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Michigan State University Agricultural Experiment Station
Technical Bulletin
J.H. Waring, Horticulture
Issued May 1931
36 pages

Technical Bulletin No. 112 May, 1931

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RESIDUAL EFFECTS OF FRUIT THINNING WITH THE LOMBARD PLUM*

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The thinning of fruits, where the natural set is excessive, has long been practiced by amateur and commercial growers. The immediate effect of fruit thinning is to improve the size, perfection, and market value of the fruits that remain on the trees until harvest.

Numerous authors, either reporting their own observations or communicating advice to orchardists, have suggested that, in addition to this more obvious effect, there is a benefit to the tree, the possibility of an influence on future crops, and the avoidance of injury from cold to be gained by the prevention of over-bearing. Concerning such effects, the literature disclosed much difference of opinion and some lack of experimental evidence, and this seemed to justify the investigation herein reported.

There were several reasons for selecting the plum as the principal subject for investigation. First, an orchard on which growth and crop records had been kept and which was situated on soil of apparent uniformity was accessible in the orchards of the Graham Horticultural Experiment Station at Grand Rapids, Michigan. Secondly, the Lombard variety of this fruit, by reason of its heavy-cropping tendency, should afford abundant experimental material with decided contrasts.

LITERATURE REVIEW

A. J. Downing (13) considered that by the practice of fruit thinning trees of apple and other fruits could be made to bear every year. Garcia (15) and Goff (16) believed and taught likewise, but Beach (1), after four years' investigation with apple thinning, concluded that it would not, on mature trees, materially influence the regularity of production, and that the profits, if any, must come from the crop thinned. Subsequent careful experimentation has tended, more often than otherwise, to corroborate Beach. Even so, the matter is not yet determined. Walker (44) found thinned peach trees to have abundant strong fruit buds for the next season's crop, whereas unthinned trees "were scarcely able to live", and Dickson (12) found thinned trees of several varieties of plum to set fuller crops the year following than did the unthinned trees. A recent report of Magness and Overley (30) clearly shows a large leaf area per fruit to be conducive to fruit-bud formation in the same year; hence, to successive fruit-

*Also submitted to the Graduate Faculty of Michigan State College in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

ing. However, the finding by Waugh (45) of a lack of perfect blossoms on a seedling plum following a year of exhaustive bearing indicates one way in which heavy fruiting limits a following crop.

That fruit production operates as a check upon vegetative growth in the same season has been reported by Bedford and Pickering (2), Partridge (37), Wiggin (48), Chandler (10), Hooker and Bradford (23). and Roberts (39) all working with apple trees or their subdivisions. Reed (38) found the same true with apricot, and Murneek (32, 34, 35, 36) with tomato, in which the fruit appears extraordinarily capable of absorbing the important plant constituents and thus effectively checking vegetative growth. Murneek (33) also finds similar conditions in the apple to be accompanied by similar effects.

On the contrary, Mack (29) found in biennial-bearing trees of apple the tendency to make the longer average growth in the same season that the larger crop is borne. Tucker and Potter (43), with Baldwin apple, likewise found terminal growth greater on fruiting limbs than on non-fruiting. Their suggestion that the presence of fruit on some spurs appeared to be dominant in determining shoot growth is quite at variance with Murneek's conclusions from the tomato. It seemed possible to them that the accumulation of carbohydrates when there was no crop to utilize them might retard shoot growth. Chandler and Heinicke (11) found the rate of growth in Oldenburg apple and Poorman gooseberry reduced by fruiting but not to the extent reported by Murneek for tomato plants. From equal leaf areas, the residue of dry matter was larger with fruiting than with deflorated plants, and the explanation offered is that there may be photosynthesis in the fruit and more rapid photosynthesis in a given leaf area of the fruiting tree.

Exhaustion from heavy fruiting has been reported by many others, with and without reference to specific effects. Thomas Hitt (21) earlier than 1768 advised thinning to avoid the tree's becoming weak "by bearing too plentifully." Waugh (46) said of the June drop, as a natural means of thinning, that it was often the salvation of the trees. Many varieties of plums, he found, set larger crops than could be matured without disastrous results.

Of the severe killing of fruit trees in Maine in the winter of 1904-5, Munson (31) wrote, "In almost every case coming under the writer's observation, the trees which suffered most were those which had borne a full crop the previous year. * * * There is little doubt that had one-half the fruit been removed from such trees early in the summer, less trouble would have been experienced."

This observation is abundantly supported by evidence in subsequent reports of the Maine station. Chandler (7) observed the same effect of over-bearing and found that thinning enabled the tree to set more hardy buds for the next crop. Laboratory tests (8) suggested to him that thinning acts to prolong the rest period rather than to increase the intrinsic hardiness of the fruit buds. Macoun (28), following the winter of 1917, found killing in Wealthy apple proportionate to the preceding crop. Bearing trees, he observed, suffered more than trees not yet in bearing. Of somewhat special pertinence is a case cited by Bradford and Cardinell (5) of plum trees bearing excessively, dropping their foliage early, and then succumbing to the severe cold of the winter of 1880-81, and their citing T. T. Lyon's statement, 1874, that the plum seldom suffered in the climate of Michigan unless weakened by disease or the over-production of fruit. Dickson (12) finds that thinning plums affords relief from winter injury.

Gourley (17) found area and air-dry weight of leaves to be distinctly greater in the light-crop year than in the bearing year of two apple varieties. Wiggins (47) found a similar reduction in area and traced it to a reduced number of leaves on bearing spurs, not to smaller size. Chandler (9), however, observed leaves of heavily-blooming apple and pear trees to be noticeably smaller even before the bloom had fallen, and that the mere formation of many blooms greatly inhibited spring growth. Swarbrick (41) found, with Court Royal apple, 50 per cent more spur leaves per spur and 300 to 400 per cent greater leaf area on spurs in the off year.

By chemical analysis a number of persons have attempted to learn the relative effects of heavy and light fruit bearing upon the storage of reserve nutrients. Hartig (20), cited by Hooker and Bradford (23) found it usual in many trees for a seed year to follow one or more years of rest in which surpluses are accumulated. Hooker (22), Hooker and Bradford (23) and Kraybill with several co-workers (24), present data which make possible certain generalizations concerning relative differences in constituents of bearing and non-bearing apple spurs at the approach of the dormant season, when calculated to the dry weight basis: In the bearing spurs, dry weight is somewhat lower in percentage; but titratable acidity, potassium, and total carbohydrates are higher. Nitrogen content of both classes of spurs is essentially the same; so, apparently, is the phosphorus. Of the carbohydrate fractions, starch is consistently lower in fruiting spurs and free reducing substances are slightly higher; however, the fluctuations in percentage of non-reducing and total sugars and acid hydrolyzable substances other than starch seem to lack consistency in amount or direction.

Certainly, however, there is a tremendous need for refinement and standardization of technique in sampling and analysis, and of presentation as well, the past lack of which renders an interpretation of the literature and the results reported herein subject to much error. To this end the papers of Loomis (26), Tufts (42), Harley (18), and Kraybill, Sullivan and Miller (25) are most timely and welcome.

METHODS OF PROCEDURE

Experimental

Preliminary to the application of differential treatments in the orchard, and in order to make a beginning in the accumulation of data when the problem was undertaken in the fall of 1924, some sampling was done in the orchards at East Lansing, taking advantage of normal differences in bearing exhibited by the trees. Spurs of Lombard plum were labeled before harvest and, on October 1, were collected and classified on the basis of leaf and fruit number per spur. Wood samples also were taken from branches bearing light and heavy crops. Record was made of the numbers of leaves and fruit on the spurs, and the samples were oven-dried at 90° C. with weighings at intervals.

Two large trees of Lady apple were observed to be fruiting heavily on some branches, lightly on others, and not at all on others. On October 13, samples of wood and leaves from bearing and non-bearing areas were preserved by drying for chemical analysis. On November 19, additional samples were taken from spurs, shoots, and three-year wood of Lombard plum, and the samples were intermittently weighed while drying to determine the rate of water loss as before.

In the hope of learning whether the degree of fruiting might affect certain constituents of the bark and wood at the bases of large branches, bark samples were taken on November 27 from the Lady apple trees, and wood samples were taken by borings made with an auger to approximately uniform depth. These samples were subsequently dried with weighings at six hour intervals, and some were analyzed for carbohydrate constituents.

In the summer of 1925, an experiment in thinning was begun in a block of Lombard plum at the Graham Horticultural Experiment Station, Grand Rapids, on soil of apparent uniformity. The trees had been set in 1920,

Fig. 1.—Lombard plum orchard at Grand Rapids, 1925. Rows to left thinned; right unthinned.

bore their first fruit in 1924, and set a very uneven crop in 1925. Fifty-six trees in six contiguous rows were left unthinned. Forty-eight trees in the following six rows were thinned to one inch or more between fruits. In 1926, the natural set was uniformly heavy, and the 48 trees previously thinned were again thinned (June 29 to July 3), but seven of them in a single row at the middle of the block were thinned more severely. Counts indicated 2.9 fruits removed to 1 remaining, and 6.5 to 1, respectively, in the two degrees of thinning. In 1927, there was a complete crop failure. In 1928, the set was heavy and no thinning was done; this afforded an opportunity to measure some residual effects of previous thinnings. All the trees were handled alike in other respects. They were not pruned in the duration of the experiment beyond the light cutting necessary to secure samples. Figures 1, 2, and 3, with explanatory notes, present views of the orchard and the experimental plots and show the relative fruitfulness of the trees in 1925 and 1926. A close examination of Figure 4 will disclose the set of fruit, which was normal throughout the experimental

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Row	1	2	3	4	5	6	7	8	9	10	Thinning
L	3	6	—	5	—	2	6	5	4	9	
K	3	1	—	—	—	5	5	1	2	7	
J	2	1	9	5	—	3	0	1	1	5	Moderate
I	2	—	6	3	—	3	4	1	1	1	
H	2	5	8	2	—	2	0	2	5	1	
G	3	3	—	7	—	—	0	1	0	0	
W - - -											- - - E
F	4	2	1	1	—	7	0	2	0	0	
E	4	2	8	4	—	4	3	5	1	5	
D	6	6	7	7	5	3	1	0	4	6	None
C	2	2	6	6	0	4	1	2	0	4	
B	—	5	8	—	3	1	6	3	5	2	
A	4	6	5	9	7	6	5	5	0	7	

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Fig. 2.—Plan of plum thinning experiment in 1925. Figures at coordinate points indicate tree positions and the relative natural set of that year, the larger figures indicating the heavier set of fruit. The dashes indicate trees eliminated from the experiment.

block in 1926, and the relative loads of fruit the trees were permitted to mature.

Following the thinning treatment, attempts were made to discover what differences might have been created in growth of tree and in crop; in chemical constituents of tree and fruit; in amount of water present; and in the relative amounts in free and bound states; in spur growth, functioning, and mortality; and in blossoming.

Row	1	2	3	4	5	6	7	8	9	10	Thinning
L	9	10	—	10	—	6	6	7	7	8	
K	9	10	—	—	—	8	9	8	8	10	
J	10	9	9	9	—	8	8	7	9	9	Moderate
I	8	—	10	10	—	7	7	9	10	8	
H	8	10	9	9	—	9	8	9	10	9	
G	10	10	—	10	—	—	9	10	8	8	Severe
F	9	9	8	7	—	9	10	8	9	10	
E	9	9	10	9	—	10	10	10	10	9	
D	10	10	10	10	7	9	9	8	9	10	None
C	10	9	10	10	6	10	8	10	9	10	
B	—	9	10	—	9	9	8	9	10	8	
A	9	10	10	7	9	10	9	9	6	10	

Fig. 3.—Natural set of fruit in 1926. Trees designated by the higher figures were preferred subsequently as sources of sample materials. Observe introduction of more severe thinning in Row G.

Analytical

Dry Weight—Samples preserved by drying were placed, as collected, in weighed, stoppered bottles and weighed and then dried to constant weight in a drying oven at 90-95° C. The difference between the first and final weights was calculated to the percentage of moisture in fresh sample and also to the dry-weight basis. To obtain data as to the rate of giving up of water, bottles were removed from the oven at intervals, stoppered, cooled in a desiccator, weighed, then returned to the oven for further drying.

Carbohydrates—On samples of 1924, free reducing substances, sucrose, starch, and total polysaccharides were first determined by the direct weighing of cuprous oxide. The conditions of reduction were Allihn's and the procedure otherwise essentially that of Hooker (22). Subsequently, determinations were made of the acid hydrolyzable substances extracted from the starch residue by the method of Kraybill and associates (24).

Fig. 4.—Bearing branches typical of the thinning done in 1926. Left to right, unthinned, thinned moderately, thinned severely.

For final presentation, results for free reducing substances and sucrose were recombined as total sugars, and those for starch and total polysaccharides were discarded.

On samples of 1925, essentially the same methods were followed.

Wood samples of 1926 were preserved by drying. Soluble sugars were extracted from two-gram samples with 80 per cent alcohol in continuous fat extractors (Bailey-Walker). Clarification was accomplished by first evaporating off the alcohol, then taking up with water and transferring to a 250 c. c. volumetric flask, neutralizing, if necessary, with sodium hydroxide, and proceeding to clear with neutral lead acetate and de-lead with sodium carbonate as before. Fruit flesh and pits were preserved in alcohol and were handled and analyzed essentially after the method of Kraybill and associates (24). The conditions of reduction were Munson and Walker's, and the product weighed as cupric oxide. To the determinations of previous years was added that of the ether extract in the case of three samples of plum pits, by the direct method.*

Ash, phosphorus, nitrogen—The determinations of ash, phosphorus, and nitrogen were made by chemists of the Maine and Michigan agricultural experiment stations, both employing official methods. In 1925, nitrate nitrogen was not included; in 1926 and 1927, it was included.

Bound water—The percentages of unfree or bound water in leaves were determined by the dilatometer method of Bouyoucos (4), a method which has been applied by Rosa (40) and others to plant tissue studies. In sampling, care was exercised to select leaves from spurs or shoots arising in wood of the same age, that had similar position and light conditions, and that actually exhibited the specified fruiting condition. Samples for comparison were collected in succession as quickly as possible, placed in containers that held them loosely but covered, and kept cool but dry until tested. Later, samples were held in an iced refrigerator until removed one at a time for the determinations. In making the test, the method followed at first was to grind a large sample, use five grams in the dilatometer, and place the remainder of the ground material in a tared sample bottle for the determination of total moisture. Later, discs for the tests were cut from the leaves with a Ganong punch and the remaining portions were saved for total moisture, no grinding being done.

The dilatometer bulbs were of the wide-mouth type and of 60 c. c. capacity. They were closed with tallowed cork stoppers and no thermometers were inserted. The ice-and-salt freezing mixture was regulated to —4°C. outside the dilatometers, a temperature that was not sufficiently low. Freezing was extremely slow on this account, and too few samples could be handled. It had not been observed that Rosa (40) had used temperatures down to —6°C. inside the dilatometer, and the paper of Lott (27) had not been published.

H-ion concentration—In mid-July, 1925, an attempt was made to determine the hydrogen-ion concentration of leaf tissue fluids. Two-gram samples were macerated with sand and water, diluted to a definite standard, and filtered. Tests of the filtrate for pH against methyl red, and for titratable acidity against phenol red with 0.1 N. NaOH, indicated that no valuable data could be secured by either method with the facilities available.

*Official and Tentative Methods of Analysis, 2nd Ed., rev. to July 1, 1924, p. 117. Assoc. of Official Agr. Chemists, Washington, D. C., 1925.

It may prove of interest that both trials suggested greater acidity in the leaves of thinned trees.

Mathematical

It is presumed unnecessary to give formulae or to cite authority for the standard biometrical methods employed in calculating the probable error of the mean, standard deviation, coefficient of correlation, and probable error of this coefficient. Where deviations in pounds of fruit or in centimeters of growth are accompanied by probable errors of the difference, or where such differences and their probable errors may readily be approximated by inspection, the criterion of significance is that the difference be about three times its probable error. And as to coefficients of correlation, decided correlation is assumed to exist between the characters measured when the coefficient is greater than 0.5 and at least six times its probable error.

PRESENTATION OF RESULTS

Fruit Production

The record of fruit production by the experimental trees is presented in Table 1. In interpreting this table, it should be borne in mind that the crop of 1924 was the first the trees produced and preceded any differential treatment, and that the crop of 1928 followed a year of no crop whatever.

Table 1.—Average yields of fruit, 1924-1930.

Crop Year	Unthinned in 1925 and 1926	Thinned moderately in 1925 and 1926		Thinned severely in 1926	
	Lbs. per tree	Lbs. per tree	Dev. from unth. (%)	Lbs. per tree	Dev. from unth. (%)
1924	4.18±0.48	6.69±1.55	60.0	3.00± 0.84	−55.2
1925	32.25±2.02	18.72±1.31	−42.0	20.57± 5.06	−36.2
1926	132.95±3.38	67.87±1.81	−49.0	34.80± 2.69	−73.8
1928	224.35±6.40	281.46±8.01	25.5	328.86±16.27	46.6
1929	59.19±3.41	1.24±0.43	−97.9	None	−100.0
1930	198.6 ±4.8	208.1 ±7.1	4.5	212.1 ±26.	6.8

The second table is added to show the relation between the amount of fruit matured and the size of individual fruits.

Table 2.—Average numbers of plums in one pound.

Crop Year	Unthinned in any year	Thinned moderately in 1925 and 1926	Thinned severely in 1926
1925	33.06	21.09	....
1926	38.93	22.62	20.43
1928	20.28	30.88	29.71

These tables convey the information that in the year before thinning was started the trees destined for moderate thinning produced a few more plums, and those to be thinned severely a few less plums than did those that were to serve as checks. The differences were not significant biometrically. In 1925 and 1926, the crops were reduced and the weights of individual plums increased in proportion to the severity of thinning.

In 1927, there was no crop, a failure which could not be associated with bud injury* or in any way with the experimental handling of the trees. It seems probable that the heavy set of the preceding year inhibited flower-bud formation and it is evident that even the heavy fruit thinning of that season (1926) did not materially affect that process.

Subsequent crops, here recorded, were not thinned. The 1928 crop was characterized as a fair or good crop even on the trees not formerly thinned, but as tremendous on those that had been thinned. The differences in production were clear-cut; the crops were inversely proportional to the loads the trees had carried in 1926, and could be explained only as an effect of thinning.

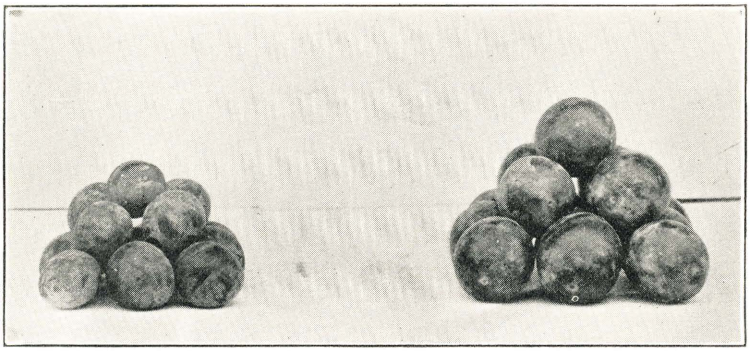


Fig. 5.—Relative size of plums, 1926. Fourteen in each pile. Left, unthinned; right, thinned.

In 1929, the pendulum of production swung the other way; the effect of heavy fruiting was seen in a crop materially reduced, but the reduction was significantly greater on the trees that had been relieved of heavy fruiting in 1926 but permitted to over-bear in 1928. The 1930 crop, following a year of comparative rest and being four crops and five years removed from differential treatment was uniformly heavy. Practically every tree required some thinning and there was no longer any clear cut evidence of a residual effect from the thinning treatments of 1925 and 1926.

The possibility of an effect of bearing on the time of ripening was not made a point for special observation, but the station superintendent wrote, concerning the 1928 crop, that the trees in the south half (unthinned, then bearing the lighter crop) ripened their fruit from two to three weeks earlier than the others.

*Buds were not sectioned to determine this; the question arose too late. The superintendent of the station, however, was very definite in his statement that bud killing did not occur. It has been ascertained since, though, that complete killing of cherry fruit buds occurred April 23.

Growth of Trees

Trunk circumference—The measurements of trunk circumference in inches presented in Table 3 show for 1920 and 1924 no significant differences in size between the groups of trees. In all later years, however, they show significant gains in growth to have been made by the moderately thinned trees over the unthinned, and by the severely thinned over the moderately thinned. In the smaller growth increments of 1928, an inhibiting effect of the extreme crop borne that year by trees formerly thinned may be seen.

Table 3.—The trunk circumference record, inches.

Fall of Year	Unthinned in 1925 and 1926	Thinned moderately in 1925 and 1926		Thinned severely in 1926 only		
	Mean circumf.	Mean circumf.	Gain over unthinned	Mean circumf.	Gain over unthinned	Gain over thin. mod.
1920	1.58 ±0.02	1.62 ±0.03	0.04 ±0.03	1.54 ±0.07	−0.04 ±0.08	−0.08 ±0.08
1924	9.29 ±0.09	9.43 ±0.11	0.14 ±0.15	9.80 ±0.24	0.51 ±0.25	0.37 ±0.26
1926	11.89 ±0.12	12.77 ±0.14	0.88 ±0.19	14.10 ±0.35	2.21 ±0.37	1.33 ±0.38
1927	13.63 ±0.13	14.72 ±0.15	1.09 ±0.20	16.36 ±0.38	2.73 ±0.40	1.64 ±0.40
1928	15.05 ±0.13	15.65 ±0.15	0.60 ±0.20	17.13 ±0.37	2.08 ±0.39	1.48 ±0.40
1929	16.55 ±0.16	17.31 ±0.17	0.76 ±0.23	19.00 ±0.44	2.45 ±0.46	1.69 ±0.47

A clearer picture of the relative growth of these three groups of trees before and after thinning is obtained by expressing the increments in percentage, as is done in Table 4.

Table 4.—Percentage increments in trunk circumference within treatments.

Period	Trees not thinned	Trees thinned moderately 1925, 1926	Trees thinned severely (1926)
1920–1924	527.8	482.1	536.3
1924–1926	19.9	35.4	43.9
1927	14.6	15.3	16.0
1928	10.4	6.3	4.7
1929	10.0	10.6	10.9
1924–1929	76.8	83.6	93.9

Here, it is plain that the check trees and the severely thinned made about the same percentage growth prior to the first thinning, the moderately thinned not doing quite so well. In the two years of thinning and in the following year (1927), growth may be said to have been proportional to the degree of thinning. In 1928, it was inversely proportional to the size of crop carried, and, in 1929, although all three groups of trees made essentially the same percentage growth increments, still it holds that those that bore the most grew the least in trunk circumference.

All this evidence supports the statement that thinning the crop results in greater trunk thickening and that full cropping slackens growth.

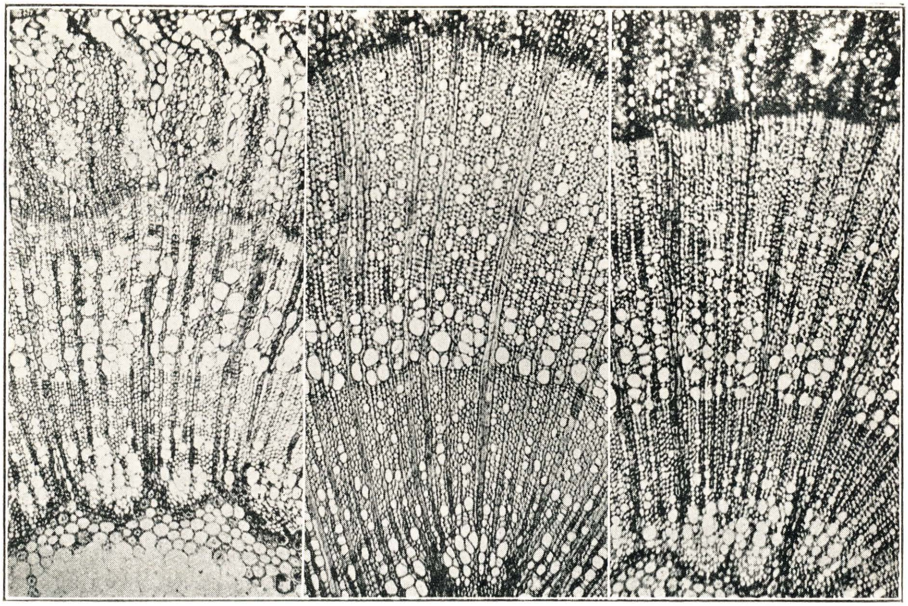
Terminal and diameter growth—On July 3, 1926, the day on which fruit thinning was completed, 50 terminals on trees of each treatment were measured and labeled. Measured again July 26, the average length growths for the 23-day interval were found to be 0.12, 1.52 and 2.59 cm., respectively, for the unthinned, the moderately thinned, and the severely thinned. It was

Fig. 6.—Condition, under crop of 1928, of end trees in rows thinned in 1926. Propping was not required for trees not thinned.

apparent that terminal buds formed and length growth ceased about July 3 on the unthinned trees, and that growth continued for some time longer on trees relieved of heavy cropping.

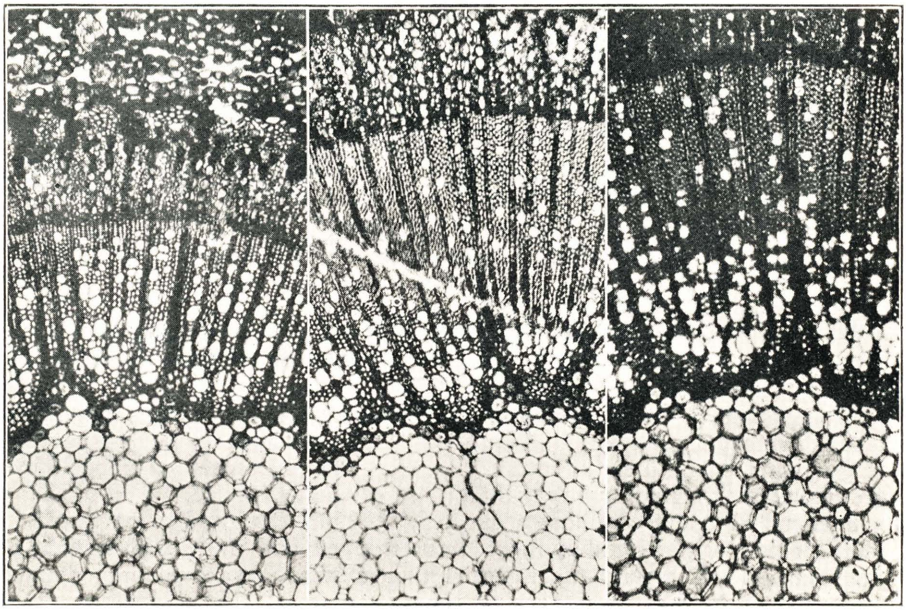
More numerous measurements of terminal growths of the same year, made during the following dormant season, showed distinct but not striking length differences. In diameter, however, the terminals of the thinned groups were significantly larger than those of the unthinned.

Sections of spurs and shoots cut July 3, 1926, disclosed great similarity in the amount of xylem in those from thinned and unthinned trees. By September 15, however, the material thus studied gave evidence of much more xylem in the trees carrying the fewer fruits. This difference was more emphatic in the November sampling, as may be seen by comparing Figures 7, 8, and 9.



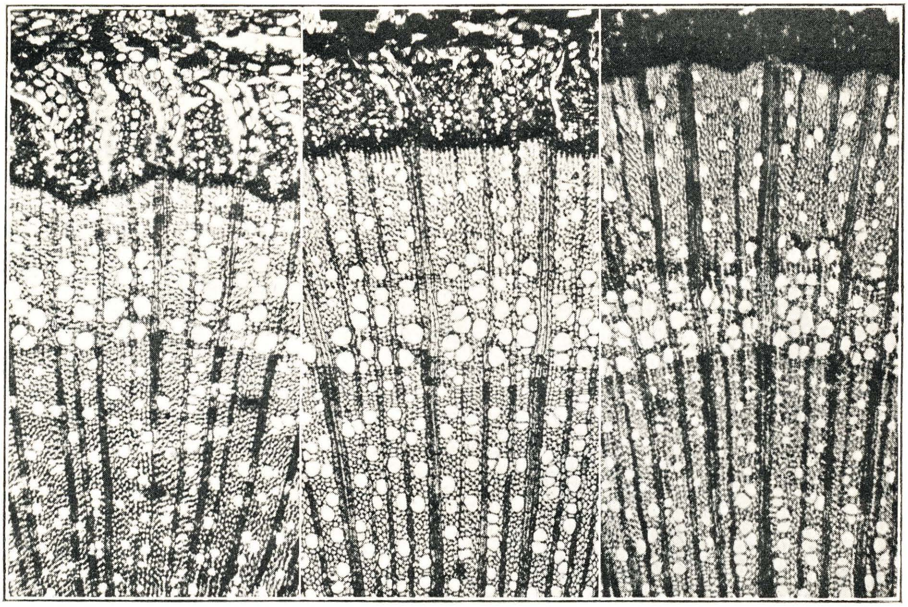
Not thinned. Moderately thinned. Severely thinned.

Fig. 7.—Sections through two-year spur wood Sept. 15, 1926. Little summer wood was developed in trees not thinned.



Not thinned. Moderately thinned. Severely thinned.

Fig. 8.—Sections through current season's shoots, Nov. 1, 1926.



Not thinned. Moderately thinned. Severely thinned.

Fig. 9.—Sections through two-year shoots, Nov. 1, 1926. Diameter growth by the laying down of summer wood continued much longer in the thinned trees.

In the summer of 1927, differences in growth and in luxuriance of foliage were outstanding. One observer, not knowing the nature of the experiment, judged it to be a test of nitrate fertilizer, the unthinned trees receiving none and the others making excellent response. To obtain quantitative data, several different studies were made.

First, 100 terminals and sub-terminals selected at random were measured on two trees of each treatment on July 29, before length growth had ceased. An additional tree in each was likewise measured on August 25, by which time most terminal buds had formed. The results, averaged, are presented in Table 5.

Table 5.—Length growth of branch terminals (in centimeters) to dates given, 1927.

Treatment, 1926	To July 29		To August 25	
	Means of 200	Gain over unthinned	Means of 100	Gain over unthinned
Unthinned	20.55±0.41	....	17.56±0.42	....
Moderately thinned	31.70±0.54	11.15±0.68 (54.3%)	34.58±0.98	17.02±1.07 (96.9%)
Severely thinned	34.30±0.51	13.75±0.65 (66.9%)	34.50±0.91	16.94±1.00 (95.9%)

Apparently the season's length growth of branch terminals was almost doubled on trees that had been relieved of heavy fruiting in the preceding year, and again length growth was longer continued on trees.

The terminals pictured in Figure 10 were representative of 35 and 21 terminals taken July 26, 1927, from unthinned and thinned trees, respectively. Their average lengths were 13.8 and 28.3 centimeters. Fresh weights of those from the unthinned trees averaged 6.12 grams, 0.44 gram per centimeter of length, and of those from thinned trees, 16.51 grams, 0.58 gram per centimeter. Corresponding dry weights per terminal were 2.07 and 5.85 grams, and, per centimeter, 0.15 and 0.21 gram. It is thus seen that there was an even greater increase in the thickness than in the length of these shoots.

A histological study was made concerning xylem formation in 1927. It was thought that by wounding the bark to the cambium at two different times a measure could be obtained of the growth during the interval. Certain shoots and spurs were accordingly scored on August 25th and on October 3rd. The dates proved too late to give the desired result, but Figure 11 is included in this report as typical of the lot and evidence that healing was complete after August 25th wounding but that no wood was formed except in the vicinity of the wound.

This was true quite generally of samples from unthinned trees as well as from thinned. The healing of such late wounds is doubtless related to the crop failure and consequent formation of a wide annual ring, a relationship which has been observed by Bradford and Sitton (6).

Table 6 presents averages of terminal growth measurements made on July 27, 1930.

Table 6.—Some length growths of 1928, 1929 and 1930 (in centimeters), averaged.

Year	Number measured	Unthinned	Thinned moderately	Thinned severely
1928	15	25.7	9.5	9.5
1929	15	28.0	28.4	31.0
1930	26	13.2	16.1	15.5

While making these measurements, the following observation was recorded, "The impression holds that growth is the sturdier in general on the thinned trees. Leaves are certainly darker and larger. Conditions are somewhat as they were in 1927."

The tabular material supports this impression as to the 1930 growth; indicates small differences in growth in 1929, and these in favor of the thinned trees, which bore no fruit; and shows once more the drag of the crop the thinned trees bore in 1928.

Vigor and mortality in spurs and shoots—In July, 1927, two attempts were made to determine what might be the effects of heavy and light bearing upon the performance of spurs and shoots, which are listed in the tables as outgrowths.

First, four representative branches were cut from unthinned and four from thinned trees so as to include all growth of 1922 to 1926. The objective was to determine whether light bearing, as modified by fruit thinning, might exert a measurable influence in keeping the spurs alive and functioning. In Table 7, the left-hand column indicates successive years of branch growth; column two, the growth in length each branch made; and column three, the number of nodes in that length, as determined by a count of living and dead or non-functioning nodes. Finally, the percentage figure is arrived at by dividing the number living by the total number of nodes. The percentages obtained indicate a possible slight influence of fruit thinning on the continued functioning of spurs on branch wood as old as five years.

Fig. 10.—Terminals of Lombard plum representative of the growth of 1927. Left, of trees not thinned; right, thinned.

Table 7.—Summarized data from measurement of eight branches July 22-25, 1927. All branch and shoot lengths of the several years indicated, and all nodes and outgrowths arising in such age areas are included.

Year	Branches from unthinned trees			Branches from thinned trees		
	Length (in.)	Total nodes	Outgrowths living	Length (in.)	Total nodes	Outgrowths living
1922	22	38	10	35	44	18
	10	20	2	...	...	...
	3	46	10	36	43	13
	22	28	15	21	28	9
Total	57	132	37	92	115	40
Average	14.3	33.0	9.3	30.7	38.3	13.3
Living, Per cent	...	...	28.2	...	...	34.8
1923	43	60	23	40	70	19
	44	60	31	22	31	12
	26	37	11	19	20	13
	18	25	5	21	20	11
Total	131	182	70	102	141	55
Average	32.8	45.5	17.5	25.5	35.3	13.8
Living, Per cent	...	...	38.5	...	...	39.0
1924	59	96	27	134	207	102
	15	29	7	64	95	44
	71	110	35	149	213	84
	23	28	12	52	70	22
Total	168	263	81	399	585	252
Average	42.0	65.8	20.3	99.8	146.3	63.0
Living, Per cent	...	...	30.8	...	...	42.9
1925	59	129	51	52	111	45
	40	70	55	71	169	64
	120	235	93	151	273	138
	3	6	1	40	78	15
Total	222	440	200	314	631	262
Average	55.5	110.0	50.0	78.5	157.8	65.5
Living, Per cent	...	...	45.5	...	...	41.5
1926	29	60	48	23	48	39
	...	...	...	55	123	98
	59	121	78	83	167	120
	2	4	3	78	140	100
Total	90	185	129	239	478	357
Average	22.5	46.3	32.3	59.8	119.5	89.3
Living, Per cent	...	...	70	...	...	74.7

This line of study was continued in the same month on 14 branches, seven from unthinned and seven from thinned trees. The results, summarized, appear in Table 8, in which the years indicated are those in which the recorded growth was made. For example, measurements of all growth made in 1925 on all parts of a branch except its main axis were tabulated under that year.

Table 8.—Summary of counts and measurements on 14 branches, 1927: number of nodes on wood giving rise to the outgrowths; number of outgrowths living and per cent these are of the total nodes; length all outgrowths made in the years indicated, and average length.

	On branches from trees	
	Unthinned	Thinned
1925—Total nodes	536	460
Living outgrowths:		
Total number	274	316
Per cent	51.1	68.7
Total length, cm	892.1	630.2
Average length	3.26	1.99
1926—Total nodes	584	643
Living outgrowths:		
Total number	385	491
Per cent	65.9	76.4
Total length, cm	894.0	858.2
Average length	2.32	1.75
1927—Total nodes	551	687
Living outgrowths:		
Total number	519	619
Per cent	94.2	90.1
Total length, cm	1185.8	1827.0
Average length	2.28	2.95

We have here rather more than a mere indication that spurs may live and function longer on trees that are thinned. It is of interest also to observe that, although on the branches selected to represent the thinned trees, the spur and shoot growth of 1925 and 1926 was the shorter; in the following year, these branches overcame their handicap and surpassed the unthinned in average length of such outgrowths. The presumption is that this exemplifies a cumulative and residual effect of thinning.

A more comprehensive examination was made in the spring of 1928 of 54 branches carefully selected as representative of the three treatments that had been applied in 1926. The technique employed was to tally from the apex downward the occurrence of leaf buds, flower buds, latent buds, spurs, and shoots. Each spur and shoot was handled by the same technique. Length increments of branches were recorded by years, and those of smaller divisions were recorded in total. Spurs and shoots arising in three-year wood (of 1925) had made two years' growth. Such portions of the results as pertain directly to vegetative performance are inserted here, bud studies being reserved for separate treatment under another heading.

The numbers of branch terminals involved were 14, 24, and 16, corresponding to the numbers of branches representing the unthinned, moderately thinned, and severely thinned conditions; the spurs from two-year wood, 182, 327, and 172; shoots, 15, 21, and 20; spurs from three-year wood, 157, 283, and 213; shoots 23, 44, and 35; and spurs on shoots arising in three-year wood, 68, 158, and 39, respectively. Only in the items of spurs and shoots arising in three-year wood did the numbers, when averaged, show consistent increase to correspond with fruit thinning, and it cannot be asserted even of these that thinning was the cause.

Increased length growth of thinned over unthinned was consistent in branch terminals (means 12.40, 14.35 and 15.30 inches); spurs from two-year wood (0.38, 0.48, and 0.63 inches); shoots from two-year wood (4.03, 5.81, and 9.00 inches); and spurs on shoots arising in three-year wood

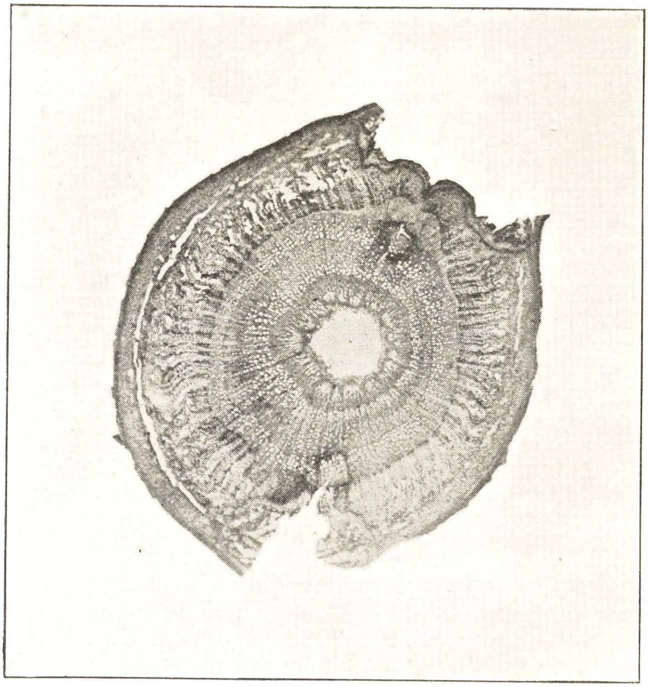


Fig. 11.—Section through three-year shoot. Wounds made August 25, 1927 (upper) and October 3. Xylem formation after August 25 was limited to the vicinity of the wound.

(0.31, 0.39, and 0.41 inches). The significance of these differences was established biometrically except for branch terminals, of which the numbers were necessarily small and the probable errors large. Even so, these differences are consistent, large, in line with other findings, and are attributable to the thinning treatment.

One thing found common to the structures showing increased length to correspond with reduced fruiting was age, all represented growth of one year only, 1927. Likewise, age was common to the structures which showed decreased length. They all included growth of 1926 and 1927. Lack of biometric significance, in their cases, might be invoked to avoid seeking an explanation, or it may be suggested that the pull of polarity favored the

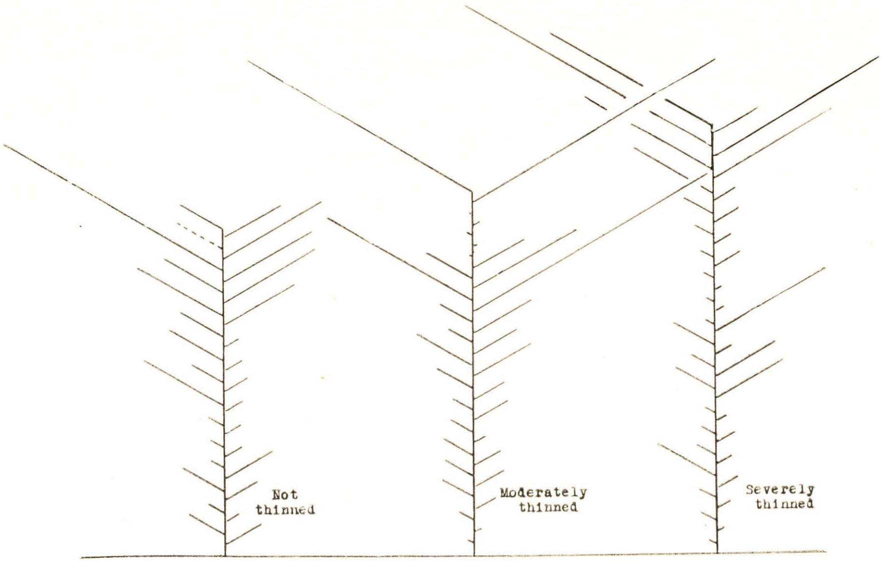


Fig. 12.—Localization of length of laterals (spur and shoot) from 3-year wood of plum branches at end of 1927 growing season.

spurs and shoots nearer the branch terminals and that the denser shade they created on thinned trees, as compared to unthinned, inhibited growth of structures from three-year wood. Out of all this, it appears only that thinning has promoted growth in the following year.

From the same data, graphs (Figures 12 and 13) were constructed in

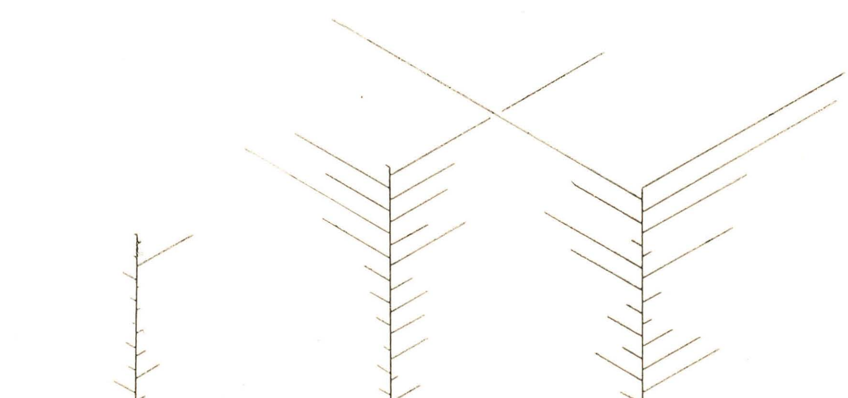


Fig. 13.—Localization of length growth of laterals (spur and shoot) from 2-year wood of plum branches at end of 1927 growing season.

order to disclose whatever tendency there might be toward localization of the more vigorous lateral growths as a result of thinning. The mode of construction was this: each of the 14 unthinned branches, of course, had a first spur or shoot occurring near its base. The average length of these, 0.2 inch, is represented in Figure 12 as the lowest lateral line from the main axis. Only 11 branches had 10 spurs, however, and only one had 27. The upper laterals on the graphs, consequently, represent diminishing numbers of spurs and shoots. Somewhat arbitrarily it was assumed that with greater numbers of lateral growths there were more nodes, and the internodes were represented uniformly in the graphs as being 0.5 inch in length.

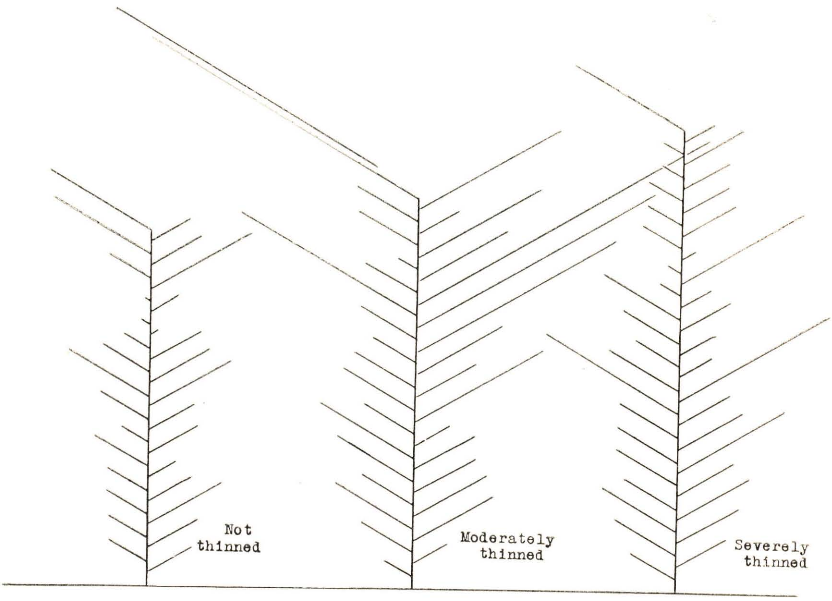


Fig. 14.—Location of flowers in 1928 on spurs and shoots arising in 3-year wood. Length of line is proportional to the number of flowers on each lateral.

There is some evidence in Figure 12 of increased growth of laterals arising near distal ends of three-year wood on thinned branches. The same tendency is more pronounced in those arising in two-year wood (Figure 13) and shows a terminal or polar localization of growth stimulus. It is also apparent that the crop of 1926 exerted a residual inhibiting influence on lateral growth of 1927 on unthinned trees which did not extend to those that had been thinned.

The data for the flowers that occurred on these spurs and shoots, were handled in similar fashion, and in the graphs (Figures 14 and 15) the lateral lines indicate, by their relative lengths, the presence of few or many flowers on the structures found at successive nodes. The graphs depict remarkably even distribution of fruiting area, more even, in fact, than was the growth. And as to numbers of flowers, although they are clearly somewhat correlated with the length of the structures bearing them, they are relatively more abundant on the shorter growths. There is no clear evidence of localization, and the influence of thinning seems to have been simply that with increased growth there were more flowers, not that they were distributed differently on branches of the ages studied.

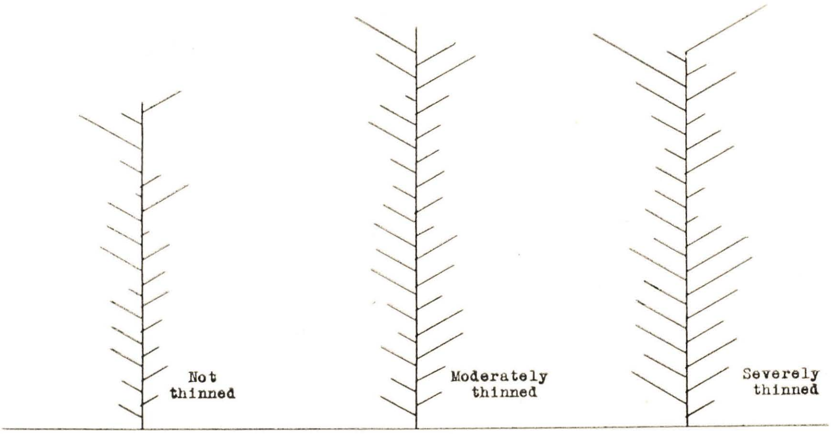


Fig. 15.—Localization of flowers in 1928 on spurs and shoots arising in 2-year wood. Length of line is proportional to the number of flowers on each lateral.

Leaf number and area—To gain information concerning the effects of thinning on leaf number and area, while measurements were being made in July, 1927, on a number of branches, the numbers of leaves were recorded on four spurs of each branch and from each age area (two-year, three-year, and four-year wood). After this was well under way, it appeared that counts of secondary spurs present might be of value, and this detail was added. The results are presented in Table 9 and indicate a rather consistent increase of about one leaf per spur in the three areas and a stronger tendency of the spurs to form secondary terminals as probable results of the thinning treatments.

Table 9.—Leaf number and spur branching on spurs arising in wood of several ages

	Unthinned			Thinned		
	1926	1925	1924	1926	1925	1924
Spurs tallied	52	52	44	56	54	48
Total leaves found	275	431	749	341	493	901
Leaves per spur	5.3	8.3	17.0	6.1	9.1	18.8
Spurs tallied*	36	36	36	36	36	28
Secondaries found	0	20	73	0	36	69
Secondaries per spur	0	0.6	2.0	0	1.0	2.5

*Tallied for presence of secondaries. Several branches had been worked before this detail was added.

Weights of 600 spur leaves each from unthinned and thinned trees, showed that the entire leaves from the thinned were more than 4 per cent heavier, but discs one centimeter in diameter punched from these leaves in the case of the thinned trees, were only 2 per cent heavier. For shoot leaves, the corresponding differences were, for entire leaves, 37 per cent; and for discs, 6.5 per cent. It is concluded that the leaves of thinned trees were, in the following year, larger in both area and thickness, but particularly so in area, and that this difference was far more pronounced in the shoot leaves than in the spur leaves.

In August, 1927, when the greater shoot growth of the thinned trees was so striking, several correlation studies were made. Forty-three terminals from an unthinned tree formed the basis for the coefficient presented in the first line of Table 10. Thirty-six from unthinned and 35 from thinned trees were used in the calculations for the remainder of the table.

Table 10.—Coefficients of correlation and means involving lengths of terminal shoots, in centimeters, numbers of leaves on such shoots, and lengths and numbers of internodes. Lombard plum, 1927.

Constants	Unthinned and thinned together	Unthinned trees only	Thinned trees only
Terminal length and leaf number	....	0.92±0.016	....
Mean terminal length	....	20.30±1.32	....
Mean leaf number	....	21.40±0.98	....
Terminal length and internode number	0.93±0.012	0.86±0.029	0.74±0.052
Mean terminal length	33.73±1.20	21.25±0.79	46.57±1.03
Mean internode number	29.15±0.59	23.33±0.54	35.11±0.49
Internode length and internode number	0.77±0.033	0.51±0.083	0.14±0.113
Mean internode length	1.10±0.02	0.89±0.02	1.32±0.02

The results are entirely in line with normal expectation as to a high degree of correlation existing between the lengths of shoots and the numbers of leaves or of internodes upon them. The fact of special interest is that with increased length of shoot the degree of correlation fell, and an explanation is found for this in the corresponding increase in length of internode. Fruit thinning is followed by an increase in leaf area and there is evidence of an increase in numbers of leaves, but it is clear that on account of lengthened internodes, the increase in numbers of leaves is not quite proportional to the increased length of the shoots on which they are borne.

It must be explained that these shoots were selected to represent the range in length rather than accurately to represent the two lots of trees. This will account for the rather extreme differences in the means.

Buds and flowers, and their functioning—Reference is made again to the branches mentioned on page 13, where the numbers and length growths of their various parts were dealt with. The occurrence of spurs and shoots, and of three kinds of buds, from terminals to three-year wood is presented in Table 11.

Table 11.—Numbers of spurs, shoots and buds in fall of 1927 on branches representing thinning treatments of 1926, averaged with the branch as a unit.

	14 Branches not thinned	24 Branches thinned moderately	16 Branches thinned severely
On branch terminals:			
Shoots	0.00	5.00	0.00
Fruit buds	0.43	0.92	1.06
Leaf buds	19.50	20.50	22.56
Latent buds	7.36	5.00	5.75
Total	27.29	31.42	29.37
On 2-year wood:			
Spurs	13.00	13.63	10.08
Shoots	1.07	0.88	2.19
Fruit buds	0.00	0.04	0.00
Leaf buds	0.00	0.21	0.94
Latent buds	0.00	0.06	0.88
Total	14.07	14.82	14.09
On spurs from 2-year wood:			
Fruit buds	11.50	17.00	18.94
Leaf buds	17.07	15.67	12.81
Latent buds	17.93	20.25	6.94
Total	46.50	52.92	38.69
On shoots from 2-year wood:			
Fruit buds	0.07	1.08	1.63
Leaf buds	6.43	7.08	17.00
Latent buds	6.07	4.71	6.19
Total	12.57	12.87	24.82
On 3-year wood:			
Spurs	11.21	11.79	13.31
Shoots	1.64	1.83	2.19
Fruit buds	0.00	0.00	0.00
Leaf buds	0.00	0.00	0.19
Latent buds	0.00	0.00	0.00
Total	12.85	13.62	15.69
On spurs from 3-year wood:			
Fruit buds	15.50	22.21	28.06
Leaf buds	23.36	17.42	20.38
Latent buds	14.00	25.04	14.94
Total	52.86	64.67	63.38
On shoots from 3-year wood:			
Spurs	4.86	6.58	2.44
Fruit buds	1.14	4.42	4.06
Leaf buds	18.93	15.17	22.94
Latent buds	10.29	8.08	11.88
Total	35.22	34.25	41.32
On spurs from shoots:			
Fruit buds	3.43	8.25	4.00
Leaf buds	5.50	6.00	2.56
Latent buds	7.93	10.25	0.94
Total	16.86	24.50	7.50
GRAND TOTALS	218.22	249.07	234.86

The relative numbers of fruit and leaf buds were further compared on the percentage basis (Table 12).

Table 12.—Percentage comparison of numbers of fruit and leaf buds expressed as increases or decreases from the numbers on branches from unthinned trees.

	Thinned moderately		Thinned severely	
	Fruit buds (Per cent)	Leaf buds (Per cent)	Fruit buds (Per cent)	Leaf buds (Per cent)
On branch terminals	113.8	5.1	147.8	15.7
On spurs from 2-year wood:				
Per branch	47.8	−12.4	64.7	−9.1
Per spur	41.0	32.5	99.1	103.0
On shoots from 2-year wood:				
Per branch	1425.4	10.2	2188.7	164.4
Per shoot	1747.8	34.9	1941.8	138.6
On spurs from 3-year wood:				
Per branch	43.3	−25.4	81.1	−12.8
Per spur	36.3	−29.1	52.5	−26.5
On shoots from 3-year wood:				
Per branch	286.4	−19.9	255.5	21.2
Per shoot	246.1	−28.2	166.8	−9.0
On spurs on shoots from 3-year wood:				
Per branch	140.6	9.1	16.7	−53.4
Per shoot	162.5	19.0	43.6	−42.7
Per spur	77.5	−24.3	132.4	−7.2

At the outset, the tremendous percentage differences in the case of fruit buds on shoots from two-year wood demand a word of explanation. They are based on the occurrence of a single fruit bud on wood of this classification on all the branches from trees not thinned, and of 26 such buds on both the thinned classes.

Decidedly increased numbers of fruit buds occurred on the thinned trees on branch terminals, on spurs and shoots arising in two-year wood (wood of 1926), on spurs and shoots arising in three-year wood, and on the ultimate structures measured, the spurs arising in shoots or lateral branches. The absence of a single exception serves to emphasize the fact of a positive influence of fruit removal on subsequent fruit-bud formation.

Increased numbers of leaf buds occurred consistently only on branch terminals and on the shoots arising in two-year wood. A similar consistent leaf-bud increase is seen on spurs from two-year wood when averaged per spur instead of per branch.

The differences found in numbers of latent buds suggest no consistent influence of fruit thinning, and they are dismissed from further consideration.

In general, the numbers of flowers correspond with those of fruit buds, but were of slightly greater magnitude because of the occurrence of two flowers in some of the buds of the species represented, *Prunus domestica*. Table 13 shows the average numbers of flowers per fruit bud on the several branch parts.

Table 13.—Numbers of flowers per fruit bud, spring of 1928.

Location	Unthinned	Thinned moderately		Thinned severely	
	Average	Average	Dev. from unthinned	Average	Dev. from unthinned
			(Per cent)		(Per cent)
Branch terminals	1.33	1.23	−7.5	1.29	−3.0
Spurs from 2-year wood	1.44	1.35	−6.3	1.46	1.4
Shoots from 2-year wood	1.00	1.23	23.1	1.23	23.1
Spurs from 3-year wood	1.45	1.42	−2.1	1.43	−1.4
Shoots from 3-year wood	1.19	1.37	15.1	1.35	13.4
Spurs on shoots	1.50	1.43	−4.7	1.39	−7.3

Only a single flower occurred on the shoots from two-year wood on the unthinned branches studied, as compared to 32 flowers in both thinned classes. This accounts for the large percentage differences on this item, but it does not necessarily render them insignificant. The evidence as a whole, however, would scarce support a definite statement that fruit thinning did or did not affect the number of flowers per fruit bud.

On certain of the branches on which flower counts had been made in 1928, the numbers of fruits that set were later recorded, and, in Table 14, are presented the results expressed in percentages of the total numbers of flowers borne on one-year, two-year, and three-year branch areas that actually set fruits.

Table 14.—Percentage of flowers that set fruit, 1928.

	Unthinned	Thinned moderately	Thinned severely
Terminal area—1927:			
Branches counted	14	18	15
Fruit buds	6	22	17
Individual flowers	8	27	22
Fruits set	1	20	14
Percentage set	12.5	74.1	63.6
2nd Year area—1926:			
Fruit buds	162	411	299
Individual flowers	232	550	434
Fruits set	131	434	321
Percentage set	56.5	78.9	73.9
3rd Year area—1925:			
Fruit buds	281	759	523
Individual flowers	406	1123	737
Fruits set	307	844	572
Percentage set	75.4	75.2	77.6

The thinning treatment applied in 1926 was apparently responsible for increased numbers of fruit buds and flowers and for an increased percentage of flowers setting fruits in 1928. This is exhibited in all three areas, but the percentage increase in set is greater on the two-year wood than on the three-year and is greatest of all on the one-year wood.

Storage of Nutrients

Upon undertaking this study of fruit thinning, it was believed likely that striking contrasts in the amount of fruit matured would be accompanied by significant differences in percentage of nutrients stored in the trees. Determinations of carbohydrate substances were introduced early, but the plan and procedure were not sufficiently refined to tell this part of the story as well as might have been. A few determinations of nitrogen, phosphorus and ash were also made as the study progressed. The carbohydrate results only are presented in tabular form in Table 15.

The analytical results will now be considered on the basis of the parts analyzed.

Plum—The one-year wood (with bark) of thinned trees in 1926 showed increased percentages of total sugars and starch over the unthinned but reduced percentages of acid hydrolyzable substances and of ash. To the slight differences in nitrogen and phosphorus content, no significance could be attached. The current season's wood, both in July and in August of 1927, showed lower percentages of nitrogen, phosphorus, and ash in the thinned trees.

In two-year wood (with bark) of thinned trees there seems to have been, in 1925, lower percentage content of total sugars, slightly lower of starch, and higher of acid hydrolyzable substances. In 1926, thinned trees showed lower total sugars and higher phosphorus and ash but no consistent differences in percentage content of starch, acid hydrolyzable substances, or nitrogen.

In three-year wood (with bark) of thinned trees the analyses for 1925 show higher percentage of acid hydrolyzable substances, slightly higher starch content, and insignificant differences in other constituents. In the following year, wood of this age showed lower total sugars, acid hydrolyzable substances and phosphorus, higher starch and ash, and no difference in nitrogen to correspond with thinning.

Only one series of fruit samples was analyzed, these being of the crop of 1926. In the edible portion, there appeared no significant difference in percentage of total sugars but reduced starch and increased acid hydrolyzable substances other than starch in fruits from thinned trees. The pit analyses suggest no difference in total sugars to accompany the fruit thinning, and no starch present, but increased fat percentage and reduced acid hydrolyzable substance in those from thinned trees.

Apple—The only analytical results that are presented for apple are those of bark removed from the bases of large scaffold limbs, and of sapwood borings from the same places. In the bark, the lighter bearing trees appeared to have a lower percentage of total sugars and a higher percentage of acid hydrolyzable substances than the heavier bearing trees. In sapwood of lighter bearing trees, lower total sugars and slightly lower acid hydrolyzable substance are suggested.

Results of preliminary work with samples which included two-, three-, and four-year wood of Lady apple (with bark) are not included in the Tables. Such wood from a tree that bore no crop, as compared with a tree that bore a heavy crop, showed lower percentages of starch and total polysaccharides and higher of reducing sugars and sucrose.

These results as a whole confirm the conclusion drawn from the literature (page 4) in so far as the constituents determined correspond. On the basis of the percentage content, it would be natural to conclude that no sufficiently dependable differences were found in the carbohydrates, and probably none in the nitrogen, phosphorus, or ash to afford a key to how internal conditions may vary with the observed rather outstanding contrasts in fruit production, tree growth, and winter hardiness. But, were there no

Table 15.—Total sugars, starch, and acid hydrolizable substances other than starch in per cent of dry weight.

Description and date of sampling	Total sugars		Starch		Acid hydrolyzable substances other than starch	
	Heavy crop	No crop	Heavy crop	No crop	Heavy crop	No crop
Apple, November 27, 1924						
Bark, large limb	9.07	10.30	......	......	14.7	12.9
Bark, large limb	7.59	9.14	......	......	23.0	13.4
Sapwood, large limb	3.79	2.22	......	......	25.9	25.4
Sapwood, large limb	3.68	2.68	......	......	21.9	13.4
Plum, December 5, 1925	Unthinned	Thinned	Unthinned	Thinned	Unthinned	Thinned
2-year wood with bark	7.81	7.57	3.49	3.50	16.6	18.5
2-year wood with bark	5.76	5.32	3.20	2.07	11.6	13.9
2-year wood with bark	4.47	4.80	1.48*	1.54*	20.1	21.4
2-year wood with bark	5.12	4.94	3.14	2.73	15.8	17.0
3-year wood with bark	7.73	7.46	3.46	3.82	16.8	18.4
3-year wood with bark	4.74	4.92	2.77	1.96	11.1	13.5
3-year wood with bark	4.33	5.13	1.87*	2.06*	22.0	22.7
3-year wood with bark	4.50	4.57	2.98	3.36	15.3	14.8

Lombard plum, December 1, 1926	Total sugars: Unthinned	Moderately thinned	Severely thinned	Starch: Unthinned	Moderately thinned	Severely thinned	Acid hydrolyzable substances: Unthinned	Moderately thinned	Severely thinned
1-year wood with bark	6.86	6.68	8.06	0.99	1.65	1.62	13.75	11.34	12.28
2-year wood with bark	7.20	7.04	6.53	2.82	2.62	2.86	13.56	13.07	14.41
3-year wood with bark	9.45	6.21	5.93	0.80	1.61	3.63	19.73	19.71	19.58
Fruit, flesh	58.89	57.25	61.72	6.29	4.21	3.51	8.21	10.18	9.05
Fruit, pits	4.28	4.45	4.10	0.00	0.00	0.00	25.87	18.57	18.18
				Fats, lipoids, etc.					
Fruit pits	......	......	......	8.98	9.05	9.59			

*Starch in four samples was determined without hydrolyzing maltose. This accounts for the low values obtained. They doubtless have comparative value, but of course do not represent the true amounts of starch present.

differences whatever in percentage content, the total quantities of reserve substances would be much greater in the thinned trees by reason of their increased growth, and doubtless this is of more significance. The point may be emphasized by reference to Table 15. If the percentages of total sugars and starch are combined and the results for the several samples of a kind are averaged, the final figures for the thinned trees are closely comparable to those for the unthinned. Since, therefore, it has been demonstrated that the thinned trees at the same time made much the greater wood growth, their reserves clearly were greater in quantity. The showing is particularly favorable to the thinned trees also in view of the fact that they had consumed more carbohydrates for purposes of growth.

In this connection, it is estimated that the individual trees put the following quantities of dry matter into the crop of 1926: unthinned, 24.7 pounds; thinned moderately, 11.3 pounds; thinned severely, 5.8 pounds. These figures are significant of the relief from production of dry matter in fruits that is brought about by thinning. The presumption is that there is a corresponding transfer of energy toward the building and filling of storage tissues, not overlooking the possibility of some synthesis occurring in the fruits or that the leaves of heavy-fruiting trees may be somewhat more efficient photosynthetically.

Water—Amount and Condition

Horticultural literature abounds in suggestions of relationship between the amount and condition of water in plant tissues and observed differences in hardiness to cold. Furthermore, it is an established fact that heavy cropping reduces the cold resistance of hardy fruit species, and it may be assumed as at least possible that fruit thinning would have the opposite effect. Determinations of percentage content of total water, of free and bound water, and of rates of water loss upon drying in tissues from light and heavy bearing and from thinned and unthinned trees were therefore considered an important phase of the present investigation.

Total moisture (per cent)—Total moisture was determined on 98 samples through four years' time and calculated to the percentage of fresh and of dry weight in each case. There were many contradictions in the array of data when assembled for comparison, but, more often than otherwise, in the spurs, shoots, and younger branch wood of Lombard plum, and in the sapwood and three-year-old branches of Lady apple, the more fruit the tree carried, the higher was the percentage of water present. This was not true of the leaves of plum, collected in all cases in July, or of the edible portion of plum fruits, but the differences were in the same direction in apple leaves collected in mid-October and in the plum pits. In the main, these results corroborate the finding by Hooker (22) of highest water content from March until November in bearing spurs of apple, less in nonbearing, and least in barren spurs.

Rate of water loss in drying—In the fall of 1924, 19 samples of plum wood (with bark) representing distinct variations in the fruiting condition of spur, shoot, and branch were dried with intermittent weighings. Of eight comparisons thus made possible, in six cases the material representing the lighter fruiting condition lost moisture the more rapidly, in a single case the reverse was true, and in the other the curves of water loss were almost identical. If we might assume for the moment, on the testimony of Munson (31), Macoun (28), Bradford and Cardinell (5), and Dickson (12), that the lighter bearing trees are the more hardy, it is of interest that these results are not in agreement with Boswell's determinations (3) for leaves of cabbage and tomato that hardy tissue loses water less rapidly than tender in the drying oven, or with Rosa's (40) finding in hardened cabbage plants a marked increase in the ability of the plant cells to retain water against freezing. They are in accord with the report following that in the summer of 1925 higher percentages of free and lower of bound water were found in leaves of the thinned (lightly fruiting) trees.

This discussion should make clear the necessity for caution in reasoning from results with one-season plants in the seedling stage that similar physiological causes and effects will follow in the same relationships with hardy, woody, fruit-bearing perennials such as the plum.

Bound water—Dunn and Bakke (14) and others have found evidence that the hydrophilic colloids are able to hold water within the cell and prevent death from the dehydrating force of freezing. In the present study, bound water determinations were limited to leaves sampled in July of two years. The results appear in Table 16.

Table 16.—Percentages of total, free and bound water in plum leaves.

Sample number	Bearing condition of branches	Total moisture Fresh basis	Free water	Bound water
	July 6, 1925:			
1	Heavy set, not thinned	63.6	27.2	36.4
2	Heavy set, thinned	64.4	34.6	29.8
3	Light set, not thinned	64.7	39.0	25.7
4	Light set, thinned	63.9	41.0	22.9
	July 7, 1925:			
1	Heavy set, not thinned	65.3	34.2	31.1
2	Heavy set, thinned	64.1	36.0	28.1
3	Light set, not thinned	65.1	31.1	34.1
4	Light set ,thinned	64.7	34.2	30.5
	July 17, 1925:			
1	Heavy set, not thinned	62.6	36.0	26.6
2	Heavy set, thinned	63.2	39.6	23.6
3	Light set, not thinned	62.0	37.0	25.0
4	Light set, thinned	64.6	37.4	27.2
	July 27, 1926, 8 a. m.:			
1a	Unthinned	62.97	33.60	29.37
2a	Moderately thinned	62.41	32.35	30.06
3a	Severely thinned	62.46	27.25	35.21
	July 27, 1926, 4 p. m.:			
1b	Unthinned	60.83	34.50	26.33
2b	Moderately thinned	60.76	31.25	29.51
	July 28, 1926, 8 a. m.:			
1c	Unthinned	63.61	36.00	27.61
2c	Moderately thinned	63.54	36.50	27.04
3c	Severely thinned	63.02	28.75	34.27
	July 28, 1926, 2 p. m.:			
1d	Unthinned	59.76	33.40	26.36
2d	Moderately thinned	60.94	27.00	33..94

Before discussing the trend of these results, some of the possibilities of error should be indicated. On the first day July 6, 1925, leaf samples were taken at 10:00 and 11:00 a. m., 1:30 and 2:30 p. m. Each successive sample contained less free water, and it was questioned whether the differences were not due to the hour of day rather than to the fruiting condition of the trees sampled. The technique was modified so that trees in all treatments were sampled within the same hour but without certainty of relief from this error. Failure of duplicates to check at times seemed attributable to the loss of free water by evaporation in the brief time required to prepare the second sample for the test. Since, therefore, the test is delicate, the chances for error large, and the determinations few, it would be folly to draw sweeping conclusions. Furthermore, it is an open question whether the summer condition of leaves bears any relationship to winter hardiness or to any other residual effect of fruit thinning.

Of six comparisons possible in the 1925 determinations, the leaves from thinned trees in every case contained more free water and, in every case but one, less bound water than those from unthinned trees. In 1926, every comparison (save possibly 1c and 2c) shows the reverse condition, less free water and more bound water in leaves from thinned trees.

Since both years were crop years, it did not appear possible to explain this reversal solely as a result of differences in bearing, even though the crop of 1926 was much the larger.

It was suggested that a difference in amount of rainfall, such that more moisture was available in one year, may have eliminated the influence of the fruits. This was investigated. The Weather Bureau reports the following precipitation for Grand Rapids (in inches):

	April	May	June	July
1925	3.17	0.98	1.13	4.58
1926	1.99	3.44	2.66	2.93

Now, if we may assume that the amount and condition of water in the leaves in late July are dependent more upon the immediate supply of water than upon the rainfall of May and June, the most plausible explanation is this: In 1925, the July rainfall was above normal and the heaviest crop was relatively light, whereas, in 1926, the July rainfall was less than normal and there was real overbearing. Thus, it would be expected that leaves of trees in a given fruiting condition might have had higher free water content in 1925 than in 1926. In general, this seems to have been the case. It is not at all clear, however, why the thinning of the heavier crop should have caused leaves to contain less free and more bound water.

Altogether, the 1925 results with bound water supplement those of 1924 for rate of water loss, and the 1926 results are in line with what others have found with cabbage and tomato. They do not indicate clearly a residual effect of thinning and are presented to show that they do not.

INTERPRETATION

This investigation, if its results have any considerable scientific or practical value, owes much to the intervention of a crop failure and to the fact that emphasis was placed upon the measurement of the effects of fruit thinning in one year on the performance of the trees in several subsequent years when the fruit was not thinned. For the same reason, however, it allows to remain to a considerable extent unanswered the question of what might be the response to regular, annual fruit thinning. It is strongly indicated that, for one thing, the development of trees to large size would be more rapid with consequent increased capability to carry large crops to maturity and that, furthermore, by reason of its obvious effect on fruit-bud formation and set, thinning will provide the most essential basis for regular cropping.

Since most of the observed residual effects were manifest in growth or in functions easily associated with increased vigor, it might be practical under some circumstances to substitute pruning for thinning as a means of reducing the numbers of fruits and to attain the desired vigor through judicious soil management. However, pruning fails to space the remaining fruits to the best advantage and high soil fertility tends to cause overproduction, and, in either case, much fruit of small size and low quality would result when the set is heavy.

When, therefore, improvement in market grade is essential to the successful marketing of a fruit crop, fruit thinning is surely to be recommended. The bearing habit (annual or otherwise) and quality rating (dessert or culinary) of the variety determine the market premium on grade and may largely determine the advisability of thinning. This experience with the Lombard plum suggests the wisdom of a regular practice as regards fruit thinning, since otherwise extreme overbearing may result and thus defeat the original purpose.

No winter of sufficient severity occurred in the duration of this investigation to afford any evidence touching the effects of thinning in relation to winter-killing. Sufficient evidence is cited from the observations and experiments of others with apple, peach, and plum, however, to justify the continued recommendation of fruit thinning, when the set is heavy, as a precaution against winter-injury to the trees. In making the decision whether to thin for this reason, the grower will do well to consider the accumulated experience of others with the variety in question and in similar situations.

SUMMARY

1. In two years, 1925 and 1926, three conditions of fruiting were produced on trees of Lombard plum by no thinning, moderate thinning, and more severe thinning.

2. The total crops in 1925 and 1926 were reduced and the size and weight of individual fruits were increased in proportion to the severity of thinning.

3. A uniform crop failure in the following year, 1927, could not be associated with the thinning treatments.

4. Without further thinning, effects were measured in the crops of 1928 and 1929, and were predicted for that of 1930. In 1928, the thinned trees bore much the heavier crops, in 1929 the lighter, as compared with unthinned trees.

5. The thinning of a heavy set of fruit resulted, in the same year, in increased trunk circumference, shoot length and diameter, and "summer wood" in the xylem. It delayed the formation of terminal buds.

6. In the following year, with no crop, the length, thickness, and dry weight of shoots were greater on thinned trees. Fruit thinning in one year promoted growth of spurs and shoots the next year, and some growth effects continued to the fourth following year.

7. That fruit thinning may prolong the vigor and functioning of spurs is strongly indicated.

8. The growth stimulus to lateral shoots and spurs which resulted from fruit thinning was localized in those toward the distal end of a season's branch growth.

9. With increased length of fruit-bearing laterals there was increased flower production, but the distribution of flowers was more even, no localized effect being apparent.

10. Spurs of thinned trees bore increased numbers of leaves the following year, and showed a greater tendency to produce secondary spurs.

11. Leaves of the following year, as a result attributable to fruit thinning, were larger in area and in thickness. The increase in area was the more marked and the effect was more pronounced in shoot leaves than in spur leaves.

12. With increased length of shoot, internodes were found to increase in length as well as in numbers; hence, the numbers of leaves did not increase strictly in proportion to length of shoot.

13. In the year following the thinning of 1926, without exception, numbers of fruit buds were greater on wood of three years' formation. In general, there was a corresponding depression in numbers of leaf buds.

14. In 1928, the percentage of flowers that set fruits was greater on trees that had been thinned two years before. This was most marked in the terminals, receding to the three-year wood area.

15. Of chemical constituents or stored nutrients, the percentage differences which were found lack sufficient consistency to warrant conclusions as to how they might be modified by fruit thinning. It is suggested that the relative quantities of stored carbohydrates, nitrogen, or other constituent might be more significant.

16. The results indicate that the less fruit a tree carries, the lower is the percentage of water in spurs, shoots, and branches of apple and plum and the more rapidly is this water given up in the drying process.

17. Under the heading Interpretation, an attempt is made to point out the practical implications of the results of this investigation to the management of orchards.

ACKNOWLEDGMENT

Grateful acknowledgement is made of assistance rendered by others in the initiation and pursuit of this study, particularly to V. R. Gardner for making available the facilities of the Michigan Agricultural Experiment Station and for a helpful interest throughout; to F. C. Bradford for pertinent suggestions all along the way; to John W. Crist for assistance with the laboratory techniques and for actual participation in the taking of data at the field station; to W. C. Dutton for help with the photographic work; and to H. M. Wells for the taking of samples and measurements and for keeping the investigator informed of conditions at the orchard at times when he could not be there in person.

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