"THIN WOOD" PRUNING
CONSIDERED FROM THE STANDPOINT OF
PHOTOSYNTHATE PRODUCTION.

Thesis

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by
Barzillai S. Pickett
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V. R. Gardner

INTRODUCTION

A method of pruning apple trees of bearing age developed at the Michigan Station by Ricks and Gaston and described by them under the name "thin wood" has been extensively employed and with rather uniformly successful results. It consists essentially in removing from the tree its comparatively slender or so-called "thin" bearing wood and in leaving its thick or stocky bearing wood. Varying percentages of the wood of intermediate character are removed, depending on conditions. More specifically the chief distinguishing characteristics of the "thin" wood are: (1) basal diameters of four-year-old growths do not exceed one-fourth inch, (2) most of these slender branches tend to grow in a downward direction, (3) most of them are found in the lower and interior portions of the tree. Contrasting thick, stocky fruiting branches of the same age are three-eighths inch or more in diameter and are found principally in the upper and outer portions of the tree. Removal of the slender wood and retention of the stocky wood is recommended in "thin wood" pruning because of the close correlation found between stockiness of branch and quantity, grade and quality of fruit produced. The dividing lines between thin and intermediate branches and between intermediate and thick branches are more or less arbitrary and, in a sense at least, the reasons as well as the directions given for the pruning are empirical. The relative uniformity of the results attending "thin wood" pruning, however, suggest that it is adjusted to and makes use of basic principles of tree growth and nutrition.

It was with the objective in view of discovering why "thin wood" functions less efficiently than thick or stocky wood that this investigation was begun.

REVIEW AND DISCUSSION OF LITERATURE

The literature dealing with pruning, light in relation to growth, and photosynthesis, is extensive, yet most of the material is not arranged to show the interrelation of the three. There are many references in "pruning" literature to the importance of light as it affects pruning; nevertheless, because the relationships seem so obvious, little detailed attention has been given them. In their reviews and discussions of pruning and "pruning" literature Auchter and Knapp (1), Chandler (5), and Gardner, Bradford and Hooker (8) often make statements indicating that light is important to growth and fruit production and give methods to improve light conditions within the tree by pruning. The results expected are an improvement in the development of the fruit itself and in the growth of the inner branches.

Pruning as a means of regulating the amount of light reaching the leaves on the tree, and so influencing growth, has had various interpretations and different expressions in practice. Of the earlier American horticulturists Downing (7) seems to have had the clearest conception of how light conditions within the tree should modify pruning. He believed that only the weak, crowded branches in the interior of the tree should be removed. This type of pruning leaves those branches which he considered best adapted to the production of good fruit, since they are best exposed to light. Other writers are of the opinion that no pruning should be done, since pruning generally reduces yields of fruit. Still others believe thinning out the top is the best method of pruning, since it permits light to pass through to the inner branches. Bedford and Pickering (3) favor the natural pruning method in which only dead limbs and branches causing mechanical injury are removed. They provide adequate data in support of this system.

Ricks and Gaston (14) divided the apple tree into three sections which they termed "top", "outside", and "inside". The "top" of the tree consisted of the branches making up the upper 1/3 of the tree canopy; the "outside" was that part of the tree canopy below the "top" and extending toward the trunk approximately 1/3, or somewhat less, of the distance from trunk to branch tips; and the "inside" was the remainder of the tree's volume. They found that the branches on the "inside" produced predominately "U. S. Commercial" grade fruit, the "outside" branches made chiefly "U. S. No. 1" grade apples, while in the "top" "U. S. Fancy" grade fruit constituted the major portion of the crop. An investigation of the type of fruit produced showed that the predominant grade produced on "thin" wood was "U. S. Commercial", on "intermediate" wood "U. S. No. 1", and on "thick" wood "U. S.

Fancy". Ricks and Gaston found that, in general, "thick" branches were found in the "top" of the tree, "intermediate" branches in the "outside" and "thin" branches on the "inside". It is not possible to draw sharp lines of demarcation, for both "thick" and "intermediate" branches may be found in both "top" and "outside" portions of the tree, the first predominating in the "top", the latter in the "outside". Similarly, some "intermediate" wood may be found "inside" the tree, although in dense trees the predominant class is "thin" wood. The general distribution of "thin" wood in the tree suggests that its development and growth might be similar to that made by wood which is intentionally shaded.

The range of light intensities, producing maximum photosynthesis in higher plants was investigated by Blackman and Matthaei (4). Their experiments showed that the range was from .39 full sunlight for cherry laurel to .69 full sunlight for *Helianthus tuberosus* at 27.5° C. Probably, at that temperature, maximum photosynthesis for the apple falls at some point between these two extremes. Hoover (12), working with a small grain plant, found that the maximum was above 1500 foot candles.

Popp (13) worked out the relation between light and vigor in soy-bean seedlings. He exposed seedlings to light of different intensities and found that, between 26 and 4500 foot candles, vigor was directly proportional to light intensity.

"Thin" wood has been shown to produce fruit which is frequently under grade because of small size and poor color. Schrader and Marth (15) made an investigation of the direct effect of light on the growth and color of fruit. They did not shade the leaves. It was found that if light was reduced to .614 normal, or slightly more than 1/3, size was reduced 2 to 3 percent, and the color of normally red fruit was reduced from 96.9 to 47.5 percent.

Gourley (9) and Auchter (2) used artificial shade, effected with screens, that filtered out about 67 percent of the normal light falling on apple trees. Measurement of leaf thickness showed the shaded leaves were 53 percent as thick as leaves on unshaded trees. Microscopic examination showed them to have only one layer of palisade cells as compared to three in unshaded apple leaves. Shaded wood increased in size and in dry matter much less than did unshaded wood.

That the amount of light which is received by apple leaves may vary considerably with the location of the leaves was shown by Christopher (6). He also showed that, on days with the relatively high average of 5000 foot candles for 12 hours, leaves on the west side of mature apple trees received only enough light for four hours of maximum photosynthesis. Christopher used 1500 foot candles, the figure suggested by Heinicke, as the basis for his calculations.

Heinicke and Hoffman (11), who worked with the apple, state: "A mean light intensity above 1500 foot candles would probably support maximum photosynthesis if other conditions were favorable". Later Heinicke (10) found that over a wide range of light intensities a 20 percent increase in intensity resulted in a comparable increase in carbon dioxide absorption 75 percent of the time. A decrease in the light intensity of 25 percent was accompanied by a similar decrease in absorption 70 percent of the time.

It appears from these citations that light below 1500 foot candles may become a limiting factor for photosynthesis by apple leaves, and consequently for the growth of apple branches.

MATERIALS AND METHODS

Materials: Experiments were performed both at South Haven and at East Lansing, Michigan. At South Haven 11 Grimes Golden trees 15 years old were used, at East Lansing 10 trees of different varieties and ages.

Of the trees at South Haven four were selected for photosynthesis experiments because of their uniformity and excellent physical condition. The remaining seven trees were used for growth studies and for samples of "thin" and "thick" branches and leaves. The four uniform trees were divided into two pairs, one pair pruned and the other unpruned. Of the trees at East Lansing, two Duchess of Oldenburg trees 12 years old, and a Winesap and Grimes Golden tree 20 years old were used in the photosynthesis studies. The other trees were used for studies of light and leaf relationships.

Methods: One hundred leaves from "thin" and "thick" branches of Grimes Golden apple trees were studied to discover differences in structure and form. The number of layers of palisade cells and the thickness of the leaf were determined microscopically. The length and thickness of 50 "thin" and "thick" one-year-old shoots were also determined for comparative purposes. Sampling in these cases was based on the diameter of the branches at the base of four-year-old wood.

The relation of light to the production of organic matter was studied by measuring, with a Weston Photoelectric meter, the intensity of light falling on the "thick" branch leaves of a single Winesap tree at the beginning and end of three-hour experimental periods. Light intensity was transformed into foot candle hours by multiplying the average light intensity for the experimental period by one. Samples were chosen so that they received from 0 to 3770 foot candle hours of light. It was necessary to shade the leaves to get samples from leaves receiving less than 1000 foot candle hours. A sample of leaves receiving no light was taken by bagging the leaves in threefold brown paper bags which transmitted only .1 percent of the incident light. The bagged samples were always taken on the side of the tree away from the sun*. Sixty leaves were used in each sample. The bagged samples were used to obtain the changes in organic matter due to respiration and translocation.

The intensity of light falling on leaves of "thick" and "thin" branches was determined by measuring the intensity of light falling on the ventral side of two hundred leaves from each branch class on 10 different trees which varied in age, density of foliage, and variety. Results are expressed in terms of foot candles of light intensity.

Two series of samples for photosynthesis determina-

*The temperature within the bags did not differ more than one degree from air temperature.

tions were taken from trees in the South Haven orchard, one series from the pruned trees and the other from the unpruned trees. Samples were taken from "thick" branch spur and shoot leaves on all trees, and from "thin" wood spur and shoot leaves on the unpruned trees. Samples were collected approximately every two weeks during the spring and summer of 1936. From the trees in the East Lansing orchard a composite sample of spur and shoot leaves on "thick" branches and a similar sample from "thin" branches were collected at ten-day intervals from July 12 to August 20, 1937, from each of the four trees used.

Measurements comparing "thin" and "thick" leaves were made by the "half-leaf" method developed by Sachs and modified by Ganong. It was necessary to make some changes in the technique as developed by Ganong to meet the limitations of apple leaves. Because of the numerous large veins in apple leaves, and because of their small size it is difficult to get uniform samples with the 1 cm^2 leaf punch, and hence, in 1937, a smaller punch, cutting discs .3144 cm^2, was made and used. Samples taken with either punch showed that they were equally satisfactory when sampling was done carefully on large leaves*.

*A series of 15 samples of 30 discs taken from the same 30 apple leaves within a period of 30 minutes collected with a 1 cm^2 punch showed a mean ashless dry weight of .3034 ± .0006 gram. A similar series taken with the .3144 cm^2 punch but consisting of 60 discs taken from 30 leaves, had a mean weight, free of ash, of .1515 ± .0002 gram.

Samples for photosynthesis determinations were made at sundown and at sunrise and sunset of the following day. All of the samples were placed in tared weighing bottles immediately after collection, taken to the laboratory, weighed, dried at 70° C. for 12 hours, weighed again to obtain sample dry weight and moisture content, and then ashed. The ash weight was subtracted from the total dry weight to get the organic matter content of the samples. The first two samples were used to measure metabolism in the dark, and the second and third samples to measure metabolism in light as indicated by differences in organic matter content between the samples. The difference between samples 1 and 2 was divided by the number of hours of darkness and multiplied by the number of hours between sunrise and sunset to find the change in organic matter to be attributed to respiration and translocation*.

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*It seemed doubtful that measurements taken at night would show metabolism rates high enough to make their use satisfactory. A comparison of six bagged samples taken during a single day with an equal number of samples made the same night is given in the following table. Individual differences are large but the average difference is small.

Comparative Metabolism Rates of Apple Leaves at 23° C. Made by Bagging Leaves during the Day, and Apple Leaves Open at Night with an Average Temperature of 17.25° C.

	Change in Organic Matter, Grams	
	Bagged samples, determinations made between 2 and 5 PM, Aver. Temp. 23° C. Total time: 3 hours.	Open samples, determinations made at night between sunset and sunrise. Aver. Temp. 17.25° C. Total time: 8 hours.
	-.0034	-.0024
	-.0062	-.0020
	-.0055	-.0084
	.0012	-.0023
	-.0037	-.0178
	-.0032	-.0116
Total weight	-.0208	-.0445
Aver. Sample wt.	-.00347	-.00742
Aver. change per hr.	-.00116	-.00092

The difference between samples 2 and 3 was considered as metabolism in light. The difference between samples 1 and 2, after adjustment for time, was added to the above difference and the combined value was then termed the increase in organic matter due to photosynthesis*.

*The usual procedure with the "half-leaf" method is to use short intervals of time, often two-hour intervals, rather than the long intervals used here. For apple leaves this is awkward because the leaves vary considerably in thickness from tip to base, the areas not invaded by large veins are few, and the leaves themselves small. Most apple leaves are too small to allow more than 6 or 8 cm^2 discs to be removed. For these reasons the use of fewer time intervals was considered more valuable provided it could be shown that results nearly like those obtained from short interval readings followed. The table below is based on data taken from very large leaves on a Rhode Island Greening tree at South Haven. Each of the comparisons is made from separate samples taken at the times shown.

A Comparison of the Short Interval and Long Interval Method of Sampling for Change in Organic Matter

Short Interval (2 hour) Method		Long Interval (Sunset, sunrise, Sunset) Method	
Time	Change, gm.	Time	Change, gm.
5:45 AM	start	5:45 AM	start
7:45	-.0081*		
9:45	.0011		
11:45	.0108		
1:45 PM	.0051		
3:45	.0026		
5:45	.0099		
7:45	.0018	7:45 PM	.0172
9:45	.0018*		
11:45	.0048*		
1:45 AM	.0112*		
3:45 AM	-.0156		
5:45	-.0137	5:45 AM	-.0175
Total Change:	.0353		.0347

*Starred items carry the wrong signs and must be subtracted

Twenty-eight pairs of branches having nearly identical diameters at the base of four-year-old wood, at the base of one-year-old wood, nearly identical growth habits, and having the same number of fruits and leaves were chosen for growth studies. Fourteen pairs were "thin" wood branches and the others "thick" wood. Growth of the two types of branches was compared on the basis of increase in bulk as measured in terms of dry weight. One of each of the 28 pairs of branches was cut July 21 and the second August 3, 1936. The increases in bulk of the new growth, the old wood, and the fruit were recorded in grams. The leaf area was measured, and the relative photosynthesis, expressed as grams of organic matter produced during the interval for the average leaf area was recorded. Of the 28 pairs of branches selected 4 pairs of "thin" wood branches, and 4 pairs of "thick" wood branches had to be discarded because of loss of fruit or mechanical injury.

EXPERIMENTAL RESULTS

A comparison of the physical characteristics of "thick" and "thin" branches and leaves is given in Table 1. The fourth column contains general information concerning branches which were artificially shaded by Gourley (9) and Auchter (2). It is used to give a comparison between "thin" wood and shaded wood.

TABLE I

The physical characteristics of "thick", "thin", and shaded branches

Characteristic	"Thick"	"Thin"	Shaded
Diameter:			
base of 4-year-old wood	.38"	.25"	
base of new terminal shoots	.22"	.15"	weak
Length of new terminal shoots	18.00"	4.00"	short
Increase in bulk, 3-year-old branches, including fruit*	7.69gm	3.39gm	less than unshaded wood
Thickness of leaves	.20mm	.14mm	53% less than unshaded wood
Layers of palisade cells	2-4	1-2	one

*During a 13-day period

Diameter at base of 4-year-old wood: (14)
Diameter at base of new terminal shoots: average of 50 branches.
Length of new terminal shoot: average of 50 branches.
Increase in bulk of 3-year-old branches: average of 10 branches.
Thickness of leaves: average of 100 leaves.
Layers of palisade cells: range of 100 leaves.

That there is a difference in the physical characteristics of "thin" and "thick" wood is clearly demonstrated by other features than the ones by which Ricks and Gaston chose to define them. The leaves of "thin" wood are much thinner than those of "thick" wood; their internal structure differs in that the "thin" wood leaves have but one layer of palisade cells as compared with three or four in "thick" wood leaves. Four-month-old shoots of "thick" wood generally have greater basal diameters and are usually much longer.

"Thin" wood and intentionally shaded wood have several characteristics in common. Terminal growth is short and weak, neither "thin" wood nor intentionally shaded wood increases rapidly in size or weight. The leaves are about half as thick as those on branches more favorably exposed to sunlight, and have but one, infrequently two, layers of palisade cells.

Because the problem appeared to be a matter of light relationships, some effort was made to find the relationship between the production of organic matter by apple leaves and the light which the leaves received. Table II gives data on the production of organic matter by the "thick" wood leaves of a Winesap apple tree as affected by the amount of light.

Increase in the production of organic matter with increase in light intensity is made obvious by Table II. The relationship is curvilinear. The curve of best fit, after the method of least squares, is that of the second degree in the potential series. This is shown in Figure 1, together with its equation, the standard error of y, and the coefficient of correlation.

The degree of correlation, r = 0.8998, is high. It falls within the 5 percent point of Fisher's table and is clearly significant.

The standard error of y (±0.367) is high. This is as must be expected from any method for the study of photosynthesis under uncontrolled conditions. Deviation may, in part, be explained by fatigue, suddenly changing leaf activity because of temperature or light variation, or other variable factors.

It is evident that leaf activity as measured by the production of organic matter is closely related to the amount of light falling on the leaf surface. With the scope of the curve of "photosynthesis" in mind, it was desirable to investigate the relation of light to the production of organic matter by "thin" and "thick" branch leaves. During the summer of 1937 a group of samples for photosynthesis determinations were taken at the same time light measurements were made. The production of these samples, in terms of grams per square meter of leaf surface per hour, averaged .783 gram at 546 foot candle hours. From the formula, given in Figure 1, "thick" wood leaves should average .890 gram at this degree of illumination. The difference of .107 gram is only one-third the size of the standard error, indicating that "thin" wood leaves are not less efficient per unit area than "thick" wood leaves.

Actual and comparative light intensities received by the leaves on the "thin" and "thick" branches of apple trees are given in Table III. Light intensity from the sun and zenith varied considerably, even on clear days, under Michigan atmospheric conditions. The comparative values, that is, percent of direct sunlight, give a more representative picture of the difference in the amount of light falling on "thin" and "thick" wood apple leaves than the absolute figures; yet each form of presentation has certain useful features which require consideration.

The intensity of light falling on "thin" wood leaves varies more directly with the density of foliage than with any other factor except interference by clouds. Trees 1 and 2, which had some "intermediate wood," but no "thin" wood inside the tree, received on the leaves of the inner branches from 1183 to 1090 foot candles of light between the hours of 2 and 3 PM on a clear, slightly hazy day when direct sunlight average 6955 foot candles. The trees of group II had some "thin" wood, most of it nearly large enough to be "intermediate" in character. The leaves on this wood received, on the average, 390 foot candles of light, while the "thick" wood leaves obtained 3152 foot candles during a period when direct sunlight was approximately 8528 foot candles. The older trees, in group III, had a large amount of "thin" wood, some of it extremely "thin" in type. Leaves on the "thin" wood in these cases averaged 142 foot candles of light when the mean intensity of direct sunlight was 8339 foot candles. "Thick" wood leaves on trees of this group received an average of 3188 foot candles of light.

Use of some of these light values in the equation of Figure 1 indicates that "thin" wood leaves may produce, at 109 foot candles, .374 gram of organic matter per hour, and at 428 foot candles they may produce .758 gram per hour*.

The relative values are similar to those of Blackman and Matthaei (4), except that Blackman used as his value for full sunlight the maximum amount of light received from the sun. The comparative values given in Table 3 are obtained by dividing the average amount of light falling on leaves by the direct sunlight intensity at the time readings were taken. The "thin" wood leaves on the trees of group II received .046 full sunlight, and those of group III .017. The average amount of light received by "thick" wood leaves on all of the trees in these two groups was .374 full sunlight. From the formula for the production of organic matter as related to the amount of light, maximum photosynthesis at about 23° C. would occur with .439 full sunlight. Since Blackman and Matthaei show that maximum photosynthesis (at 27.5° C.) requires from .36 to .69 full sunlight it is

*The standard error of these figures is ± .367 gram.

evident that "thin" wood leaves, which receive on the average less than .04 full sunlight, cannot be very active in the production of photosynthate.

The data so far discussed have been limited with respect to time and by some arbitrary rules of procedure. It remains, then, to find whether or not "thin" wood and "thick" wood leaves and branches will react in the same fashion over a long period of time, during which entire days are considered rather than intervals of a few hours. The results of this study are given by Tables 4 and 5, which will be separately considered. Table 4 shows the results of the 1936 season and Table 5 those of 1937. Table 4 is so arranged that comparisons may be made between leaves from spurs and shoots on "thin" and "thick" wood on both pruned and unpruned trees. It is noticeable that every series of samples varied widely from the mean result; yet in few cases did "thin" wood leaves equal or exceed the production of organic màtter by "thick" wood leaves.

The extremes of production by "thick" wood leaves are 15.87 grams per square meter of leaf surface as the maximum attained, and -8.07 as the minimum, the average being 5.36 grams per day. For "thin" wood leaves the extremes are 7.00 and -16.20 grams, respectively, for the maximum and minimum production, while the average for the 90-day period was -0.38 gram. "Thick" wood leaves on unpruned trees averaged slightly higher in production of organic matter over the 90-day period than did the same type of leaves on pruned trees. On unpruned trees all "thick" wood leaves averaged 6.02 grams of organic matter per square meter of leaf surface per day; on pruned trees the leaves produced an average of 4.71 grams.

In order to illustrate the course of organic matter production during the period of the experiment, and to compare the rate at which each type of leaf is able to make organic matter, Figure 2 was developed. This graph shows the summation curves for the production of organic matter by "thin" and "thick" wood leaves as they appear, when developed in the following manner: The daily production for each two successive readings was averaged, multiplied by the number of intervening days, and the totals added successively. It will be seen that for about 30 days following June 5 "thin" wood leaves, in general, showed no apparent photosynthesis*. After July 8 "thin" wood leaves were active. Comparisons of yields of organic matter by the two types of leaves were made by drawing a straight line from the point of origin to the end point of the curve, and determining the slope of the line. Because of the nature of the curve for "thin" wood as drawn from the 1936 data, and shown in Figure 2, two lines were drawn, C_1 from the point of origin to a point 33 days out on the X axis along B, and C_2 from this point to the end point of the

*Reference to Table 4 will show that this is not invariably the case.

summation curve. The amount of organic matter which was manufactured by "thick" wood leaves for each gram used or produced by "thin" wood leaves was calculated by dividing the slope of the line representing the production of "thick" wood leaves by the slope of line with which it was to be compared. For example, the slope of A_1 divided by the slope of B_1 shows that for each gram of organic matter produced by "thin" wood leaves for the 90-day period "thick" wood leaves manufactured 12.9 grams.

From June 5 to July 8 "thin" wood leaves must have received from the tree or branch, on the average, 1 gram for each 3.25 grams of organic matter made by the "thick" wood leaves. During the latter part of the experimental period "thin" wood leaves manufactured 1 gram of organic matter for every 3.32 grams produced by "thick" wood leaves.

The question of whether or not "thin" wood is actually parasitic may be considered from two viewpoints on the basis of the data shown. First, if the data in Table 4 are reviewed, it appears that "thin" wood could be parasitic since the average unweighted daily production is -0.38 gram. The table does not take time into consideration as the graphs in Figure 1 do. From June 5 to July 8 "thin" wood was not making organic matter as fast as it was being used, and at this time there is a possibility that the wood was not self-supporting. From July 8 to September 5 the production of organic matter by the "thin" wood leaves on these same trees exceeded by 144.3 grams the amount that was lost during the first part of the experimental period, indicating that "thin" wood was not entirely parasitic, if at all so.

The data collected in 1937 define more exactly the extent of the difference in organic matter production by "thin" and "thick" wood leaves. The extremes of production, as shown in Table 5 were for "thick" wood leaves 13.09 grams and 1.50 grams as compared with a maximum of 3.87 grams and a minimum of -1.11 grams per square meter of leaf surface per day for "thin" wood leaves. The average production for "thick" wood leaves was 6.34 grams as compared with 1.66 grams for the "thin."

Comparisons (Figure 3) were made between the relative amount of light received by "thick" and "thin" wood leaves on these trees. "Intermediate" wood leaves on Duchess tree No. 1 located "inside" the tree received .158 the amount of light falling directly from the sun. These leaves produced .27 as much organic matter as did the "thick" wood leaves or an average of 2.35 grams of organic matter per day. "Thin" wood leaves on Duchess tree No. 2 received .05 full sunlight; yet they produced a daily average of 1.92 gram of organic matter per square meter of leaf surface per day which was .35 the amount produced by "thick" wood leaves on the same tree. The "thin" wood leaves on the Winesap tree received .021 full sunlight and made .23 as much organic matter as the "thick" wood leaves or an average of 1.42 gram of organic matter per day. Grimes Golden "thin" wood leaves received .012 full sunlight and produced .22 as much organic matter as the "thick" wood leaves on the same tree or a daily average production of .93 gram per square meter of leaf surface per day between July 13 and August 20, 1937. This tends to indicate that "thin" leaves may be from slightly below equally efficient to more than three times as efficient per unit of light received per unit of leaf area as "thick" wood leaves. However, it is apparent that much more time is required for them to produce an equal amount of organic matter. Even the "intermediate" leaves on Duchess tree No. 1 would require 2.7 times as long to produce the amount of organic matter produced by the average for all "thick" wood leaves.

A comparison was made between the average summation curves for "thin" and "thick" wood leaves for the data collected in 1937 similar to that made from the data of 1936. It was found that between July 13 and August 20 "thick" wood leaves produced 3.5 grams for each gram made by "thin" wood leaves (Figure 4).

If the leaves on "thin" wood are less able to make food for branch and fruit growth, the branches, as well as the fruit, must suffer from the lack. There should be some relation between the amount of organic matter produced by photosynthesis and the amount laid down in the branches during the growing season. A comparison of the amount of growth made by "thin" and "thick" branches, and the amount of organic matter which the leaves could have produced at the same time is presented in Table 6.

Per unit of leaf area "thin" wood leaves made about 11 percent as much organic matter as did "thick" wood leaves, and the branches increased 43 percent as much in bulk during the interval shown by Table 6. Assuming, however, that respiration of leaves, branches and fruit required 20 percent of the manufactured organic matter, as suggested by Heinicke (11), "thin" wood leaves produced a little more than twice the amount of dry matter laid down. Under the conditions of this experiment "thin" wood was not parasitic, for obviously the leaves were fully capable of supporting the branches and supplying sufficient elaborated materials to account for branch maintenance and the small growth made. It is equally evident that the corollary, that "thin" wood makes little growth because it is supplied with small quantities of elaborated food, is true.

CONCLUSIONS

Since growth is limited by the amount of food and food materials which the branches obtain from tree* and leaf it is apparent that the size and development of fruit and branch will be limited by the quantity of either which the branch is able to obtain. The amount of elaborated plant food which the branches will get from the leaves on them is modified by the quantity of light which the leaves receive. Since relatively little light falls on "thin" wood leaves the amount of elaborated plant food which the branches will get will be much less than is produced by the more strongly illuminated "thick" wood branches.

The size of fruit borne on "thin" wood branches is subject to two adverse factors, the first being the fact that the available supply of elaborated food will be small, and the second that less light falls on the fruit itself. Fruit on wood which obtains from less than 6 percent to not more than 43 percent as much light as fruit on "thick" branches will be smaller in size for this reason. In addition, the grade of the fruit will be reduced because fruit so poorly illuminated will not be so well colored.

With reference to pruning as a means of influencing the fruiting habit of trees and the economics of fruit

*The other possible reason for the development of "thin" wood,--that is, the restricted entrance of food materials from the remainder of the tree, is probably a minor cause since it is dependent upon severe mechanical or pathological injury, senescence, or poor soil conditions.

production the results that have been presented offer some valuable suggestions. A common pruning practice to improve the growth of fruit and branch is "thinning out", that is, cutting out some of the canopy branches so that light may penetrate deeper toward the tree trunk. This type of pruning removes much good fruiting wood. If pruning by this method could raise the level of light reaching the inner branches to that which reaches the leaves on the branches making up the tree canopy, the leaves on the branches "inside" the tree could produce, theoretically, equally good fruit after vigorous growth had been re-established. However, it was observed that at best not more than 43 percent as much light could be expected to fall on the inner branch leaves of healthy, vigorous, open trees as fell on the canopy branch leaves. Consequently, the invigoration of weak wood,--making thick, productive fruiting branches out of "thin" ones--is impracticable. The normal course is for stocky wood to become weaker, for "thick" to acquire the characteristics of "thin" wood, as it becomes older, due in large measure to shading. This tendency cannot be reversed because it is the very nature of trees (as opposed to shrubs) to produce their strongest new growth from their outer and upper extremities.

From the standpoint of orchard economics, then, it is evident that the removal of branches which make up the tree canopy is not the answer to profitable production for, with no pruning, it is these branches which receive the most light and make the best fruit. The inner branches which produce the poorest fruit and make the least growth can be removed advantageously since such pruning reduces the number of poor specimens which must be picked, handled and marketed. Of the various methods of pruning for the purpose of improving the quality of the fruit harvested, "thin" wood pruning makes the greatest use of the interpretations based on the data obtained by these experiments in photosynthesis.

SUMMARY

Experiments which were aimed to determine how directly the theory that certain branches of the apple tree are "thin" because they are poorly nourished might be applied were made with the following results:

1. On "thick" wood leaves it was found that light affected the production of organic matter according to the relationship, $Y = 0.2352 + 0.1282X - 0.00146\,X^2$, with $S_Y = \pm 0.367$. Light was correlated with production to the extent $r_{Y1} = 0.8998$.

2. "Thin" wood leaves received from .017 to .05 full sunlight as compared with from .28 to .465 for "thick" wood leaves, but were apparently equally efficient per unit leaf area, per unit of light received.

3. Two years of experiments attempting to determine the approximate amount of organic matter which "thin" and "thick" wood leaves could produce per average day showed that "thin" leaves could produce from -1.82 to 2.35 grams where "thick" wood leaves could produce from 4.19 to 8.31 grams per square meter of leaf surface per day under average growing season conditions in southern Michigan.

4. "Thin" branches did not increase in bulk as rapidly as "thick" branches but the leaves on "thin" branches were apparently able to provide, generally, enough organic matter to account for any gain in bulk which they made.

It is concluded that "thin" branches are not parasitic, except under the most extreme conditions, but that because their leaves do not receive sufficient light, they are less well nourished and consequently, "thinner" than the other branches on the tree. Furthermore, on the basis of these data, and in the light of the work reviewed, "thin" wood fruit will be less well colored (if commonly red) and smaller in size than fruit on other branches.

With respect to pruning the conclusions drawn are that it is better to remove the wood bearing poor fruit rather than to attempt to improve the growth of the weak "thin" branches by removing good fruiting wood from the outer part of the tree canopy,--the same recommendations as those made by Ricks and Gaston in their "thin" wood method of pruning.

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TABLE II

Relation of light to the production of organic matter

Light (foot-candle-hours)	Production of organic matter (grams per square meter per hour)
0	.00
30	.38
70	.10
80	.02
150	.15
160	.65
195	.65
200	.68
210	.40
520	.90
840	1.19
840	1.65
900	1.75
910	1.24
920	1.75
1010	1.23
1080	1.19
1090	.79
1090	1.94
1350	2.51
1400	1.69
1585	2.32
2640	2.05
2660	2.15
2699	2.74
2710	2.68
2710	2.23
2780	3.28
2850	2.52
2879	2.04
3180	2.38
3760	3.48
3770	3.37

$Y = 0.2352 + 0.1282 - 0.00146\ X^2$

$Sy = \pm\ 0.367$
$r = 0.8998$

TABLE III

The Intensity of Light Falling on Apple Leaves

Tree	Average Amount of Light Received by Leaves							
	"Thin" leaves		"Thick" leaves		Zenith		Direct Sunlight	
	f.c.	% D.S.	f.c.	% D.S.	f.c.	%D.S.	f.c.	% D.S.
Group I: Trees 12-years-old with open tops (No "thin" wood--measured leaves on "Intermediate" branches)								
1	1183	16.9	2788	39.6	3000	42.9	7010	100
2	1090	15.8	2450	35.5	3510	50.9	6900	100
Aver.	1136	16.3	2619	37.6	3255	46.9	6955	100
Group II: Trees 12-years-old with dense tops ("Thin" wood present).								
3	358	4.2	2423	28.5	3074	36.2	8500	100
4	349	4.0	3219	37.0	3101	35.8	8700	100
5	425	5.0	2875	34.1	2809	33.3	8450	100
6	428	5.0	3940	46.5	3500	41.5	8500	100
Aver.	390	4.6	3152	36.5	3160	36.7	8528	100
Group III: Trees 20-years-old with dense tops ("Thin" wood of extreme type).								
7	142	1.7	3419	40.5	3000	35.6	8450	100
8	163	1.8	3921	43.5	4010	44.6	9010	100
9	109	1.2	2697	30.6	3900	44.5	8791	100
10	152	2.1	2715	38.2	3200	45.0	7105	100
Aver.	142	1.7	3188	38.2	3528	42.4	8339	100

TABLE IV

CHANGE IN DRY MATTER DUE TO PHOTOSYNTHESIS

Tree	Sample	Treatment	June 5-6	June 12-13	June 19-20	July 8-9	July 26-27	Aug. 7-8	Aug. 21-22	Sept. 4-5	Mean
Individual Sample Data			(In grams per square meter per day)								
Leaves from "thick" branches											
M	Spur	Pruned	.83	5.80	.60	8.73	15.40	.50	6.07	6.20	5.52
N	Spur	Pruned	1.13	.17	10.77	2.17	8.73	.43	8.33	7.20	4.87
O	Spur	Unpruned	6.23	2.17	6.67	12.23	7.73	6.40	2.33	2.83	5.82
P	Spur	Unpruned	6.00	-1.43	7.37	3.07	13.93	5.63	5.83	4.07	5.56
Average pruned spurs			.98	2.98	5.68	5.45	12.06	.46	7.20	6.70	5.19
Aver. unpruned spurs			6.12	.37	7.02	7.65	10.83	6.02	4.08	3.45	5.69
Average all spurs			3.55	1.68	6.35	6.55	11.45	3.24	5.64	5.08	5.44
M	Shoot	Pruned	.90	6.23	10.17	1.43	6.27	10.33	-8.07	6.87	4.27
N	Shoot	Pruned	-7.13	2.43	10.77	1.07	3.80	4.03	2.67	15.87	4.19
O	Shoot	Unpruned	9.27	9.73	13.30	5.03	8.87	9.80	4.17	9.57	8.72
P	Shoot	Unpruned	.60	.20	1.33	10.90	5.33	5.53	2.73	5.13	3.97
Average pruned shoots			-3.12	4.33	10.47	1.25	5.04	7.18	-2.70	11.37	4.23
Aver. unpruned shoots			4.94	4.96	7.32	7.96	7.10	7.66	3.45	7.35	6.34
Average all shoots			.91	4.65	8.89	4.61	6.07	7.42	.38	9.36	5.29
Average all "thick" wood leaves			2.23	3.16	7.62	5.58	8.76	5.33	3.01	7.22	5.36
Individual Sample Data											
Leaves from "thin" branches											
O	Spur	Unpruned	-16.20	3.30	-.20	-9.83	1.40	.60	3.70	2.70	-1.82
P	Spur	Unpruned	-5.13	7.00	2.50	-.33	-3.27	4.70	.93	.01	.80
O	Shoot	Unpruned	-1.43	-7.20	-7.83	3.77	8.83	.33	2.50	-3.93	-.62
P	Shoot	Unpruned	.20	-1.63	-5.83	3.27	-.43	3.17	6.27	-3.60	.13
Average "thin " spurs			-10.66	5.15	1.15	-5.08	-.94	2.65	2.32	1.36	-.51
Average "thin" shoots			-.82	-4.42	-6.83	3.52	4.20	1.75	4.38	-3.76	-.25
Average all "thin" wood leaves			-5.74	.37	-2.74	-.78	1.63	2.20	3.37	-1.20	-.38

TABLE V

CHANGE IN THE ORGANIC MATTER OF LEAVES DUE TO PHOTOSYNTHESIS
1937

Samples	In grams per square meter of leaf area per day						
	July			August		Total	Mean
	12-13	21-22	28-29	10-11	19-20		
Leaves from "thick" wood branches							
Duchess I	6.76	5.36	13.09	6.73	9.64	41.58	8.31
Duchess II	5.43	1.55	4.30	8.67	7.47	27.42	5.48
Winesap	4.99	5.86	4.50	8.79	6.63	30.77	6.15
Grimes Golden	5.91	4.90	1.50	7.44	7.25	27.00	5.40
Total	23.09	17.67	23.39	31.63	30.99	126.77	25.34
Mean	5.77	4.42	5.85	7.91	7.75	31.69	6.34
Leaves from "thin" wood branches							
Duchess I*	3.87	1.90	1.77	1.86		9.40	2.35
Duchess II	1.70	2.63	-0.02	2.07	3.33	9.71	1.94
Winesap	1.27	2.77	3.09	-1.11	1.06	7.08	1.42
Grimes Golden	.56	.04	1.48	1.09	1.90	4.76	.93
Total	7.40	7.34	6.32	3.91	6.29	30.95	6.94
Mean	1.85	1.83	1.58	1.93	2.10	7.72	1.66

*The leaves used from Duchess tree No. 1 were "intermediate"

TABLE VI

A Comparison of the Growth of "Thin" and "Thick" Branches* and the Amount of Organic Matter Produced by Their Leaves

	Grams Dry Weight 7/21	8/3	Increase	Aver. leaf area (cm^2)	Production of dry matter from 7/21 to 8/3/36
"THIN WOOD"					
New wood	1.37	1.49	.12		
Wood 1 to 3 years old	.99	1.30	.31		
Fruit	20.25	23.21	2.96		
Total gain, dry matter			3.39	480	8.75 grams
"THICK WOOD"					
New wood	5.86	6.45	.59		
Wood 1 to 3 years old	6.66	8.83	2.17		
Fruit	25.49	30.42	4.93		
Total gain, dry matter			7.69	820	81.40 grams

*Average of 10 branches

Figure 1

RELATION OF LIGHT TO THE PRODUCTION OF ORGANIC MATTER BY APPLE LEAVES

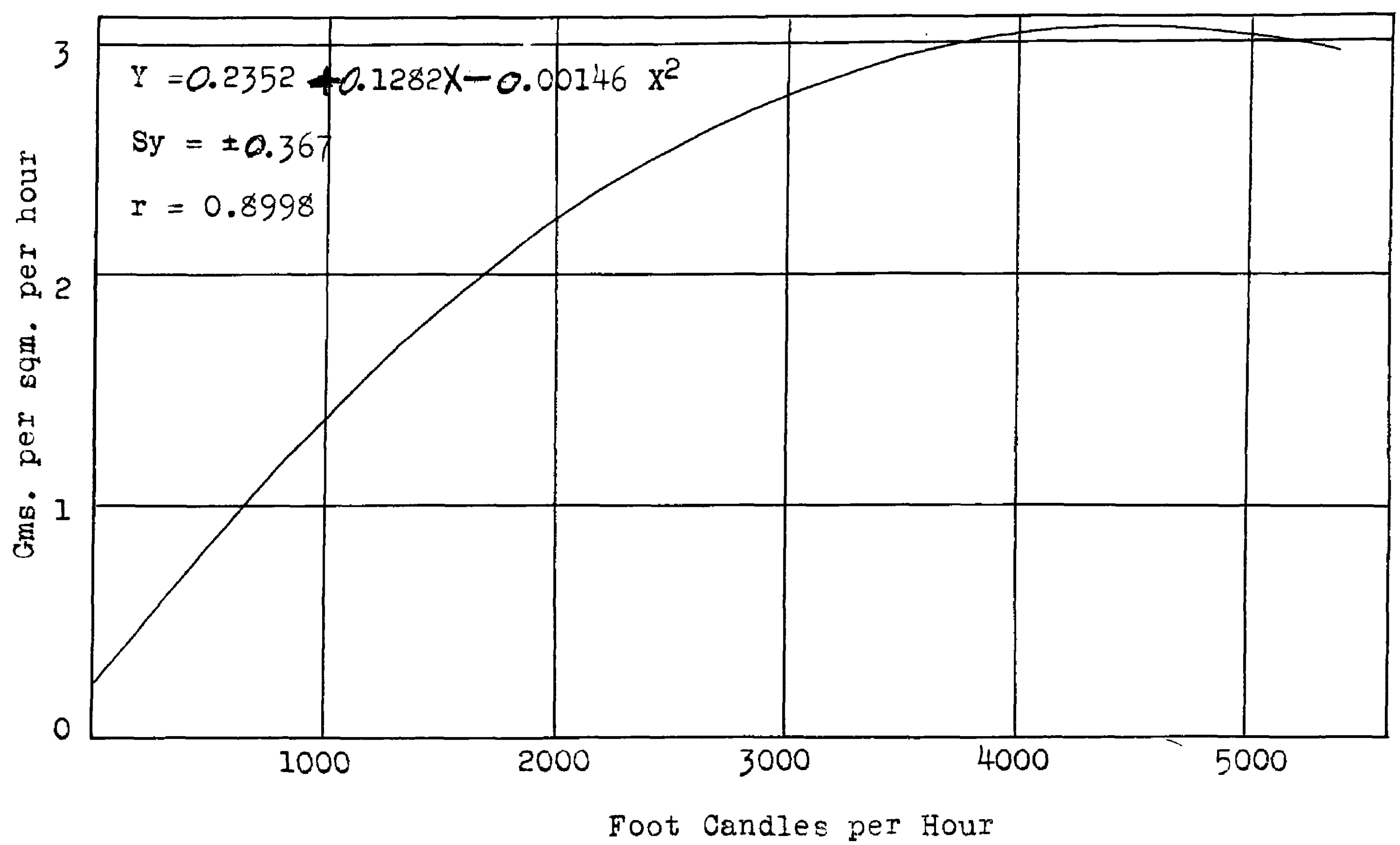
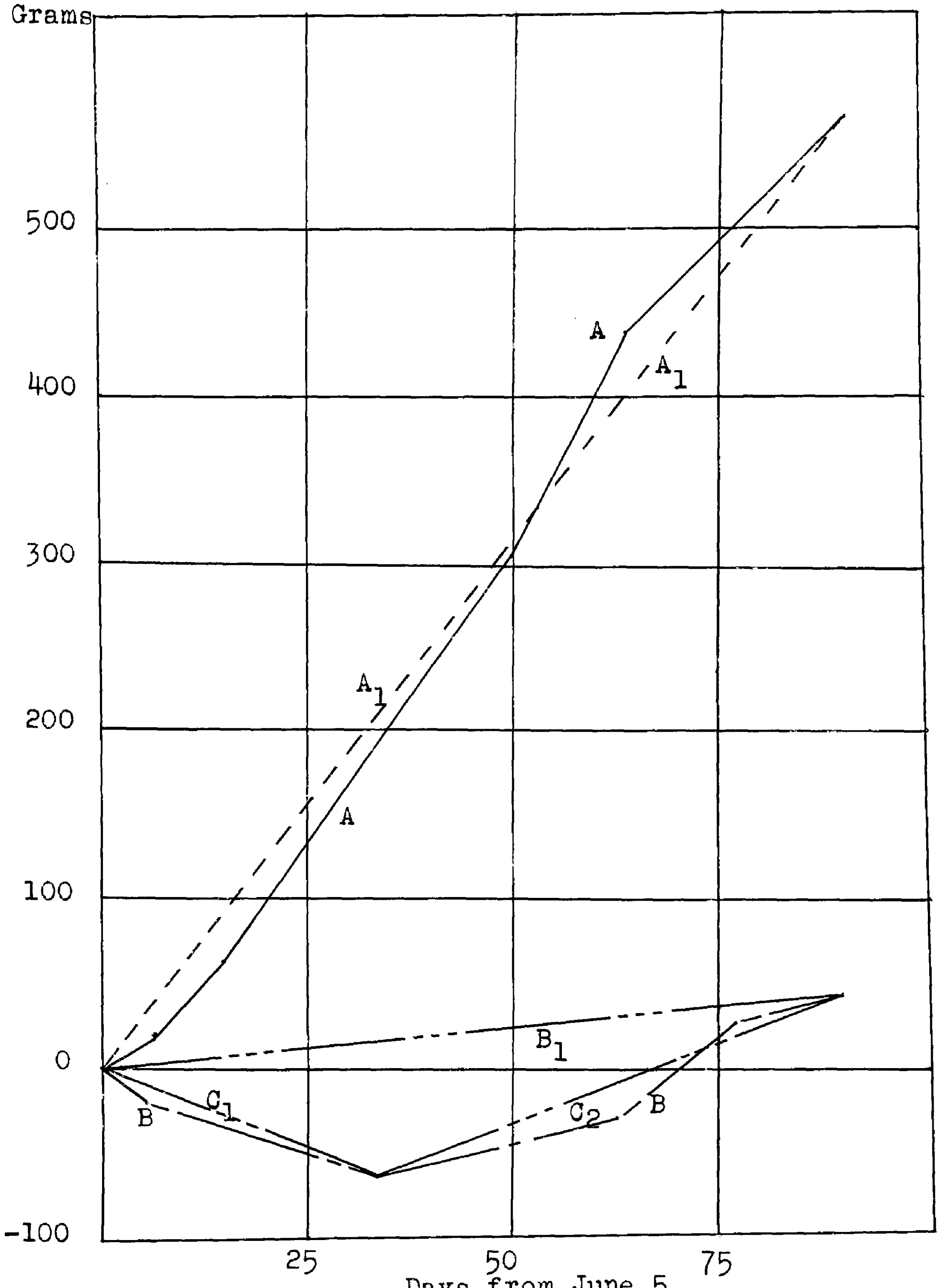


Figure 2

COMPARISON OF THE SUMMATION CURVES FOR ORGANIC MATTER PRODUCTION OF "THICK" AND "THIN" WOOD LEAVES. 1936.



A: "thick" wood leaves, summation of production

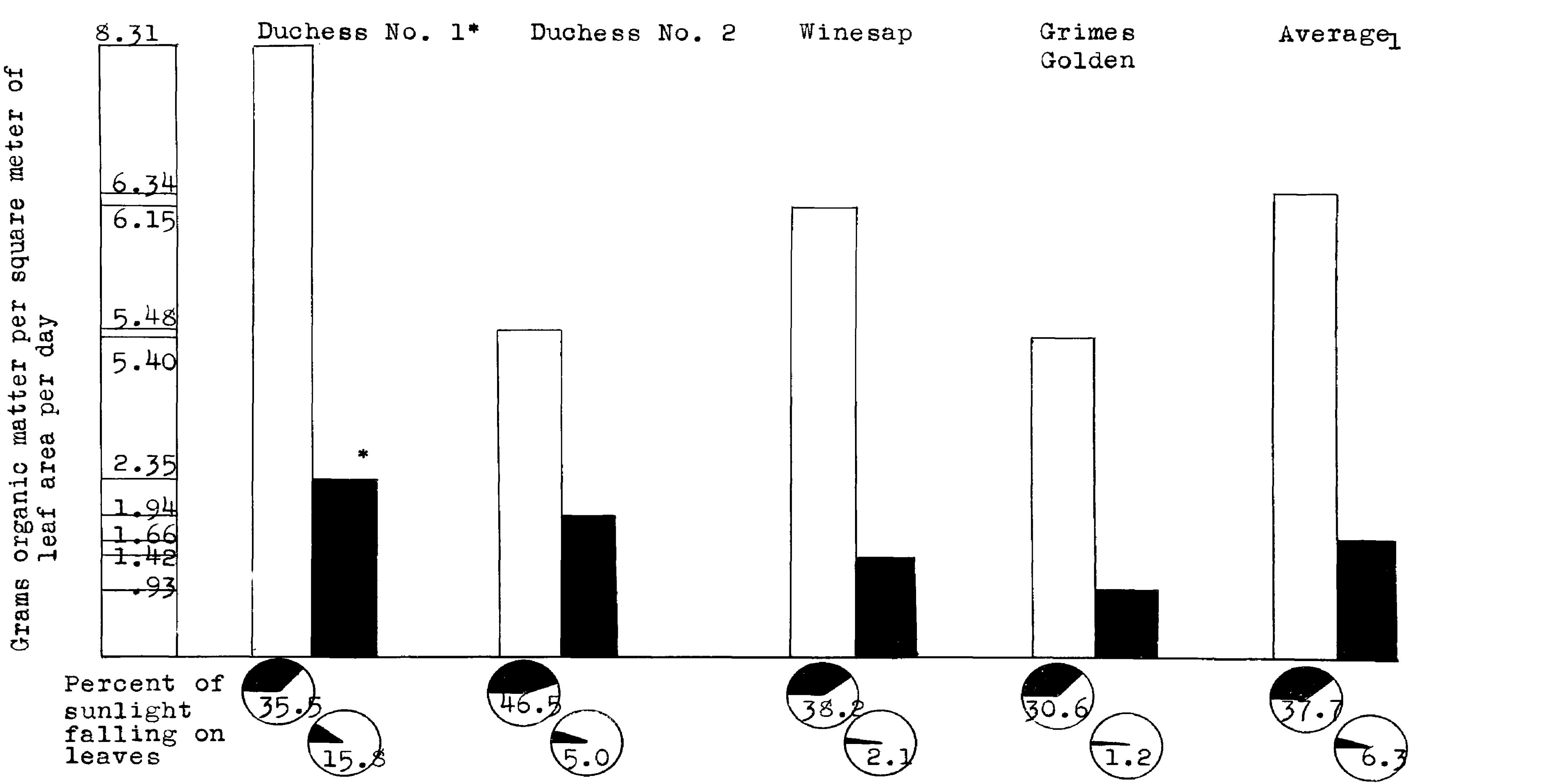
A_1: Slope = 1.250

B: "thin" wood leaves, summation of production

B_1: Slope = 0.097

Figure 3

PRODUCTION OF ORGANIC MATTER BY APPLE LEAVES
COMPARED WITH THE LIGHT RECEIVED BY THE LEAVES



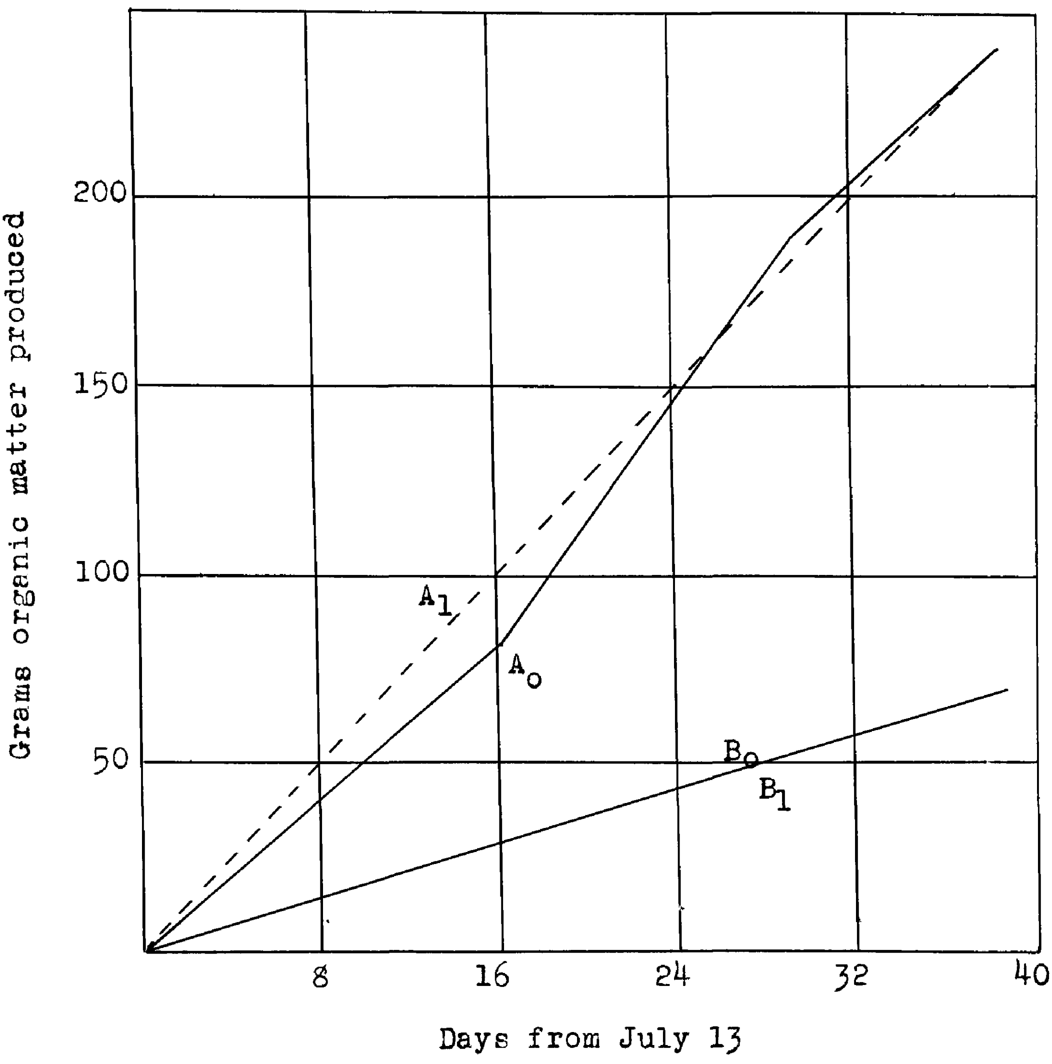
Open Columns: Average daily production by "thick" wood leaves.
Black Columns: Average daily production by "thin" wood leaves.
Circles: Full sunlight.
Black portion: part of sunlight received by leaves.
Upper circles: light received by "thick" wood leaves.
Lower circles: light received by "thin" wood leaves.

*"Intermediate" wood leaves

1 Average includes leaves from "intermediate" wood

FIGURE 4

COMPARISON BETWEEN THE SUMMATION CURVES FOR DRY MATTER PRODUCTION BY "THICK" AND "THIN" WOOD LEAVES



Slope of line A, 1.385
Slope of line B, 0.395