam soil. The trees were in an alternate-bearing cycle and were in the on year. The arrangement was a 3 × 3 factorial with seven replications of single-tree plots. Treatments consisted of removing fruit by hand in July (three months after bloom), September (five months after bloom), and November (seven months after bloom). We attempted to remove 33, 66, and 100 per cent of the fruit. The amounts actually removed, with one exception, were lower—July: 21, 38, and 94 per cent; September: 33, 51, and 98 per cent; November: 30, 45, and 99 per cent. Hereafter, however, the treatments will be referred to as 33, 66, and 100 per cent thinned. Remaining fruit was harvested at maturity in August, 1971 (16 months after bloom). The fruit set in the spring of 1971 was not thinned but was harvested as mature fruit in September, 1972 (17 months after bloom). The 1972 yield was a measure of the effect of the 1970 thinning (month and amount) on the following crop. Yield was recorded as field boxes per tree. The vegetative growth made in the fall of 1970 and the flowering in the spring of 1972 were rated. Leaf samples for carbohydrate analyses were obtained before flowering and through the June drop period of 1971. Each single-tree sample, consisting of 40 spring-flush leaves from nonfruiting shoots, was placed in a plastic bag, covered with ice, and delivered to the laboratory. After washing, the leaves were dried in a forced-draft oven at 60°C, ground in a Christy-Norris mill and then in a ball mill.

Two procedures were used for sugar analysis for different groupings of samples. One group consisted of six sample dates from April 27 to July 15, 1971, inclusive, from the nonthinned and the July-thinned treatments only. The other group consisted of all thinning treatments sampled on February 4, April 27, and July 15, 1971, only.

Samples of the first group were extracted with 80 per cent ethanol; an aliquot was dried, silylated with TRI-SIL (a mixed formula of hexamethyldisilazane, trimethylchlorosilane, and pyridine, from the Pierce Chemical Company), and injected into a Hewlett-Packard 7620A gas chromatograph equipped with a dual hydrogen flame detector and a dual glass 6′ × ¼″ OD column packed with SE-30, silicone gum rubber on 80- to 100-mesh, high-performance chromosorb W. Operating conditions were: oven temperature programmed at post-injection temperature of 125°C, held for 2 min.; level 1, increased at 8°/min. to 150° and held 1 min.; level 2, increased at 6°/min. to 200° and held 1 min.; level 3, increased 15°/min. to 260° and held 8 min.; injection temperature, 260°; detector temperature, 300°; helium-carrier gas flow, 75 ml/min.; hydrogen flow, 30 ml/min; and air flow, 300 ml/min. A Hewlett-Packard 3370A integrator was used.

Identification of compounds was by co-chromatography with known compounds, which were confirmed by mass spectrometry. (Appreciation is expressed to Dr. Noel T. Keen, Dept. of Plant Pathology, University of California, Riverside, for this latter identification.) Quantitative determination of the identified compounds was accomplished by the use of fucose as an internal standard. Starch in the residue from the ethanol extraction was digested with diastase, determined by the Anthrone procedure (Scott and Melvin, 1953), and reported as glucose equivalent. The GLC procedure and the Anthrone procedure were compared on four samples. Total 80 per cent ethanol-soluble carbohydrates for GLC was 7.63 per cent and for Anthrone, 7.53.

Samples of the second group were extracted in the same way as those of the first group. The ethanolic extract was cleared with $ZnSO_4$ and $Ba(OH)_2$ (Dugger and Palmer, 1969), and total sugars were determined with Anthrone. Starch was determined as above.

RESULTS AND DISCUSSION

Yield. Figure 1 shows the effect of fruit removal on subsequent fruiting. The yield for 1971, of course, was inversely related to the hand thinning in 1970 since it was merely a measure of the fruit not removed by that thinning. The alternate bearing habit of these trees was modified in 1972, and the degree of change was dependent on both the percentage of fruit removed by the thinning in 1970 and the date of thinning. An almost complete reversal of fruiting cycle occurred when all of the young fruit was removed in July. Less fruit removal or removal at a later date was progressively less effective.

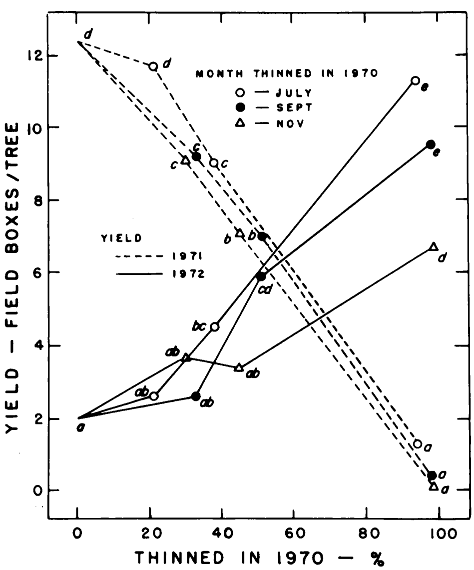

Fig. 1. Yield of Valencia oranges in 1971 and 1972 as related to month and percentage of thinning in 1970. Within each year, differences are significant at the 1 per cent level if there are no letters in common. Field box = about 50 pounds.

In figure 2, we have combined yield data from previous experiments (Jones *et al.*, 1964) with 1972 yield data of the present experiment on a relative basis. This shows the effect of time of fruit removal on subsequent yield. When an October harvest was 100 per cent on a relative basis, earlier harvests produced increasingly more yield. The relation was curvilinear with $R = 0.997$, significant at the 1 per cent level.

Fruit size. Thinning had no effect on the size of the fruit harvested in 1971 (table 1). In the next crop, fruit size was inversely related to the number of fruit on the tree.

TABLE 1

MAIN EFFECTS OF MONTH AND PERCENTAGE OF FRUIT THINNING ON SIZE OF VALENCIA ORANGES

Thinning, 1970	No. fruit per carton*	
	1971†	1972‡
By month:		
July	129	110_b
Sept.	138	104_{ab}
Nov.	137	96_a
By percentage:		
33	135	102_{ab}
66	134	99_a
100	......§	110_b

* Cartons measure 10 11/16" × 16 3/8" × 10 1/4".
† Differences for 1971 were not significant.
‡ Differences are significant at the 1 per cent level if there are no subscript letters in common.
§ Inadequate number of fruit to evaluate.

Tree condition and fall vegetative growth. On Valencia orange trees in Ventura County the most well-defined and uniform growth cycle is initiated in the spring. During the remainder of the year no new growth may occur or there may be one or more less well-defined

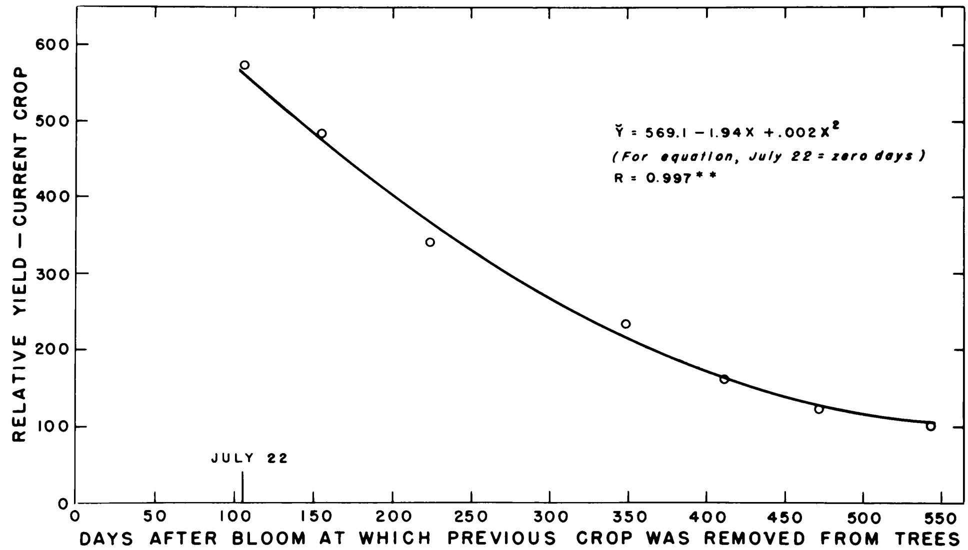

Fig. 2. Relative yield (per cent) of Valencia oranges as influenced by time of fruit removal. Latest fruit removal equal to 100. Data from present study combined with those of Jones *et al.* (1964).

vegetative cycles (Jones and Steinacker, 1951). Table 2 shows that the most fall growth occurred when all fruit was removed early. A decreased degree and a later date of thinning resulted in a decreasing amount of fall growth. The degree of thinning in November had no significant effect on fall growth; low seasonal temperature was probably the limiting factor for growth.

TABLE 2

EFFECT OF MONTH AND PERCENTAGE OF FRUIT THINNING ON AMOUNT OF VEGETATIVE GROWTH OF VALENCIA ORANGE TREES (FALL, 1970)

Percentage of thinning, 1970	Amount of vegetative growth* when thinned in:		
	July†	Sept.†	Nov.†
0	1.6_a	1.6_a	1.6_a
33	1.9_a	2.0_{ab}	1.3_a
66	2.9_{ab}	3.9_b	1.9_a
100	7.0_c	5.9_c	2.0_{ab}

* Ratings made Feb., 1971. Relative values: 0 = no fall growth, to 10 = fall growth over entire tree.
† All values are comparable; differences are significant at the 1 per cent level if there are no subscript letters in common.

Tree condition and spring growth. As discussed earlier, flowering and fruit set occur on vegetative shoots produced in the spring flush of growth. In the spring of 1971 and again in the spring of 1972 we observed that the beginning of growth was delayed by about three weeks on those trees with a heavy fruit load as compared with those with a light fruit load. Also, on the heavily loaded trees, fewer buds grew; the shoots that did grow were shorter; and relatively few flowers were produced. The net result was a much reduced yield by such trees. Thus, alternate bearing apparently may be controlled by some factor or factors that either hold buds dormant or initiate bud growth in the spring. Attempts have been made to initiate bud growth by the application of exogenous growth regulators (Krezdorn, 1969; del Rivero, Veyrat, and de Berreda, 1969; Monselise and Goren, 1969). However, Moss (1971) concluded that the use of chemical sprays to control biennial bearing by increasing flowering in an "off" year was not feasible at present.

Carbohydrates. In the GLC study of the July-thinned trees, the major iden-

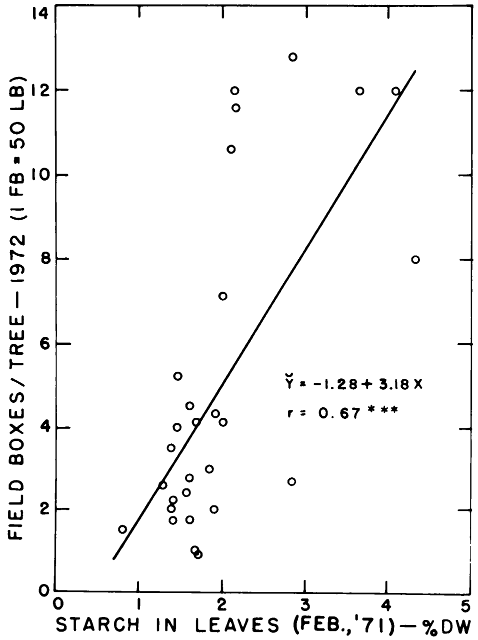

Fig. 3. Relation of 1972 yield of Valencia oranges to leaf starch level of February, 1971.

tified soluble carbohydrate in leaves was sucrose. Fructose, glucose, malic acid, and myo-inositol were present in much smaller quantities. Two other soluble carbohydrates, one of major quantity, differed from all authentic carbohydrates examined. Starch was present in major amounts in all samples.

Figure 3 shows the relation between starch content in leaves just before the beginning of spring growth and fruit set from the following flowering as measured by yield at fruit maturity ($r = 0.67^{***}$). The r value of 0.57 between total carbohydrates and yield was significant at the 1 per cent level; r 0.81 between total carbohydrates and starch was significant at the 1 per cent level; and r 0.45 between total and soluble carbohydrates was significant at the 5 per cent level. The mean value for soluble carbohydrates was 8.08 per cent, with no significance due to thinning treatment. Thus, most of the variation in total carbohydrate was due to variation in starch. The relation shown in figure 3 is in accord with results reported by Jones *et al.* (1964, 1970). Because of a lack of difference in total carbohydrates in early- and late-picked

TABLE 3

EFFECT OF THINNING IN JULY, 1970, ON CARBOHYDRATE CONTENT OF VALENCIA ORANGE LEAVES DURING THE FLOWERING AND JUNE DROP PERIOD IN 1971

Date sampled and carbohydrate	Amount of carbohydrate (per cent dry wt.) with thinning at:				Sig.*
	0%	33%	66%	100%	
4/27/71:					
Sugar†	16.17	15.64	14.71	16.67	NS
Starch	7.63	8.13	7.33	8.77	NS
5/17/71:					
Sugar	17.81	17.02	17.79	16.21	NS
Starch	8.32_a	9.65_{ab}	10.58_b	12.98_c	**
6/3/71:					
Sugar	12.32	12.36	12.12	11.34	NS
Starch	10.49_a	10.69_a	13.56_{ab}	15.95_b	**
6/17/71:					
Sugar	14.18	14.15	14.19	13.36	NS
Starch	8.04_a	8.03_a	11.50_b	10.97_b	*
7/2/71:					
Sugar	13.26	12.80	12.88	12.14	NS
Starch	6.58_a	6.41_a	9.33_b	8.88_b	*
7/15/71:					
Sugar	9.98	10.00	10.02	8.89	NS
Starch	4.96	4.67	6.16	5.99	NS

* Within date: NS = nonsignificant; * = significant at the 5 per cent level; ** = significant at the 1 per cent level. Differences are significant at the level indicated if there are no subscript letters in common.

† Sugars were combined, and include malic acid, myo-inositol, fructose, glucose, sucrose, and two unidentified carbohydrates (calculated as glucose).

trees, Jones *et al.* (1970) raised the question of the effect of carbohydrate supply during the June drop period. Table 3 shows the leaf carbohydrate content during that period. Since the concentrations of individual sugars were not affected by thinning treatment, they were combined. Even so, there was no difference in sugar concentration in the leaves in relation to thinning treatment. Starch content showed no difference at the first sampling date. At that time the leaves were about two-thirds expanded and petal fall was almost completed. Leaves of this age have a low apparent photosynthesis rate (Rhoads and Wedding, 1953) and most of the carbohydrate materials had probably been translocated from older tissues. At the second sampling date, starch was increasingly greater as the amount of thinning was increased. By that time the leaves were fully expanded and, according to Rhoads and Wedding (1953), probably no longer parasitic on the tree. June drop had not started. By the third sampling date June drop was underway and was completed by the last sampling date. During that period, differences in starch became less, and were not significant at the last sampling date. Even though starch content varied during the June drop period in relation to degree of thinning, with the amounts present, such differences would not be likely to account for the differences in fruiting (fig. 1). Under Florida conditions (Smith and Reuther, 1950; Smith, Reuther, and Specht, 1952), when fruit production was about normal, starch occurred in rather small amounts (never more than 1.4 per cent) and was almost totally spent during the spring growth period. Under Arizona conditions (Hilgeman, Dunlap, and Sharples, 1967), the larger set of young fruit on early-harvested trees was related to a small increase (from about 3.8 to about 4.5 per cent) in total leaf carbohydrate content in May.

Results are shown in table 4 for carbohydrate concentration in the leaves of the second grouping (Anthrone procedure). Since no significant interactions occurred between month of thinning and percentage of thinning, only main effects are presented. The leaf samples for the carbohydrate data shown were taken just before the beginning of spring growth, in early bloom, and at the end of the June drop period for the fruit harvested in 1972. The mature fruit for the 1971 harvest were on the trees during the leaf-sampling period. In 1971, the yield for the July, 1970, thinned trees (table 5) was greater than for the trees thinned in September or November, because of failure to achieve the desired amount of

TABLE 4
MAIN EFFECTS OF MONTH AND PERCENTAGE OF FRUIT THINNING ON CARBOHYDRATE CONTENT OF VALENCIA ORANGE LEAVES

Thinning, 1970	Amt. carbohydrate (per cent dry wt.) in leaves sampled on: 2/4/71		4/27/71		7/15/71	
	Sugar*	Starch*	Sugar*	Starch*	Sugar*	Starch*
By month:						
July	5.94	2.61_a	12.23	7.08	6.20	3.76_a
Sept.	6.03	3.00_{ab}	12.62	6.98	6.38	5.66_b
Nov.	6.07	3.28_b	12.15	6.71	6.66	6.61_b
By percentage:						
33	5.89_a	2.29_a	12.33	6.84	6.67	4.91
66	5.68_a	2.53_a	12.30	6.55	6.51	5.13
100	6.29_b	4.07_b	12.37	7.38	6.05	5.99

* Differences are significant at the 1 per cent level if there are no subscript letters in common; absence of subscript letters indicates nonsignificant.

TABLE 5
MAIN EFFECTS OF MONTH AND PERCENTAGE OF FRUIT THINNING ON YIELD OF VALENCIA ORANGES

Thinning, 1970	Yield* (field boxes†/tree)	
	1971	1972
By month:		
July	7.3b	6.1b
Sept.	5.5a	6.0b
Nov.	5.4a	4.6a
By percentage:		
33	10.0c	3.0a
66	7.7b	4.6b
100	0.6a	9.2c

* Differences are significant at the 1 per cent level if there are no subscript letters in common.
† Field box = about 50 lb.

thinning. Even so, the July-thinned trees produced more fruit in 1972. But prebloom starch accumulation (table 4) associated with the bloom for the 1972 yield was less in the July-thinned trees and was less at the end of the June drop period. Thus, in the comparison of thinning dates, leaf carbohydrates apparently do not suggest a limiting factor for fruit set. Time of thinning had no effect on sugar accumulation at any sampling date. Prebloom accumulation of sugar and starch was greater in the 100 per cent thinned (table 4). This was positively correlated with the 1972 yield. During flowering and at the end of June drop, however, the carbohydrates were not different.

The 100 per cent thinning resulted in an almost complete reversal of alternate bearing (see fig. 1). Whether or not the reversal of cycle will hold over a period of years or quickly revert to the original cycle remains to be determined.

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