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Studies of Varietal Vigor and Growth in Apple Trees

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STUDIES OF VARIETAL VIGOR AND GROWTH IN APPLE TREES

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STUDIES OF VARIETAL VIGOR AND GROWTH IN APPLE TREES

INTRODUCTION

Constant differences in form are the chief means of identification throughout the plant world. Not only is this fact true between orders and families, but also between species and even varieties within the species. Distinct varieties in the species of wild plants are comparatively few. However, many of the species which have been brought into cultivation by man and used by him for food and other economic purposes are split into numerous distinct varieties. For example, the apple, one of the most important fruit plants, has a multitude of varieties each with its distinct characteristics of fruit and habits of tree growth.

Chance observation in the orchard shows that the trees of one variety differ considerably from those of another variety in their height and spread of branches and amount of annual growth. These inequalities in amount and kind of growth are often spoken of as representing differences in vigor between varieties and are characteristic for each of the varieties under similar growing conditions. Hedrick (18) says, "Vigor must not be confused with size. Vigor may be defined as internal energy. Small trees may be as vigorous as large one." Yet, the amount and kind of growth made by the tree in any one year is certainly an expression of the vigor of the tree at that particular time. Thus, the accumulated growth for several years must be representative of the vigor of the tree during that period.

On these differences in varietal vigor of growth, the planting classification of varieties

is based. It is recognized that under similar conditions of environment such varieties as Baldwin and Rhode Island Greening grow large and bear relatively late in life, while Yellow Transparent and Wealthy produce much smaller trees in the same length of time and bear fruit at a younger age. For these reasons, the former varieties are used as "Standards" or permanent sorts, while the latter are used as "Fillers" or temporary varieties to be planted between the permanent varieties, thus, increasing the production of the orchard during its early life.

The question arises as to the nature and possible cause of these differences in vigor of growth between the varieties. To attempt to throw light upon the basal causes of these differences doubtless would involve a study of the factors of inheritance and the individuality of the cell protoplasm of the several varieties. Yet,

because these cell characteristics are expressed through physiological processes, it is possible to make some comparisons of the factors in which varieties differ and to speculate as to the nature of these differences and why they exist. Thus, the investigations herein reported were undertaken for the purpose of studying these differences in growth, measuring them quantitatively, and, if possible, throwing some light upon the factors behind these visible external variances.

LITERATURE

So far as is known, no one has ever made a detailed comparative study of all of the factors involved in the question of vigor of growth in apple trees. Beach (2) probably has come the nearest to covering the subject in his descriptions of the different apple varieties. Table I is a summary of most of the varieties here studied, as taken

from his work. Hedrick (18) also deals with the subject, but only in a very general way. He says, "Size of tree is a very reliable character to determine varieties of any of the pome fruits." He also says, "Size of leaf, if given in figures, is a most valuable determinant of varieties of all pome fruits." Measurements made by Cummings (8) on a young variety apple orchard show that relation exists between the size of trunk and the yield, and also between the size of head and the yield. Alderman and Crane (1) give figures to show that some relation is to be found between the trunk circumference, shoot growth, and yield for the varieties which they studied. Hedrick and Anthony (19) found that within a variety, the volume of the tree head is closely related to the total yield of the tree. Hedrick (17) and Ellenwood (12) give figures which show that trees of the same age of different varieties, when grown side by side, differ

greatly in their total yield over a period of ten years. Thompson (36) presents data on the weights of leaves, new wood, trunk, and roots of young apple trees which indicate that some relation exists between these several factors, and that the same factors vary considerably between the varieties studied.

METHODS OF ATTACK AND MATERIALS USED

The factors involved in a study of vigor are several in number and cannot, logically, be considered under one head. Hence, it was decided to divide the studied into two parts: (1) those dealing with measurements of external characters of the wood growth; and (2) those dealing, primarily, with leaf studies and the relations between leaf and wood characters. Part one has to do with measurements of height, diameter, internode length, and stockiness of one year old nursery trees; while

part two is concerned with the study of leaf area and its relation to the volume and weight of wood, leaf weights, photosynthetic activity, and transpirational differences.

One year old nursery trees were selected as the best material for use in these studies. The chief advantages of using nursery stock are, (1) that the varieties grow side by side under as nearly the same conditions of environment as possible, (2) that their entire season's growth is easily measured, and (3) that they are obtainable in quantities large enough to permit the application of statistical methods to the measurements, and at the same time practically eliminate variations which would be found in small numbers due to certain individual trees.

The material used was grown in the nursery of The J. W. Adams Company, Westfield, Massachusetts, on a very uniform, deep, and level area

TABLE I. DESCRIPTIONS OF TREE, TWIGS AND INTERNODES - Beach

Variety	Tree	Twigs	Internodes
Baldwin	Large Very vigorous	Long, moderately stout	Medium to long
R. I. Greening	Large and vigorous	Medium to long, stocky	Usually stout
King	Vigorous	Long, moderately stout	Long to below medium
McIntosh	Vigorous	Medium to short, slender	Long to below medium
Wagener	Dwarfish	Short, moderately stout	Medium to short
Yellow Transparent	Medium, moderately vigorous	Short, stout	Medium
Oldenburg	Medium size	Moderately long, slender	Long
Red Astrachan	Medium to rather large Moderately vigorous	Medium to long, stout to rather slender	Long
Wealthy	Dwarfish to medium, moderately vigorous	Long, slender	Long
N. Spy	Large, vigorous	Long to medium, slender to moderately stout	Long to rather short.

of sandy loam soil. All trees were one year old whips grown from budded stock. In selecting the individuals to be measured, only whips, which were unbranched and which had not been checked or stunted in their growth, were considered. Any individuals which were noticeably abnormal in growth were discarded. The studies here reported extend, all or in part, over a period of four years and involve some 5700 individuals, representing eleven different apple varieties. Wherever possible an effort was made to secure at least 150 individuals of each variety for a given measurement. However, in many cases this was not possible and fewer individuals had to be used. For this reason the yearly measurements of height, diameter, and length of internode are given in Appendix Tables A to E, inclusive. The method of calculation is that described by Davenport (9) and is the usual method of evaluating population curves. In each case the

variety, number of individuals, mean, standard deviation, and coefficient of variability, with probable error of each, have been given for each of the four years, so that some idea may be had of the nature of the populations measured.

PART I. STUDIES OF WOOD CHARACTERS

HEIGHT

The most noticeable difference between varieties, as they stand in the nursery row, is that of height. Growing side by side under as nearly the same conditions as possible, trees of one variety will average much taller than those of another. Measurements of height are available for the years 1916, 1917, 1921, and 1922, for trees from the Adams nursery, and for 1916 for trees grown at Barnes Brothers Nurseries, Yalesville, Connecticut. These last are included here for

comparative purposes to show the differences which may be found in trees of the same age growing under different soil conditions. However, they are not included in the four year averages of height given in Table II and expressed in Figure 1.

The first column of Table II represents the four year average of height for each of the varieties with the probable error of the mean of the four years calculated by Peter's formula (28). Figure 1 presents the same data in graphic form. It will be noticed that there are considerable inequalities in the four year averagesof the several varieties, showing that varieties do differ in their size as nursery trees, much like they do as mature trees in the orchard. The table also shows that there are noticeable differences in the variability of the heights of the different varieties. Baldwin and Rhode Island Greening

are the most constant in height, with averages for the four years of 155.98 ± 1.50 and 136.50 ± 2.58 centimeters, respectively. Yellow Transparent and Red Astrachan show the greatest variability with three year averages of 125.94 ± 11.26 and 115.24 ± 8.89, respectively. Of course, in the case of these latter two varieties, some increased variability was to be expected, because of only having three years measurements for them while for the former varieties four years measurements are available. However, the increased variability is far too great to be accounted for by this factor alone. The variety King is fairly constant except in 1921 when for some reason its average height was very low.

Further, it will be noted in Table II, that the variability of height of the varieties in question is in inverse order to their season of fruit maturity. The early season varieties

show much greater variability of height from one year to another than do the later sorts. It would almost seem that the later sorts have a certain stabilizing influence which the earlier

TABLE II. FOUR YEAR AVERAGES OF HEIGHT, DIAMETER, AND STOCKINESS

Variety	Height c.m.	Diameter m.m.	Stockiness
Olden.	114.31 ± 8.66	10.40 ± .49	109.65 ± 4.47
*R. A.	115.24 ± 8.89	11.28 ± .70	101.93 ± 3.45
Wagener	118.31 ± 2.81	12.11 ± .28	97.82 ± 2.09
Wealthy	119.26 ± 7.13	9.82 ± .22	121.10 ± 4.64
*Y. Transp.	125.94 ±11.26	11.51 ± .90	109.10 ± 2.32
*N.Spy	133.26 ± 3.05	12.24 ± .58	109.27 ± 3.18
McIntosh	133.58 ± 3.48	11.17 ± .17	119.65 ± 3.56
Del.	136.02 ± 3.87	11.47 ± .28	118.52 ± 2.43
R.I.G.	136.50 ± 2.58	12.76 ± .18	106.92 ± 1.43
Bald.	155.98 ± 1.50	13.82 ± .16	112.96 ± .88
King	164.12 ± 7.74	13.28 ± .61	124.17 ± 2.79

* Measurements on these varieties are for three years only.

varieties do not have. This does not hold absolutely for all of the varieties in question, but still as the majority show this tendency it seems worthy of consideration.

The lower line in Figure 1 represents these same varieties as grown under different nursery conditions. It is indicated here, that, while they show the same general order of height as the others, all varieties are considerably shorter in their growth.

Examination of Table II also reveals that the varieties may be divided into three more or less distinct groups as to height; the shortest are Oldenburg, Red Astrachan, Wagener, and Wealthy; the medium class are Yellow Transparent, Northern Spy, McIntosh, Delicious, and Rhode Island Greening; and the tallest are Baldwin and King. This, in a general way corresponds somewhat to the sizes of mature trees of these varieties.

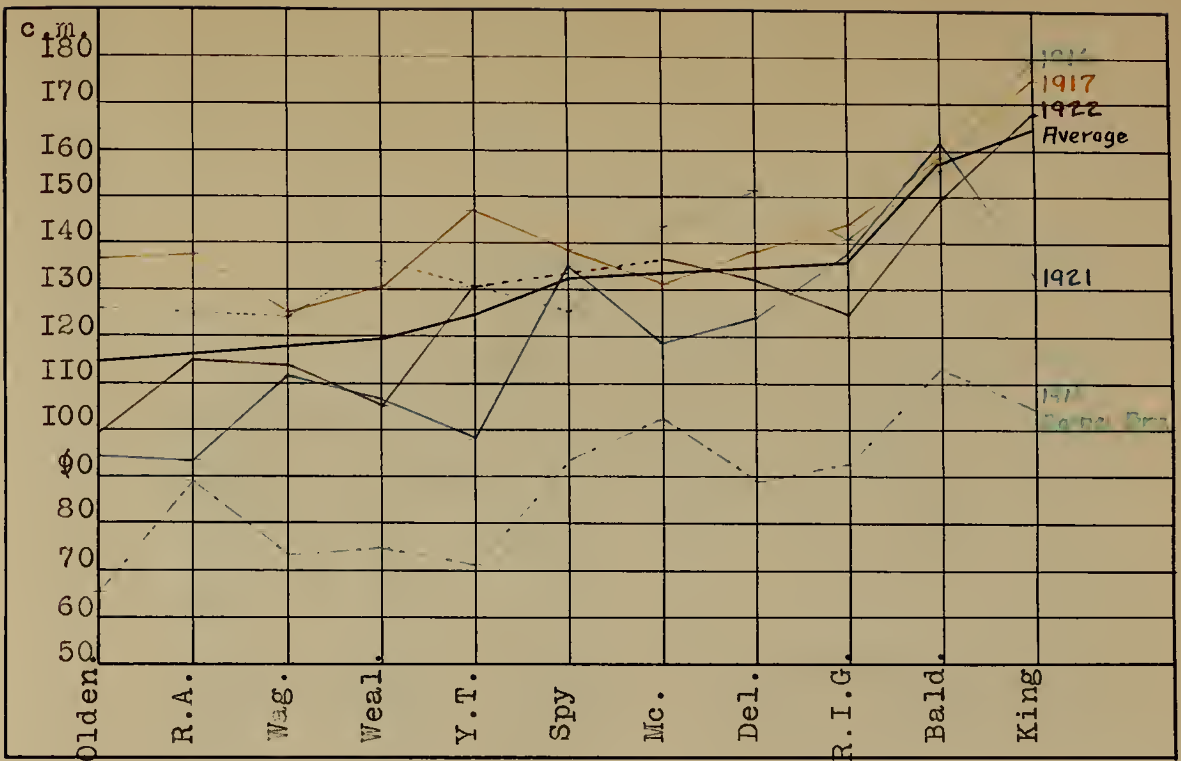

Figure I. Height of One Year Old Trees.

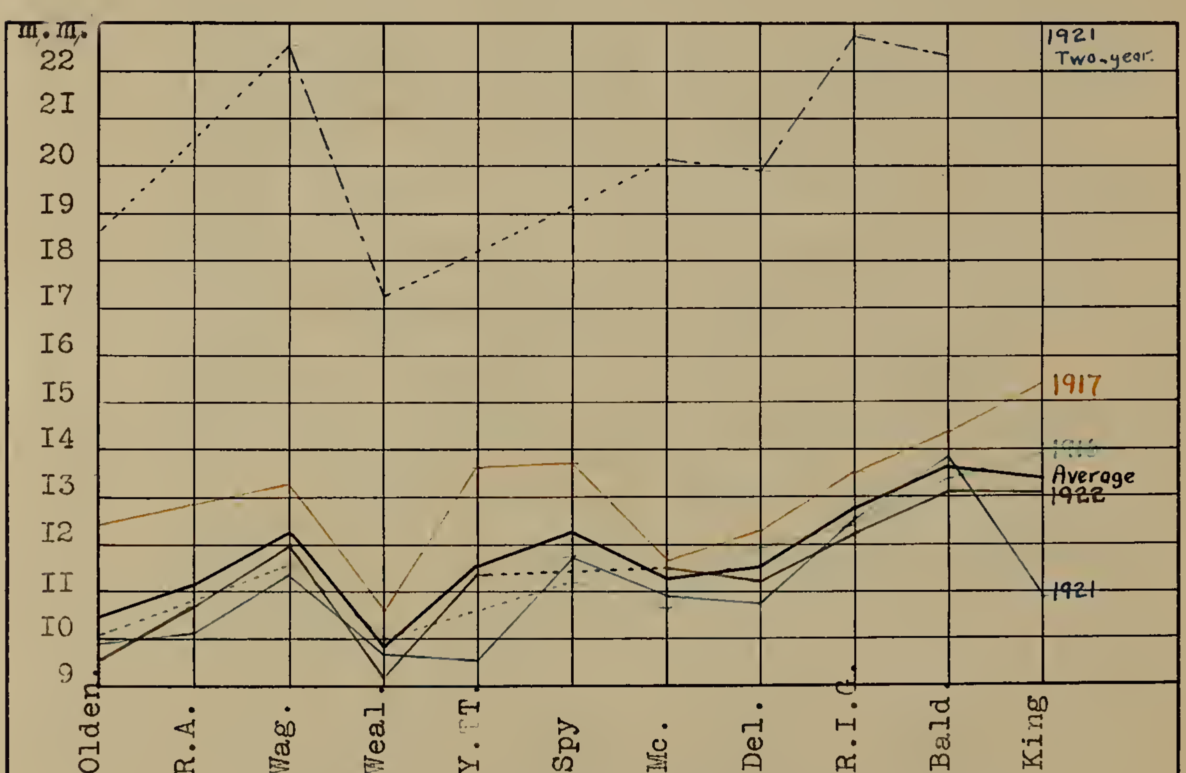

Figure 2. Diameter Of One Year Old Trees.

DIAMETER

Differences in diameter, although less apparent than those of height, nevertheless, do exist and are important characters. Diameter was measured, in all cases, with a small steel caliper, about six inches above the bud. In this factor also, figures are available for the four years for most of the varieties.

The second column of Table II summarizes the four year averages of diameter. Here again, as in height, it is found that Baldwin is the most constant with an average of 13.82 ± .16, while Yellow Transparent is the most variable with a mean diameter of 11.51 ± .90 m.m. The other varieties do not necessarily hold the same order of variability in diameter as they showed in height. For example, Wealthy which was highly variable in height is among the most constant in diameter. While on the other hand Northern Spy has increased

its relative variability in diameter over that of height. It appears that the factors at work which cause these differences in variability do not affect all varieties alike in both height and diameter.

A comparison of the average lines in Figures 1 and 2 shows that, although, there is a general tendency for increased height to be accompanied by an increase in diameter, yet, the relationship is not close nor does it hold for all of the varieties. Figure 2 also shows the diameters for a few of the varieties as two year old trees. These were taken in 1921 at the same nursery as the one year old trees and are given here to show comparison with the one year old trees. They apparently are somewhat more variable than are the one year old trees of the same varieties grown very close to them.

STOCKINESS

The index of stockiness was first used by Waugh (37) in comparing the growth of apple trees on Standard, Doucin, and Paradise stocks. It is obtained by dividing the height by the diameter, and it gives a numerical value to the already recognized differences in the relation between the height and diameter of each of the several varieties. On this basis, the varieties may be divided into stocky and slender growing sorts.

Column three of Table II gives the means of stockiness with probable errors figured for the three or four year averages; while Figure 3 presents the average and each year plotted together as shown in Appendix Table F.

Again in this factor, Baldwin shows the least variability of any of the varieties from one year to another. However, some of the

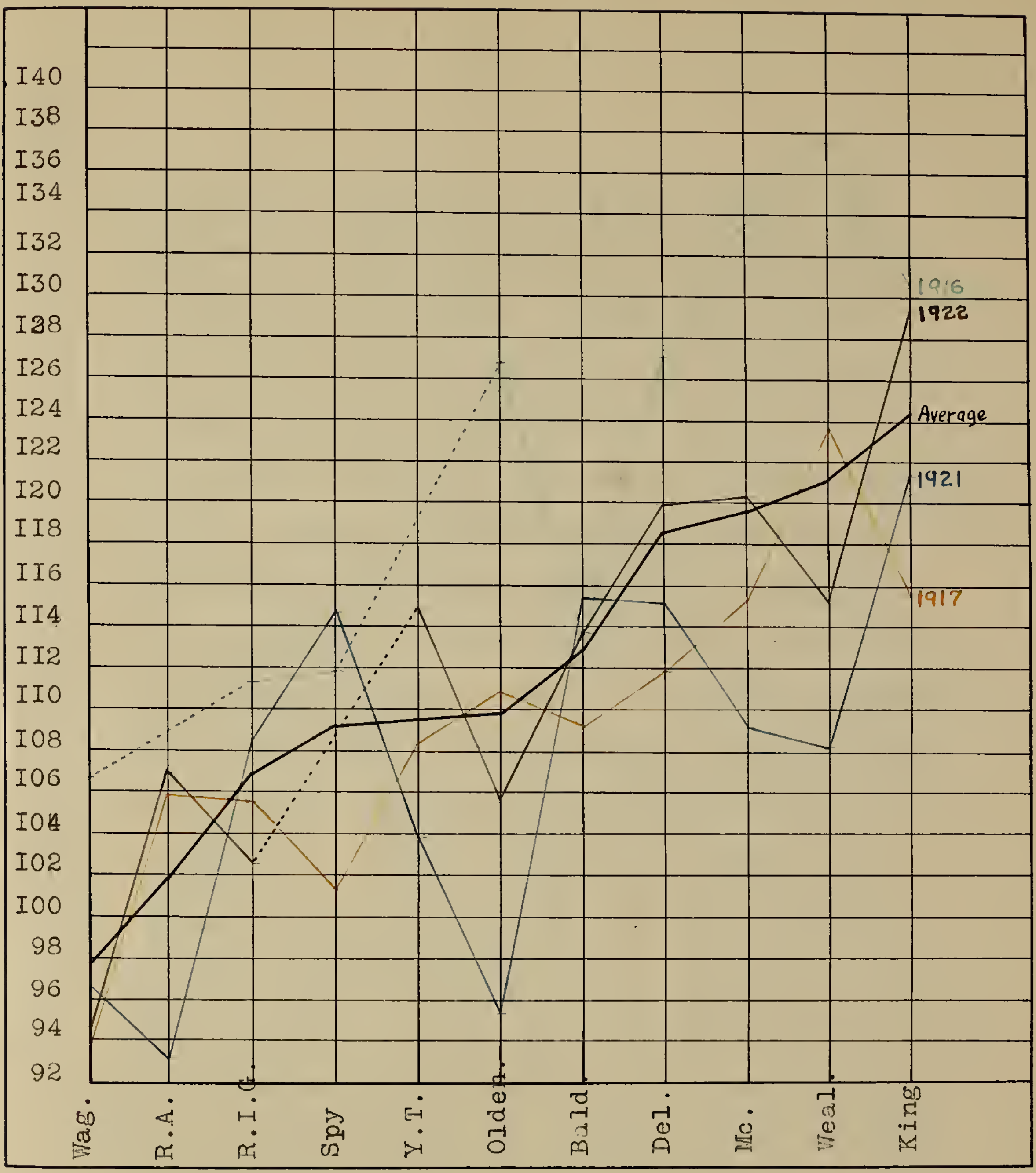

Figure 3. Index of Stockiness.

varieties, which were fairly constant in the factors of height and diameter, are extremely variable in stockiness. Yellow Transparent, which was the most variable of all varieties in height and also in diameter, is now found to be only about average in variability of stockiness. On the other hand, McIntosh which was average in variability of height and very consistant in its diameter, is shown to be among the most variable in stockiness. These data seem to indicate that the varieties differ considerably in different years in their relation between height and diameter; or that an increase in height, of a given variety in any year, does not necessarily mean a corresponding increase in diameter for the same variety. Recall here the statement made above, 'the factors at work which cause these differences in variability do not affect all varieties alike in both height and diameter'.

Some interesting points will also be noticed in the stockiness of the several varieties. Wagener is the most stocky with an average index of 97.82 ± 2.09. Oldenburg with an index of 109.65 ± 4.47 is much more stocky than is Wealthy which has an index of 121.10 ± 4.64. This is the relation that would be expected for these two varieties from observation on older and bearing trees. The variety, King, in spite of its height, is the most slender growing of all the varieties having an index of 124.17 ± 2.79. This index is even greater than that of Wealthy which is commonly thought of as being a very slender growing sort. However, the mature trees of King are very conspicuous because of their long sparsely-branched limbs.

There are also evident variations in the averages of stockiness of all varieties from year to year. The averages are as follows:

122.0 ± 3.01 for 1916, 109.2 ± 1.52 for 1917, 107.4 ± 1.97 for 1921, and 112.2 ± 2.29 in 1922. Comparing these averages by Student's method (35), to see if their differences are significant, it will be found that for 1916 and 1917 the odds are 33332:1; for 1917 and 1921 they are 10.9:1; and between 1921 and 1922 the odds are 29.7:1. As it is usually considered that odds of at least 30:1 are desirable for showing conclusive differences with this method, it can hardly be said that the difference between the stockiness of 1917 and 1921 is important. For 1921 and 1922 the difference is probably significant, and between 1916 and 1917 there is a most decidedly significant difference in stockiness.

LENGTH OF INTERNODE

Measurements of internode length were taken for the years 1921 and 1922. In this case

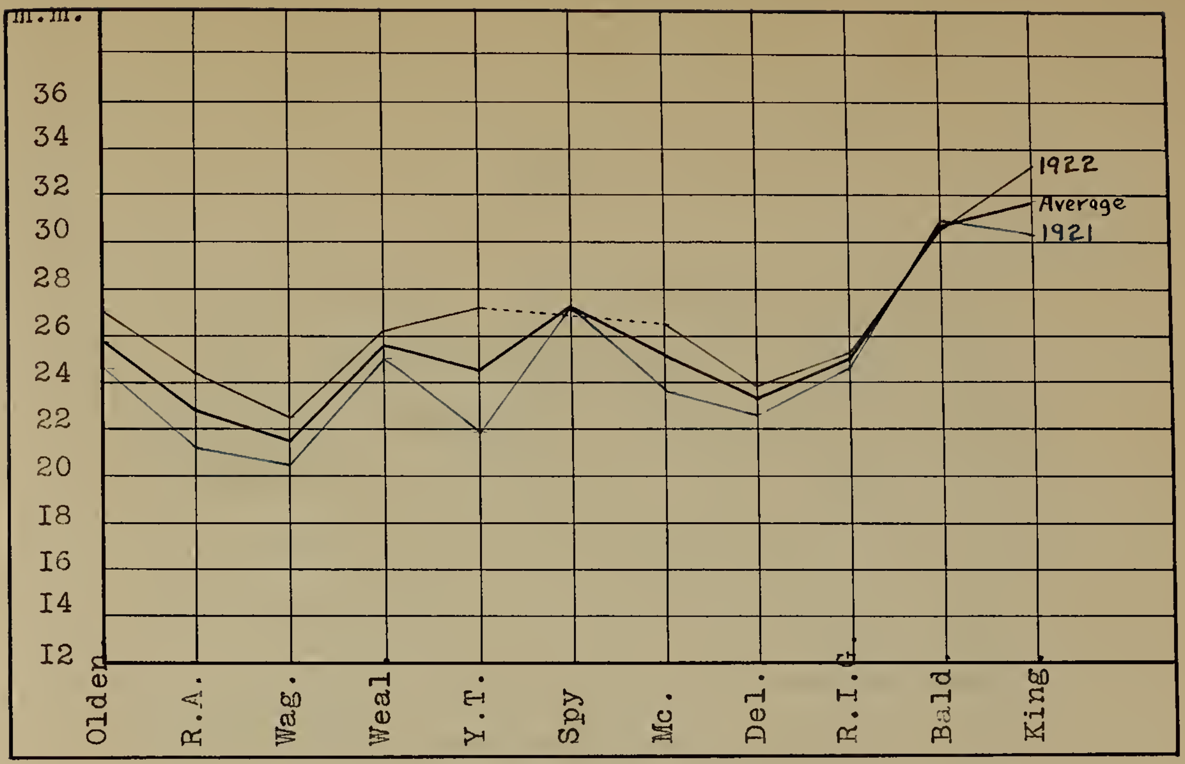

Figure 4. Length of Internode.

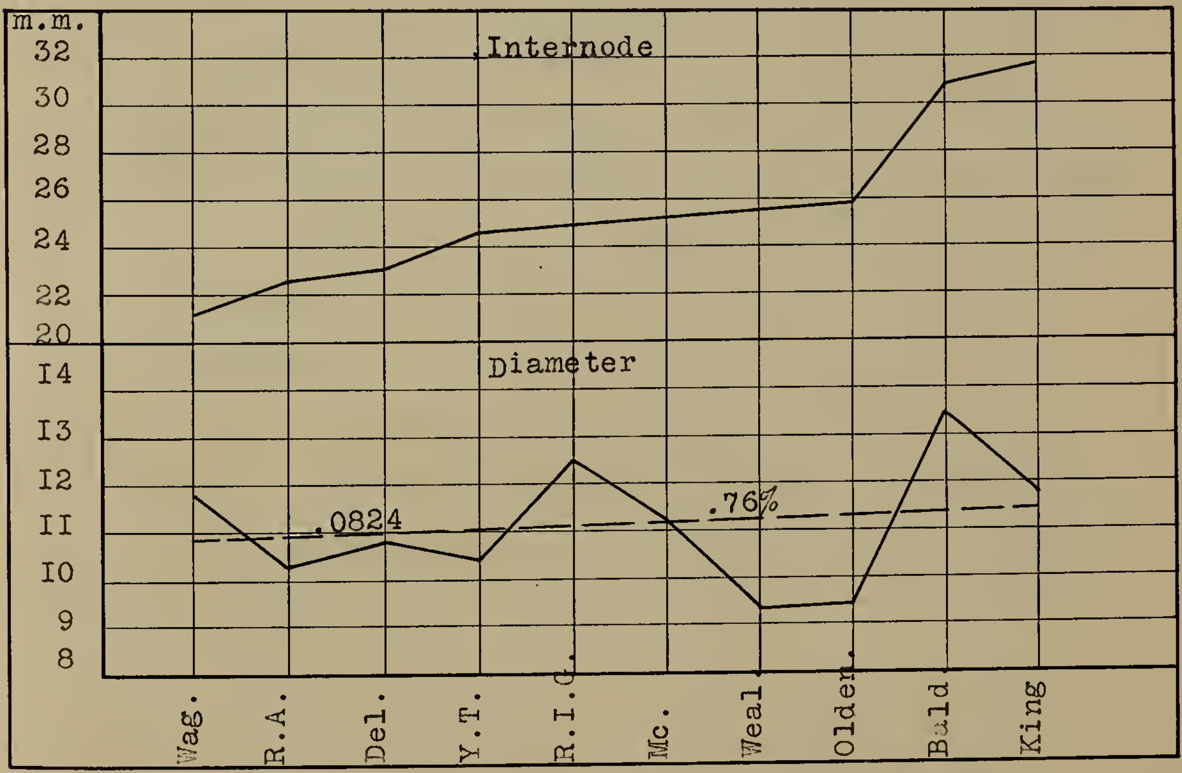

Figure 5. Comparison of Diameter and Internode.

each measurement taken represents the average of ten consecutive internodes. It was thought that this method would give much more reliable results than to measure an equal number of separate internodes taken promiscuously. In all cases the measurements were taken within 18 inches of the terminal bud, and only ten internodes of normal growth were measured.

Figure 4 presents, graphically, the data available on length of internode as summarized in the first column of Table III. Once more it is evident that Baldwin is the most constant of all the varieties in this factor with an average length of 30.93 ± .04 m.m. Yellow Transparent again shows the greatest variation with 24.55 ± 2.28 as an average.

The data also show that King has the longest internode, having an average of 31.85 ± 1.30 for the two years; while Wagener has the shortest

with an average length of internode of 21.33 ± .91 m.m. These two varieties happen to be the high and low ones in the scale of stockiness. However, the other varieties are not in such an order as to justify the conclusion that much of any relation exists between index of stockiness and length of internode.

The internode lengths, as here recorded for one year old trees, do not agree very closely with those reported in Table I as compiled from Beach (2). However, the latter were on mature trees and are expressed in verbal comparison only with no numerical values given. Again, the length of internode may vary with the amount of new wood produced.

COMPARISONS OF HEIGHT, DIAMETER, AND INTERNODE

The data on these three factors were not taken in such a manner as to permit the figuring

of correlation coefficients between them. It is, however, still possible to show, to some extent, the relation that exists between them, by means of the straight line method. (10)

TABLE III. TWO YEAR AVERAGES OF HEIGHT, DIAMETER, AND INTERNODE LENGTH

Variety	Internode m.m.	Height c.m.	Diameter m.m.
Oldenburg	25.82 ± 1.01	96.61 ± 2.31	9.62 ± .19
R.Astrachan	22.67 ± 1.54	104.12 ± 8.72	10.39 ± .28
Wagener	21.33 ± .91	112.62 ± 1.07	11.78 ± .23
Wealthy	25.56 ± .47	104.65 ± .38	9.39 ± .28
Y.Transprnt.	24.55 ± 2.28	114.48 ±14.13	10.41 ± .84
McIntosh	25.08 ± 1.18	129.01 ± 7.90	11.23 ± .24
Delicious	23.14 ± .59	128.11 ± 3.44	10.89 ± .11
R.I.Green.	24.94 ± .24	131.66 ± 4.62	12.48 ± .16
Baldwin	30.93 ± .04	155.75 ± 4.33	13.60 ± .28
King	31.85 ± 1.30	150.61 ±15.34	11.98 ± .90
Av. percent variability	3.76 ± .54	4.99 ± .96	3.16 ± .52

Table III represents the 1921 and 1922 averages for each of these three factors for the several varieties considered. The probable errors of the means have been figured by Peter's formula, ($P.E._m = .8453 \frac{\Sigma + d}{n\sqrt{n-1}}$) to give some idea of the variation between the two years. It is realized that two individuals are too few for reliable results; yet, as all of the averages are for two years only and only comparative results are wanted, it is believed that they will answer the purpose.

Figure 5 shows the relation between the length of internode and the diameter. The lower curve is that of diameter as plotted in the order of internode length. Observation shows that there cannot be very much relation between these two factors, but by using the straight line method (10)[x] it is found that there is a slight positive relation between length of internode and diameter, as indicated by the slope of the straight line which

x For type problem showing use of this method see Appendix Table H.

is + .0824 or .76%. However this slope is much too small to be of any significance.

Using the same method in Figure 6, to compare length of internode and diameter with height, it is found that the internode when plotted in the order of height gives a line the slope of which is + .6910 or 3.07%. This fact seems to indicate that there was a small relation between height and length of internode in those two years. Perhaps this was to be expected, as indirectly both factors are a measure of the same thing. In other words, providing the number of internodes remains constant, the greater the average length of those internodes, the greater will be the total height of the tree. Then comparing diameter with height it is found that the straight line for diameter as plotted in the order of height has a positive slope of + .3660 or a percentage slope of 3.84%. This datum

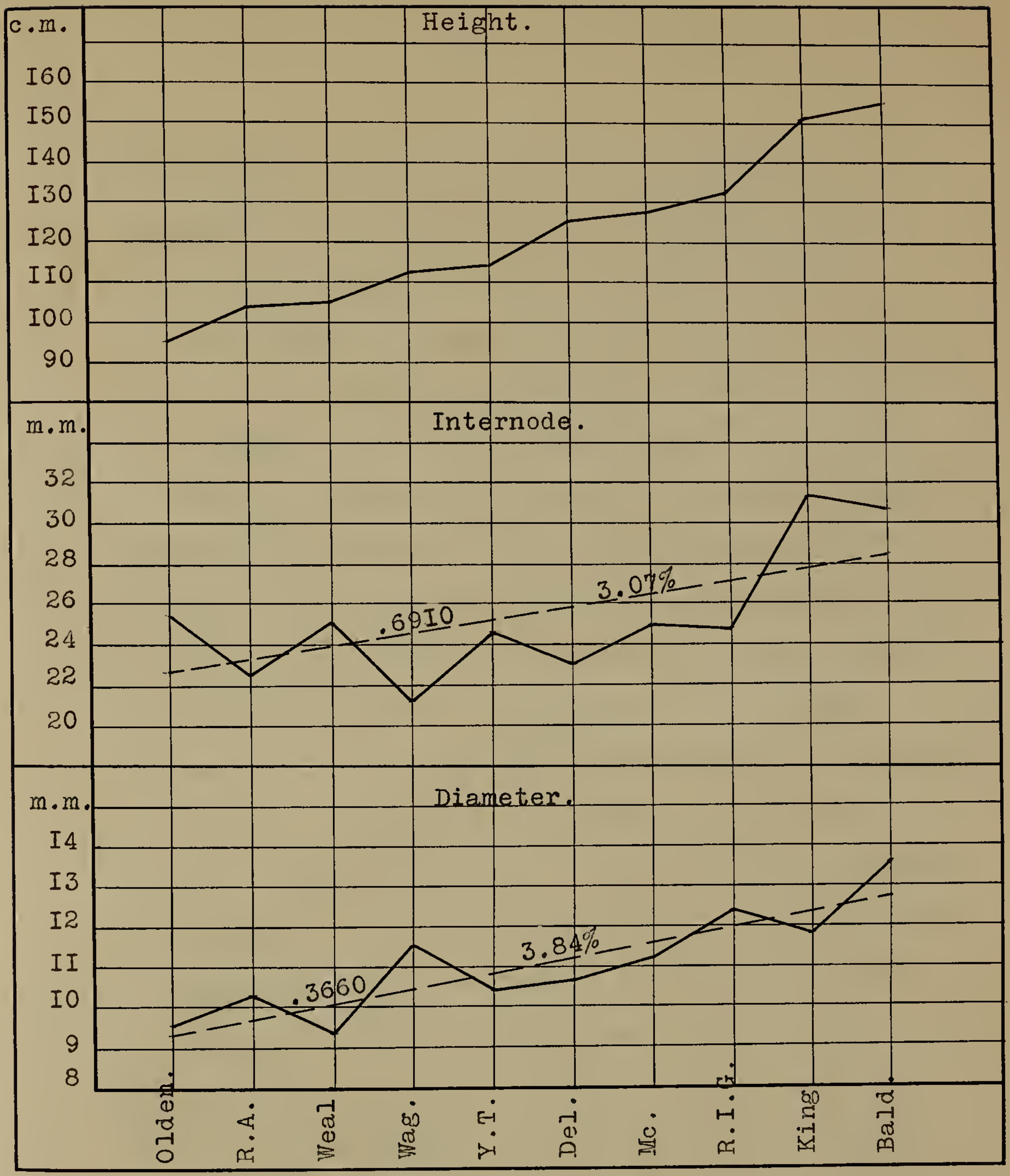

Figure 6. Comparison of Internode and Diameter with Height.

apparently shows that for the varieties in question, at least, there is a slightly closer relation between diameter and height than between length of internode and height.

The last line at the bottom of Table III represents the average percentage of variability of each of these three factors for the mean growth of 1921 and 1922, all varieties taken together. In this respect, the height shows the greatest percentage variability, it being 4.99 ± .96%; length of internode is next with 3.76 ± .54%; while diameter is the least variable of the three factors with 3.16 ± .52%. The indication here is that there is less difference between the 1921 and 1922 diameters than there is between the 1921 and 1922 internode lengths or heights. The same figures also show that the range of variability among the varieties is greatest in the case of height, as it has a percentage probable error of .96; while

internode and diameter show very similar figures with diameter having the smaller probable error of .52%. It appears from this datum that length of internode and diameter may be influenced less by fluctuations in environmental conditions than is height. It is possible that internode length is governed somewhat more by hereditary factors than are the other two, while diameter has a longer season in which to complete its growth than does height.

DISCUSSION OF PART I

A few points, in the foregoing data presented on the measurements of height, diameter, stockiness, and length of internode, are worthy of recapitulation and discussion.

First of all, there do exist differences in the size of nursery trees which are quite similar to the differences observed in mature trees of the same varieties. Probably in most cases, the

variety which produces large vigorous whips in the nursery row, is also the one which produces large growing mature trees. However, this may not always be the case, for Yellow Transparent, as seen in Table II, grows much larger in the nursery than does either Wealthy or Wagener. Yet, it is doubtful if the same relation holds between the mature trees of these varieties.

Apparently, in height at least, the varieties studied show variability from year to year in inverse order of their season of fruit maturity. The early maturing sorts such as Yellow Transparent, Red Astrachan, and Oldenburg are much more variable than McIntosh, Rhode Island Greening, and Baldwin which mature their fruit later in the season. It is known, in a general way at least, that most of the early maturing varieties stop their terminal growth earlier and shed their leaves somewhat sooner than do those varieties

which mature their fruit later. Thus, it may be possible that the varieties which stop growth early in the season are subjected to greater variations in environmental conditions from one year to another and hence show greater variation in their growth in height than do the varieties which grow through a longer period each season.

The varieties, Baldwin and Yellow Transparent, represent the extremes of consistancy and variability in height, diameter, and length of internode for the years studied. These two varieties also represent the extremes of seasons of growth and fruit maturity. The former is a very late variety, while the latter is one of the very earliest sorts to form terminal bud and mature its fruit. For this reason these two varieties were selected for further study as reported in Part II.

It is evident that the several factors respond differently to changes in environmental

conditions. Thus, it was noted above that increases in height and increases in diameter do not necessarily go hand in hand for any given variety. As terminal bud formation usually takes place two months or more before the cessation of increase in diameter, it is very possible that diameter shows a more uniform growth from year to year than does height, for the reason that diameter growth is influenced by a longer and hence less variable season from year to year than is height growth, which takes place in a much shorter time. In other words, it is very possible for the early part of one growing season to be quite materially different from the same portion of another growing season, yet for an entire season the amount of rainfall, sunshine, and the average temperatures are not radically different from those of another season. Thus, the entire season is more stable from year to year than is a part of the same.

TABLE IV. SUMMARY OF AVERAGE MONTHLY TEMPERATURE, PRECIPITATION, AND SUNSHINE. FOUR YEARS.

	Temperature Degree F.	Precipitation Inches	Sunshine Percentage
1. May, June, July	64.1 ± .81	5.17 ± .32	58 ±4.91
2. " " " and Aug. and Sept.	64.5 ± .59	4.39 ± .24	61 ±3.19

Table IV is summarized from Appendix Table G, and represents the average monthly temperature, precipitation, and sunshine for the four years as given by Ostrander (29). No. 1 gives the averages for May, June, and July as representative of the period of growth in height, while No. 2 represents the monthly averages for the entire growing season from May to September inclusive, as being the period of diameter growth. In all three factors it is apparent that the probable error, which represents variation from year to year, is less for

the entire season than for the first part of it. This fact helps to substantiate the view expressed above as to the reasons for the diameter being less variable than the height. It also helps to substantiate the belief that the varieties which grow for a short period of time each season are subjected to a greater variation in conditions from year to year and hence show greater ranges of variability than do those varieties which continue growth over a longer part of the growing season.

The averages of index of stockiness indicate that, although the tendency is for one season to be quite similar to another, the factors of environment vary sufficiently to cause differences in the growth of all varieties from one year to another. It seems as though weather conditions must play the major part in the differences of all varieties from year to year, as the trees were all

grown on the same kinds of stocks and on very uniform soil. Of course, some allowance must be made for inequalities in soil conditions and the amount of plant food available from one year to another. Yet, as the soil conditions from all external indications were the same from year to year, it is doubtful if these can account for all of the differences in growth noted above.

Table V shows the monthly averages of temperature, precipitation, and sunshine for the five months of each year. Of these three factors sunshine appears to be the most influential on stockiness, as this table shows that stockiness varies in direct proportion to the amount of sunshine. The years 1917 and 1922 had the same amounts of sunshine, but in 1922 the trees were more slender than in 1917. Perhaps this condition may be partly accounted for by the fact that there was a considerably greater amount of precipitation in 1922

than in 1917. In 1921 there was the greatest amount of sunshine and the least precipitation with the result of more stocky growth. Temperature appears to be the least important of the three factors here considered, but without question it has a positive affect upon the nature of the growth.

TABLE V. MONTHLY AVERAGES FOR THE ENTIRE GROWING SEASON. May - September inclusive.

Year	Temperature Degrees F.	Precipitation Inches	Sunshine %	Stockiness
1916	63.8	4.59	48	122.0
1917	62.8	4.05	64	109.2
1921	66.3	3.72	68	107.4
1922	65.1	5.19	64	112.2

From the work of Shaw (34), at this station, and others it is known that varieties differ in their growth on the same kind of stocks. However,

it is under this condition that mature trees of these varieties exhibit differences in size and vigor of growth. Hence, the factor of stock may be eliminated as being a constant.

Length of internode was found to show a small positive relation to height, but not as great as that of diameter to height. This relation may indicate that although height and internode length are similar in that they are indirectly a measure of the same total, yet perhaps internode length is governed more by hereditary factors and less by environment than is height. On the other hand, height and diameter are governed by the same environmental conditions, except that diameter is influenced by a longer period of the environment, Hence, diameter is more constant than height and thus shows greater relation to height than does internode length.

PART II. LEAF STUDIES AND THEIR RELATION TO CERTAIN WOOD CHARACTERS

The studies reported in this part of the investigation are for the summer of 1922 only. Several studies were undertaken, some of which gave encouraging results while others lead to no apparent conclusions.

LEAF AREA

That varieties differ in the normal size of leaf has been mentioned by several writers. Pickering (30) found that the size and weight of leaves were fairly accurate measures of the annual vigor of different apple varieties. Chandler (6) found in pruning experiments that total leaf area was in direct proportion to the total weight of the tree. Hedrick (18) says, "Size of leaf, if given in figures, is a most reliable determinant of varieties of all pome fruits." While Shaw (33) used leaf size as one of the characters in identify-

ing apple varieties by their leaves.

The average area of individual leaves was obtained by selecting one leaf from each of twenty-five individual trees of each variety. Care was taken to select leaves in the same relative positions, and of the same age and maturity. Only leaves which were normal in every respect were used. The area of these leaves was measured by means of a polar planimeter, and the average of the twenty-five taken as the individual leaf area for each variety.

The first column of Table VI gives the results obtained. There seem to be quite noticeable differences in the individual leaf areas of the varieties considered. Generally speaking, it looks as though size of leaf is somewhat related to size of tree and time of maturity of fruit. Delicious is the one variety which is an exception to this statement. These data also seem to

indicate that for the varieties in question, variability in size of leaf increases with the size. Thus, the small leafed varieties, as Wealthy with a mean of 41.35 ± .45 sq. c.m. and Delicious with 45.48 ± .58, have much smaller probable errors than do Rhode Island Greening with a mean of 72.24 ± 1.29 and Baldwin with a mean of 72.26 ± 1.16, which have large sized leaves.

TABLE VI. LEAF AREA

Variety	Individual area sq. c.m.	Av. number leaves	Total leaf area sq. c.m.
Wealthy	41.35 ± .45	39.9	1650.0
Delicious	45.48 ± .58	55.4	2520.0
R.Astrachan	49.03 ± .07	47.1	2309.0
Oldenburg	50.06 ± .77	36.7	1837.0
Y.Transprnt.	54.19 ± .71	48.1	2606.0
Wagener	59.09 ± .84	50.8	3002.0
McIntosh	63.09 ±1.16	52.2	3293.0
King	67.99 ±1.10	50.5	3433.0
R.I.Greening	72.24 ±1.29	49.9	3605.0
Baldwin	72.26 ±1.16	48.8	3526.0

The second column of Table VI represents the theoretical number of leaves on an average sized tree of any variety. The number was obtained by dividing the height of the variety by the length of internode. It is realized that this method does not give an accurate measure of the number of leaves, but as all varieties are under similar growing conditions it ought to give comparable results. It is of interest to note here that Wagener, one of the shortest varieties,has as many leaves as does King, which was the tallest growing sort for 1922. This fact, of course, is due to the difference in the length of internodes of the two varieties; Wagener having very short internodes, while King has long internodes.

The third column of Table VI gives the total leaf area of a model tree of each variety, as obtained by multiplying the individual leaf area by the theoretical number of leaves on the tree.

According to Pickering (30) the total leaf area should correspond closely to the size of the trees for the varieties considered. This fact is found to hold fairly well for the varieties given here.

VOLUME OF WOOD

A fair estimate of the volume of wood produced should be obtainable by multiplying the height of the tree by the area of the cross-section half way from the ground to the terminal bud. The data given in the first column of Table VII represent the volumes of the several varieties, calculated in this manner. Here again, the absolute accuracy of the method may be questioned somewhat, but as only comparative results are wanted, it was thought that the method used would serve the purpose.

The varieties, Oldenburg and Wealthy, are outstandingly small in volume, while Baldwin and King are distinct in the largeness of their volume.

TABLE VII. VOLUME, SPECIFIC GRAVITY, AND WEIGHT OF WOOD - 1922

Variety	Volume c.c.	Sp. Gr.	Weight of Wood Grams
Wealthy	16.718	.8066	13.4847
Delicious	31.403	.7563	23.7501
R.Astrachan	25.818	.8036	20.7473
Oldenburg	16.796	.8015	13.4620
Y.Transprnt.	33.476	.7925	26.5297
Wagener	32.413	.8085	26.2059
McIntosh	34.670	.8702	30.1698
King	56.328	.7554	42.5502
R.I.Greening	37.262	.7865	29.3066
Baldwin	52.156	.7334	38.2512

SPECIFIC GRAVITY DETERMINATIONS

Marked differences in hardness of wood of various varieties is well known to anyone experienced in pruning operations. Beach and Allen (3), in studying hardiness in the apple, found

that "specific gravity tests of dry wood, showing density, corresponded very closely with the mechanical tests, showing hardness, indicating that the two tests are fairly accurate means to the same end." This fact being true, a determination of specific gravity ought to be an indicator of the hardness of the wood and when compared with volume should give a fairly accurate measure of the total weight of wood produced.

The following method was used in the determinations of specific gravity. One twig of normal growth was collected from each of five individuals of each variety. The basal six inches of the new mature wood of each twig was selected for use. These lengths were then cut into two pieces, making two samples of five twigs each, for every variety. The samples were then dried for one week in an electric drying oven at 80°C. At the end of that time they were cooled in a desiccator and the dry weights taken. Then the weights in water were

secured by fastening the five twigs of one sample onto a Nichol's hydrometer with a rubber band. The same rubber band was used in every case so that its influence was constant. The additional weight required to sink the hydrometer to a certain mark was taken as the loss in weight due to the twigs, or the equivalent of the weight of an equal volume of water. From these figures it was possible to figure the specific gravity for each variety, as given in Table VIII.

It will be seen from this table that in every case Sample I shows greater specific gravity than does Sample II. Sample I is the basal three inches, while Sample II represents the three inches next to it. This relation agrees with the results of Beach and Allen (3), as they found the greatest specific gravity of the one year old wood to be at its base.

TABLE VIII. SPECIFIC GRAVITY DETERMINATIONS

Variety	Sample I			Sample II		
	Wt. in air (Grams)	Wt. in water (Grams)	Sp.Gr.	Wt. in air (Grams)	Wt. in water (Grams)	Sp.Gr.
Oldenburg	6.041	-1.37	.8152	4.607	-1.24	.7879
R.Astrachan	7.434	1.58	.8247	5.795	1.61	.7826
Wagener	8.246	1.66	.8324	6.515	1.79	.7845
Wealthy	6.866	1.46	.8246	5.895	1.58	.7886
Y.Transprnt.	6.140	1.42	.8122	4.895	1.44	.7727
McIntosh	9.067	1.08	.8935	7.023	1.27	.8468
Delicious	6.514	1.94	.7705	5.010	1.74	.7422
R.I.Green.	9.717	2.36	.8046	8.593	2.59	.7684
Baldwin	7.761	2.64	.7462	7.220	2.80	.7206
King	7.767	2.30	.7715	6.833	2.41	.7393

The average of these two samples was taken as the specific gravity for the variety. These averages are to be found in the second column of Table VII. It will be seen from these data that Baldwin, King, and Delicious are relatively light woods with specific

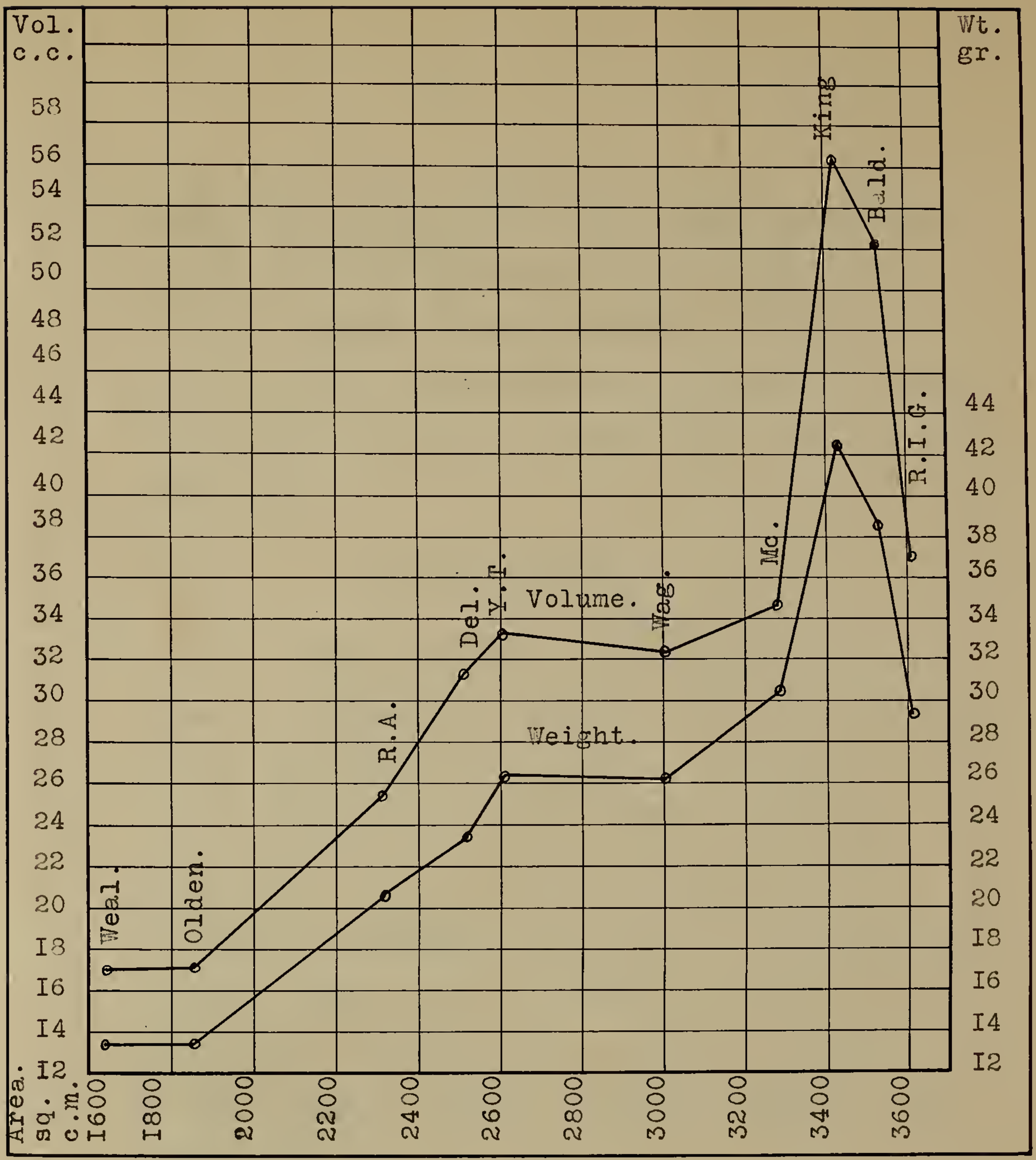

Figure 7. Leaf Area Compared with Volume and Weight of Wood.

gravities of .7334, .7554, and .7563 respectively. McIntosh, on the other hand, is unusually heavy, having a specific gravity of .8702. In the experience of the writer Baldwin and King have noticeably light, soft woods, while McIntosh wood is quite hard.

WEIGHT OF WOOD

To obtain the amount of dry matter produced in the form of wood, the volume is multiplied by the specific gravity, giving total weight of wood as found in the third column of Table VII. Here, as in volume, it will be noticed that the varieties, Oldenburg and Wealthy, are outstandingly of small weight, while Baldwin and King have much the greatest weights of any varieties. The two latter varieties will be further discussed in the next section.

RELATION BETWEEN LEAF AREA, VOLUME, AND WEIGHT OF WOOD

It was mentioned above, under leaf area, that Pickering (30) found a close relation between

the size of leaf and the vigor and size of the tree. If his finding be true some such relation should be found among the varieties here studied.

Figure 7 is plotted from the data of Table VII and presents graphically the comparisons between leaf area and volume of wood, and also between leaf area and total weight of the wood produced. The upper curve represents the volume in cubic centimeters, while the lower one gives the weight of wood in grams.

Examination of the upper curve shows that in general an increase in volume is accompanied by, or is the result of, an increase in leaf area. However, the varieties, Baldwin and King, have volumes much in excess of what their total leaf areas would seem to justify. As mentioned above, in pruning these two varieties are found to have rather light, soft woods. Perhaps it does not take as much plant food to form a unit volume of soft wood as it does

of hard wood, so this fact, in part, may account for the increased volumes of these two varieties.

However, when the specific gravitiy is determined and the total weight of wood compared with leaf area, as in the lower curve of this figure, it is found that Baldwin and King have produced a greater weight of wood for a unit of leaf area than have any of the other varieties. The weight of wood produced has made less prominent the irregularities which appear in the volume curve, but by no means has it eliminated them. The statement still holds that increased volume, and also increased weight of wood produced, are accompanied by, or probably the result of, increased leaf area; yet there seems to be an indication that there must be still other factors, such as differences in carbon assimilation, which influence amount of growth.

PHOTOSYNTHETIC ACTIVITY

The factors governing the photosynthetic activity of plants have been studied by many investigators, but there is a decided lack of harmony in the findings of their investigations. Blackman (4) gives the limiting factors in carbon assimilation as carbon dioxide supply; water supply; intensity, duration, and quality of light; quantity of chlorophyll; temperature; and amount of enzymes. It has also been thought by some others that there was a direct relation between the intensity of the chlorophyll color and the amount of carbon dioxide assimilated. However, Griffon (15) found in the case of peaches, plums, cannas, and chrysanthemums that the pale green leaves assimilated more actively than did the dark green leaves. With cereals, lettuce and begonias he found that those plants having deep green leaves possessed greater assimilative energy than did the light green ones.

Griffon (14) also believed that not only the nature of the chlorophyll, but also the thickness and structure of the mesophyll, the development of the palisade tissue, and the number and size of the chromoleucites in each cell seemed to be influencing factors in the variation of carbon assimilation. Kolkunov (22) in studying photosynthesis in grasses, came to the conclusion that assimilation in these plants varies in proportion to the size of the stomatic orifices. He also found that the assimilation of different species was differently affected by like intensities of light. Lubimenko (26) found in studying species tolerant and intolerant to shade, that the tolerant species began assimilation with much less light than did the intolerant ones, while with more intense light, assimilation of the tolerant species decreased while the intolerant were still increasing. Lubimenko (27) also found in other experiments

that in most cases the maximum dry weight was secured where light intensity was less than full summer sunlight. This finding agrees with Brown and Heise (5) who, after a review of literature, came to the conclusion that carbon dioxide assimilation is not necessarily in proportion to the light intensity but that there is really a progressively smaller augmentation in the rate of assimilation as intensity increases until the point is reached at which no measurable increase is produced by further increase in illumination. Thus, from the literature citied it may be concluded that photosynthetically plants do vary in their response to different influences. It remains to be seen if this condition holds true between varieties of the same species.

Of Blackman's six limiting factors of carbon dioxide assimilation, carbon dioxide supply may be eliminated from consideration as being fairly constant at all times under normal conditions.

Water supply was also fairly uniform as the varieties grew side by side. The quantity of chlorophyll, although found to be important by some investigators, is still of doubtful importance as often the lack of abundant chlorophyll is associated with increased activity of enzymes which frequently puts these two factors in the same class. Probably the most important factors for consideration here are temperature and the amount and duration of light. These last factors will be discussed later.

Methods

The methods of measuring photosynthetic activity are of two general types: (1) those which measure the amount of carbon dioxide taken into the leaf; and (2) those which measure the amount of carbohydrates formed by photosynthesis. Jorgensen and Stiles (20) in their review of the work

done on carbon assimilation, state that Sachs was the first man to identify starch as a product of assimilation, and that he concluded that starch is the first visible product of assimilation produced by the chloroplasts. They also say, "Brown and Morris concluded that cane sugar is the first sugar formed in the leaf and that this functions as a temporary reserve which accumulates during active assimilation. When the concentration of cane sugar reaches a certain amount, any excess of sucrose is converted into starch in the chloroplasts". Apparently this starch accumulates in the leaf throughout the period of activity and is translocated during the night, when no assimilation is taking place. Thus, a measure of the amount of starch temporarily stored in the leaf ought to give a fair estimation of the photosynthetic activity of the leaf.

As all methods are more or less question-

able, because none maintain absolutely normal conditions for growth, it was decided to use a method which would not require elaborate equipment but which would still give comparable results between two varieties at the same time. The method used was somewhat similar to that described by Ganong (13). Twenty-five leaves of each variety were covered with black paper envelopes at night; in the morning the envelopes were removed and four disks of soft parenchymal tissue, evenly distributed over the blade, were cut from each leaf, making up a sample of 100 disks of leaf tissue, 4418 square millimeters in area, from each variety. Two varieties were sampled at the same time for comparison. The hundred disk samples were put immediately into bottles containing 5 cc. of 95% alcohol, and these bottles in turn were put into an electric drying oven as soon as possible. Here they were dried to constant

weight, starting at 60° C and gradually increasing to 95° C. This process required about two days. At the end of four or eight hours similar samples were taken from the same sets of leaves and treated the same as the first samples. Thus, there were two sets of samples, The first was taken in the morning before any light had been admitted, and the second after the leaves had been exposed to the light for a certain period. The difference in dry weight of these two samples should give the amount of carbohydrates stored in the leaves during this period.

Tests of Method Used

In each test leaves of as nearly the same age, maturity, and relative exposure as possible were selected. Yet it was thought advisable to check the accuracy of the method itself. Table IX gives the results of the various ways in which the method was tested. Tests No. 1, 2, and 3 are

TABLE IX. TESTS OF METHOD

No.	Variety	Weight of Samples in grams A.	B.	Difference	Remarks
1.	Baldwin	.3936	.3917	.0019	A alcohol, B not in alcohol
2.	Baldwin	.4009	.3992	.0017	" "
3.	Y.Transp.	.3367	.3348	.0019	" "
4.	Y.Transp.	.3294	.3280	.0014	Both in alcohol
5.	Baldwin	.3943	.3891	.0052	" "
6.	Y.Transp.	.3467	.3461	.0006	" "
7.	King	.4161	.4000	.0161	Black paper all day
8.	Wealthy	.4964	.4805	.0159	" "

for samples taken at the same time but Sample A was killed in alcohol while Sample B was not killed before putting into the drying oven. Comparison of these three sets shows that in each case Sample B was lighter than Sample A by .0019, .0017, and .0019 grams respectively. From this comparison it seems fair to conclude, as had been thought at the

start, that the samples not killed in alcohol lost weight, probably due to respiration.

Tests No. 4, 5, and 6 are for samples taken at the same time, both of which were killed in alcohol. Some variation in the results is seen here. Tests No. 4 and 6 show results of .0014 and .0006 grams respectively, but Test No. 5 for some reason shows a marked difference of .0052 grams. Just why this difference should be cannot readily be explained, but as the other five tests, which compare samples taken at the same time, show fairly constant results, it is thought that some personal error was made in the collection of this sample. In spite of this variance the constancy of the other five tests is sufficient to conclude that the method is fairly accurate.

Still another test was thought advisable to see the effect of an exclusion of light during the day. For this test samples were taken

in the morning as before, but after these were taken the black paper envelopes were replaced on the leaves so that no light would be admitted. At the end of eight hours the envelopes were removed and the samples taken as usual. Consulting Tests No. 7 and 8, it will be seen that, not only was there no increase in weight in the absence of light, but that there was an actual loss in weight of .0161 grams in the case of King and .0159 grams for the Wealthy samples.

Thus, it would seem from the above several tests that the method here employed ought to give comparable results when different varieties are considered at the same time.

Presentation of Data

Because of the element of time, it was found impossible to compare more than two varieties at once. For this reason most of the work was

done with the varieties, Baldwin and Yellow Transparent. These two varieties were selected as probably being representative of two different types; Baldwin being a large vigorous grower and Yellow Transparent a rather weak grower maturing its fruit early. It will also be recalled that these two varieties represent the extremes of consistency and variability in wood characters from year to year. Some work was also done on King and Wealthy, but not enough to make their results of much value.

Table X presents the data secured from tests made at various times and under different conditions of light and temperature during the summer of 1922. It will be noticed that the first four tests were only for four hours duration. It was later thought that an eight hour period, from 8 A.M. to 4 P.M. would be more representative of what actually took place during the entire day.

The temperature figures in the table represent the mean temperatures for the particular days in question; while the light conditions recorded are for the duration of the test only.

Comparing first Tests No. 1, 2, 11, and 12, it will be seen that under exactly the same conditions of temperature and light Baldwin, in both cases, increased in weight more than did Yellow Transparent. It would almost look as though Baldwin made most of its increase in the early part of the day. However, no importance can be placed on this indication. Tests No. 3, 4, 15, and 16 were made under identical light conditions but the first two show a temperature of two degrees higher than the latter two. In this case it appears that under similar light conditions, Yellow Transparent may accumulate more at a high temperature than at a low one; while Baldwin shows the converse to be the indication. Tests No. 5, 6, 7, and 8 show the

TABLE X. INCREASE IN DRY WEIGHT

Date	No.	Time hrs.	Variety	Weights of Samples in grams A.	B.	B-A	Temp. F.	Light
7/11	1.	4	Bald.	.3659	.3960	.0301	71.0°	No sunshine
"	2.	4	Y. T.	.3543	.3661	.0118	"	" "
7/15	3.	4	Bald.	.3914	.4142	.0228	68.7	Bright sun
"	4.	4	Y. T.	.3278	.3563	.0285	"	" "
8/18	5.	8	Bald.	.4440	.4676	.0236	76.7	Half sun
"	6.	8	Y. T.	.3630	.3884	.0254	"	" "
8/22	7.	8	Bald.	.4594	.4836	.0242	62.7	" "
"	8.	8	Y. T.	.3767	.3936	.0169	"	" "
"	9.	8	King	.4302	.4467	.0165	"	" "
"	10.	8	Weal.	.4652	.4873	.0221	"	" "
8/25	11.	8	Bald.	.4193	.4405	.0212	71.0	No sunshine
"	12.	8	Y. T.	.3304	.3494	.0190	"	" "
"	13.	8	King	.3802	.4217	.0415	"	" "
"	14.	8	Weal.	.4334	.4558	.0224	"	" "
8/29	15.	8	Bald.	.4326	.4698	.0372	66.7	Bright sun
"	16.	8	Y. T.	.3666	.3940	.0274	"	" "
"	17.	8	King	.3786	.4052	.0266	"	" "
"	18.	8	Weal.	.4870	.5050	.0180	"	" "

same indication but under more pronounced temperature differences and a different light condition.

TABLE XI. TOTAL INCREASE IN DRY WEIGHT

Date	Baldwin	Y. Transp. Grams	King	Wealthy
July 11	.0301	.0118		
" 15	.0228	.0285		
Aug. 18	.0236	.0254		
" 22	.0242	.0169	.0165	.0221
" 25	.0212	.0190	.0415	.0224
" 29	.0372	.0274	.0266	.0180
Total	.1591	.1290	.0846	.0625

Table XI represents the summary of the increases in dry weight as given in Table X. This table gives the total increase in dry weight for each variety regardless of light and temperature conditions. It appears that Baldwin in a total

of forty hours increased .1591 grams while Yellow Transparent increased only .1290 grams, showing a gain of .0301 grams for the Baldwin samples. Taking the total leaf areas of the two varieties for comparison, as given in Table VI it will be found that, on the basis of the total increase in forty hours, Baldwin trees would accumulate 126.92 grams of carbohydrates while Yellow Transparent trees would accumulate 76.03 grams. Yellow Transparent with its smaller and less efficient leaf area would accumulate only about three-fifths as much in the same length of time as would Baldwin. This fact seems to indicate the possibility that Baldwin may manufacture and accumulate a greater amount of carbohydrate material throughout the entire season of growth than does Yellow Transparent. Figuring the significance of the differences of increase in dry weight between Baldwin and Yellow Transparent in Table XI it is found by Student's method that the

odds are only 14:1, which odds are too small for definite significance. Still, the indication is that with a larger number of tests these differences would be found to be important. Comparing the other two varieties, it will be seen that King increased .0846 grams in twenty-four hours, while Wealthy only increased .0625 grams, showing a difference of .0221 grams in favor of King. The data for these two varieties, although they show the same tendencies as the others, cannot be given much of any emphasis, as the odds are only about 5:1 that the differences are significant. It would require many more tests to prove any real difference in this case.

The question may be raised whether Baldwin may not translocate the photosynthetic products as rapidly as does Yellow Transparent and hence there is a storage of a greater quantity in the leaf during the period of active photosynthesis. Of course, this fact is possible and it is not known but that

it may be so, but inasmuch as the Baldwin produces the larger trees of the two varieties it seems reasonable to assume that its power of translocation is at least as great, if not greater, than that of Yellow Transparent.

TABLE XII. INCREASE IN DRY WEIGHT UNDER DIFFERENT CONDITIONS OF LIGHT

	Baldwin		Yellow Transparent	
	Sunshine	Cloud	Sunshine	Cloud
	.0228	.0301	.0285	.0118
	.0372	.0212	.0274	.0190
Total	.0600	.0513	.0559	.0308

Next, comparing Baldwin and Yellow Transparent under different light conditions, it will be seen from Table XII that in twelve hours of sunshine Baldwin samples increased .0600 grams while those of Yellow Transparent increased .0559, or a

gain of .0041 for Baldwin samples in the twelve hours. On the other hand, during very dull light Baldwin gained.0513 grams as compared with .0308 grams for Yellow Transparent, a gain of .0205 grams in favor of the Baldwin in cloudy weather. The differences between these two varieties in sunshine are negligible as it will be noticed that in the first set Yellow Transparent showed the greater increase, while only in the second case did Baldwin show an increase greater than that of the Yellow Transparent samples. However in clouds it would appear that the differences were real as Baldwin shows the greater increase in both cases. It is not possible to figure the probable error on so few tests, but the indication seems to be that the two varieties respond about alike in sunshine, while in cloudy weather Baldwin is somewhat more active than is Yellow Transparent. This point in itself may be a big factor in the relative season's

growth of the two varieties in question, as it will be recalled from Table V that from 30 to 50% of the season is usually cloudy weather.

It would be unsafe to attempt to draw any definite and positive conclusions from so few tests. Still, the results may be said to be indicative of the fact that differences do exist in the photosynthetic activity between varieties which differences may be partly responsible for variations in size and vigor of growth in apple trees.

LEAF WEIGHT

According to Pickering (30) leaf weight should compare favorably with size of the tree. The morning samples of the starch tests, as given in Table X, should be comparable. These data are summarized in Table XIII and represent the comparative weights of samples of 100 disks each, having

an area of 4418 square millimeters. These weights compare quite well with observations, Wealthy being the heaviest with a weight of .4619 grams, then Baldwin .4188 grams, King .3963 grams, and Yellow Transparent the lightest with a weight of .3531 grams.

TABLE XIII. LEAF WEIGHTS

Date	Baldwin	Y. Transparent Grams	King	Wealthy
July 11	.3659	.3543		
" 15	.3914	.3278		
Aug. 18	.4440	.3630		
" 22	.4594	.3767	.4302	.4652
" 25	.4193	.3304	.3802	.4334
" 29	.4326	.3666	.3786	.4870
Average	.4188	.3531	.3963	.4619

These weights do not agree exactly with the finding of Pickering as previously stated, but he drew his conclusions from trees of the same variety under

different conditions of vigor which need not necessarily apply between varieties. However his findings might well apply to the varieties here cited, except in the case of Wealthy which is recognized as a thick leafed kind.

Applying Student's method to the samples of Baldwin and Yellow Transparent leaves gives odds of 768:1 that the difference in weight is insignificant. In every case the Baldwin leaves were heavier than were the Yellow Transparent. Between the leaves of King and Wealthy the odds are only about 8:1 which is too small for importance. However, in this case again, King leaves are lighter in every set than are the leaves of Wealthy so that the smallness of the odds must be due to too few samples weighed.

Increased leaf weight is usually associated with increased thickness of the leaf and increased number of layers of palisade cells. A

few observations, which were made on leaves of Baldwin and Yellow Transparent, showed in every case that Baldwin had the greater thickness of palisade layer, frequently having three layers of cells while leaves of Yellow Transparent had only two layers. This condition correlates with the greater photosynthetic activity of the Baldwin leaves.

TRANSPIRATIONAL STUDIES

Whether or not transpiration is one of the factors that can be used as a measure of growth is uncertain. Kiesselbach (21), in studying transpiration as a factor in crop production of corn, found no consistant correlation between leaf thickness, epidermis thickness, and number of stomata, and the transpiration rate per unit of dry matter or per unit of leaf area of the different varieties. Neither did he find any "absolute correlation between percentage of ash,

quantity of water transpired per gram of ash content, or the transpiration per gram of dry matter." Hasselbring (16), in experiments with tobacco, came to the conclusion that absorption of salts by the roots is independent of the absorption of water and that the transpiration stream does not exert an accelerating effect on the entrance of salts. Du Sablon (11) states that transpiration is not necessary for the transportation of salts from the roots to the leaves, nor is there any relation between the transpiration and the formation of dry matter in the plants. Cullinan (7), after studying apple trees and pepper plants, decided that the mere passage of water through the plant has no influence on the assimilative activity. On the other hand, Livingston (23), in working with wheat, found that transpiration varied quite uniformly with the leaf weight, which in turn varied with the weight of the entire tops.

Sampson and Allen (31) also found a correlation existing between transpiration and the green weight of the tops of plants of the same and different species under different conditions.

A review of such contradictory literature must lead to the conclusion that either different methods give different results or that plants vary in their relation between growth and transpiration.

The question of the method to be used in studying transpiration, as in studies of photosynthesis, is an important one, as it is difficult to study transpiration without placing the plant under some condition abnormal to growth. The method employed in this study was patterned after that described by Livingston (24) and (25), which is known as the Cobalt Chloride or Hygrometric paper method.

Table XIV gives the data taken on transpiration during the summer of 1922. The figures

in this table represent the time in seconds required for the cobalt chloride paper to change from blue

TABLE XIV. TRANSPIRATION STUDIES

Date	Variety	Tree 1	Tree 2	Average
7/12	Baldwin	32.2 ± .64	31.2 ± .45	31.7 ± .39
"	Y.Transp.	28.1 ± .82	30.9 ± .59	29.5 ± .48
"	Oldenburg	37.6 ± .90	38.3 ± .82	37.95± .59
"	Fall Pipp.	33.8 ±1.12	41.4 ±1.23	37.6 ±1.03
7/19	Baldwin	48.0 ± .88	48.3 ±1.00	48.15± .64
"	Y.Transp.	48.5 ± .64	47.6 ±1.37	48.05 ±.69
7/21	Oldenburg	54.7 ±1.49	44.7 ± .93	49.7 ± .83
"	Fall Pipp.	47.5 ±1.60	46.8 ±2.13	47.15±1.29

to pale pink in color. Thus, the greater the time required for the change to take place, the less will be the rate of transpiration. It will be noticed that under these conditions the averages for Yellow Transparent are slightly less than those for Baldwin,

while Fall Pippin responded more quickly than Oldenburg under similar conditions. Inspecting the means for Tree 1 and Tree 2, it will be seen that within the same variety, two trees of similar size and growth, standing side by side and from all external appearances practically alike, vary considerably in their response to the method used. Baldwin and Yellow Transparent trees show less variations between the two individuals than do trees of Oldenburg and Fall Pippin.

Again examining the means for the individual trees, it will be noticed in many cases, in spite of the fact that each mean represents the average of twenty-five tests made, that the probable errors of the means are nearly as great as, or greater than, the differences between the means themselves. This fact probably signifies that the variations between individuals are in some cases greater than the differences between the varieties.

The tests reported were not very extensive. However the tests made seem to indicate that differences in transpiration of apple trees are not measurable by the method used.

DISCUSSION OF PART II

It was pointed out in the study of leaf area, that in a general way size of leaf is related quite closely to size of tree and also to the season of fruit maturity for the variety. The small leafed varieties here considered, as a group, are much smaller in tree and show earlier maturity of fruit than the larger leafed sorts. From this fact it seems possible that the longer season of growth and especially the larger leaf area of such varieties as Baldwin and Rhode Island Greening have a marked influence upon their producing larger trees than do Wealthy and Oldenburg.

Another point of interest is that of the region of growth of certain varieties. Shaw (32) defines the apple belts of eastern North America and says "The great climatic factor which limits the distribution of apples in general, and of different varieties in particular, is temperature." It is well known that Baldwin and Rhode Island Greening, which are typically large leafed varieties, do not grow well in the south central or Ben Davis apple belt. In that belt these two varieties mature their fruit as fall apples which are large, rather poorly colored, and very poor in keeping quality. On the other hand, such varieties as Jonathan, Stayman, Winesap, and Grimes, which are typical commercial varieties of the Ben Davis belt, have rather small leaves and when brought into the north central or Baldwin belt of New England frequently do not properly mature their crop in

the short season. A general survey of the standard commercial varieties of the two belts tends to indicate that southern varieties have small folded leaves while the northern varieties have large flat leaves. Therefore, it might be said that the southern varieties when brought to this section do not have enough leaf area exposed to the direct light to furnish sufficient plant food for the proper maturing of their crop in so short a season. On the other hand, the northern varieties mentioned above have larger leaf areas than are needed for the southern long growing season, and hence mature their fruit comparatively early, when grown under such conditions. This condition would apply only to the late maturing sorts, as the early varieties such as Oldenburg and Yellow Transparent mature their crop much earlier under the southern conditions.

It is also very probable that temperature plays a big part in this question. Shaw (32) also

classifies varieties as to the optimum summer temperatures at which they grow the best. He says, "The earlier the variety the greater may be its range of temperature without marked deterioration of the fruit." The early varieties are able to mature their crop before the extreme temperatures of the southern summer, while the slower maturing sorts have to grow through the entire season with the result that the fruit is large and very poor in quality.

Another possibility is that the northern varieties with their large leaf areas do not require as great an intensity of light for maximum photosynthetic activity as do the southern kinds. So, when southern varieties are grown in the north they are not only lacking in sufficient leaf area but what leaves they do have are not working at maximum capacity because of lower temperature and light intensity.

In the presentation of the data on the volume and weight of wood, and their relation to leaf area, it was found that leaf area alone is not sufficient to account for the large size of trees of Baldwin and King, nor was leaf area alone capable of accounting for the total weight of wood produced by these two varieties. Thus, it would appear that some differences must be present in the capacities of the leaves of different varieties to manufacture carbohydrates. This indication was found in the few suggestive samples taken for the varieties Baldwin and Yellow Transparent, which seem to suggest that under the conditions studied, Baldwin is capable of assimilating more per unit of leaf area than is Yellow Transparent, and in so doing it is capable of producing a larger and more vigorous tree than is the latter. In other words, in an entire growing season of varied weather conditions Baldwin leaves may be active more of

the time than are those of Yellow Transparent.

SUMMARY

From the studies here reported on the nature and cause of differences of varietal vigor and growth in apple trees, the following conclusions are drawn:

1. Differences have been found in the size of one year old nursery trees, which correspond quite closely to differences in size observed in mature trees of the same varieties.

2. In height the varieties show variability from year to year in inverse order of their season of growth and maturity of fruit.

3. Height has been found to be a more variable character from year to year for all varieties than is diameter.

4. It is thought that increased variability of the early maturing varieties is due

partly to the fact that they grow for a shorter and hence more variable season from year to year than do the later maturing sorts. The same condition may hold true between height and diameter, as height growth takes place in the early part of the season, while diameter growth continues until near the end of the growing season.

5. Considerable variation exists in the stockiness of the growth of the several varieties considered.

6. An increase in height for any certain variety does not necessarily mean a corresponding increase in diameter. Perhaps the two factors respond somewhat differently to similar environmental conditions.

7. All varieties show variation in average stockiness from one year to another; probably due partly to changes in weather conditions. Of the weather factors, sunshine, precipitation,

and temperature are thought to be the most important, and in the above order.

8. The varieties, Baldwin and Yellow Transparent were found to be the least and most variable, respectively, from year to year, of the varieties studied in the factors of height, diameter, and length of internode.

9. Diameter and length of internode are correlated somewhat with height; diameter showing slightly the closer relation. Practically no relation exists between diameter and length of internode.

10. Size of leaf is related quite closely to the size of tree and season of fruit maturity in the varieties reported.

11. Total leaf area corresponds fairly well with the volume and weight of wood produced, except in the varieties Baldwin and King, which have much greater volumes and weights of wood than

their leaf areas would seem to justify.

12. Varieties differ considerably in the specific gravity and hardness of their wood. King and Baldwin woods are quite light and soft, while McIntosh is heavier than most varieties.

13. Tests of increase in dry weight of the leaves of Baldwin and Yellow Transparent indicate that differences in photosynthetic activity may exist between these varieties. It is thought that similar differences may be partly responsible for the differences in size and vigor of growth exhibited among the varieties studied.

14. The apparent failure of southern varieties, when grown in the north, is thought to be due to small leaf area, folded leaves, less intense light, and lower average summer temperatures, all operating in a shorter growing season. The converse is thought to hold true when northern varieties, which have larger leaf area and flat

leaves are grown under southern conditions.

15. An attempt was made to study differences in transpiration between the varieties Baldwin and Yellow Transparent by the Cobalt Chloride paper method. This method was not found sufficiently accurate to measure differences in transpiration, if such do exist between the varieties.

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APPENDIX

TABLE A. HEIGHT OF ONE YEAR OLD TREES

Variety	N.	Mean	S. D.	C. V.
1916				
Oldenburg	51	126.85 ± 1.75	18.69 ± 1.24	14.74 ± 1.00
Wagener	102	123.72 ± 1.52	22.76 ± 1.07	18.39 ± .90
Wealthy	96	136.45 ± 1.17	16.92 ± .81	12.39 ± .61
N. Spy	96	125.58 ± 1.12	16.10 ± .79	12.82 ± .63
McIntosh	102	143.13 ± .96	14.68 ± .68	10.25 ± .48
Delicious	25	150.47 ± 3.66	27.15 ± 2.59	18.06 ± 1.78
R.I.Greening	96	140.03 ± .96	14.07 ± .68	10.05 ± .49
Baldwin	101	155.29 ± .96	14.27 ± .66	9.19 ± .43
King	66	179.65 ± 1.95	23.67 ± 1.39	13.17 ± .79
1917				
Oldenburg	78	137.16 ± .66	8.86 ± .48	6.47 ± .35
R.Astrachan	87	137.49 ± .94	13.05 ± .66	9.50 ± .48
Wagener	152	124.48 ± .71	13.36 ± .51	10.75 ± .62
Wealthy	170	131.29 ± .91	17.58 ± .63	13.38 ± .49
Y.Transprnt.	18	148.87 ± 1.42	8.99 ± 1.02	6.06 ± .68
N. Spy	170	138.63 ± .53	10.29 ± .38	7.43 ± .27
McIntosh	133	133.15 ± .76	13.13 ± .53	9.86 ± .41
Delicious	33	137.39 ± 1.27	10.85 ± .89	7.89 ± .66
Baldwin	180	157.15 ± .69	13.59 ± .48	8.65 ± .31
R.I.Green.	129	142.67 ± .63	10.54 ± .43	7.39 ± .31
King	40	175.64 ± .91	8.51 ± .63	4.84 ± .37

Unit of height measure - centimeters
Unit of diameter measure - millimeters
Unit of internode measure - millimeters

TABLE A. Concluded

1921

Oldenburg	224	93.88	±	.99	22.17	±	.71	23.63	±	.79
Red Astrachan	211	93.80	±	.86	18.49	±	.61	19.81	±	.67
Wagener	74	111.35	±	2.06	26.29	±	1.45	23.62	±	1.38
Wealthy	241	105.10	±	1.07	24.66	±	.71	23.48	±	.71
Y.Transprnt.	92	97.76	±	1.53	21.87	±	1.09	22.38	±	1.16
N. Spy	227	135.56	±	1.14	25.55	±	.81	18.85	±	.62
McIntosh	212	119.66	±	1.32	28.65	±	.94	23.96	±	.83
Delicious	240	124.03	±	1.06	24.56	±	.75	19.81	±	.63
R.I.Greening	221	137.34	±	.96	21.39	±	.68	15.56	±	.51
Baldwin	319	160.88	±	1.01	27.10	±	.71	16.84	±	.46
King	179	132.46	±	1.42	28.24	±	.99	21.32	±	.79

1922

Oldenburg	73	99.34	±	1.47	18.82	±	1.04	18.94	±	1.09
R.Astrachan	158	114.43	±	.96	18.06	±	.68	15.78	±	.61
Wagener	35	113.89	±	1.70	15.01	±	1.22	13.18	±	1.08
Wealthy	166	104.19	±	.73	14.43	±	.53	13.84	±	.52
Y.Transprnt.	56	131.19	±	1.55	17.22	±	1.09	13.12	±	.85
McIntosh	214	138.35	±	.66	14.20	±	.46	10.26	±	.33
Delicious	139	132.18	±	1.07	18.87	±	.76	14.28	±	.59
R.I.Greening	115	125.93	±	1.19	18.92	±	.84	15.03	±	.68
Baldwin	211	150.62	±	.68	14.81	±	.48	9.82	±	.32
King	72	168.75	±	.91	11.38	±	.63	6.74	±	.38

TABLE B. HEIGHT OF ONE YEAR TREES.
Barnes Brothers

Variety	N.	1916 Mean	S. D.	C. V.
Oldenburg	102	65.66 ± 1.04	15.54 ± .74	23.67 ± 1.22
R.Astrachan	161	89.84 ± 1.02	19.20 ± .71	21.38 ± .83
Wagener	149	73.61 ± 1.17	21.49 ± .84	29.19 ± 1.23
Wealthy	170	74.85 ± .96	18.87 ± .69	25.21 ± .98
Y.Transprnt.	164	71.91 ± .94	17.93 ± .66	24.95 ± .98
N. Spy	102	93.17 ± 1.37	20.70 ± .96	22.22 ± 1.10
McIntosh	102	102.87 ± 1.65	24.66 ±1.17	23.97 ± 1.19
Delicious	115	88.57 ± 1.29	20.52 ± .91	23.17 ± 1.08
R.I.Greening	150	90.68 ± 1.14	20.62 ± .81	22.74 ± .92
Baldwin	102	112.29 ± 1.52	22.94 ±1.09	20.42 ± 1.00
King	102	106.09 ± 1.83	27.61 ±1.29	26.02 ± 1.31

TABLE C. DIAMETER OF ONE YEAR OLD TREES

Variety	N.	Mean 1916	S. D.	C. V.
Oldenburg	51	10.00 ± .15	1.56 ± .10	15.60 ± 1.07
Wagener	102	11.63 ± .12	1.77 ± .08	15.22 ± .73
Wealthy	96	9.92 ± .09	1.36 ± .06	13.71 ± .68
N. Spy	96	11.22 ± .14	2.05 ± .10	18.29 ± .92
McIntosh	102	10.70 ± .09	1.45 ± .07	13.55 ± .65
Delicious	25	11.84 ± .32	2.41 ± .23	20.35 ± 2.02
R.I.Greening	96	12.58 ± .11	1.65 ± .08	13.12 ± .65
Baldwin	101	13.70 ± .10	1.53 ± .07	11.18 ± .54
King	66	13.77 ± .19	2.30 ± .13	16.46 ± .99

TABLE C. Continued

1917

Oldenburg	78	12.38 ± .08	1.03 ± .06	8.32 ± .45
R.Astrachan	87	12.99 ± .08	1.21 ± .06	9.30 ± .47
Wagener	152	13.26 ± .06	1.18 ± .05	8.92 ± .35
Wealthy	170	10.61 ± .06	1.22 ± .04	11.55 ± .42
Y.Transprnt.	18	13.72 ± .16	.98 ± .11	7.20 ± .81
N. Spy	170	13.69 ± .07	1.35 ± .05	9.90 ± .36
McIntosh	133	11.54 ± .07	1.25 ± .05	10.82 ± .45
Delicious	33	12.27 ± .12	1.05 ± .09	8.58 ± .71
R.I.Greening	129	13.52 ± .05	1.19 ± .04	9.27 ± .39
Baldwin	180	14.38 ± .06	1.18 ± .04	8.22 ± .30
King	40	15.20 ± .08	.78 ± .06	5.14 ± .39

1921

Oldenburg	217	9.84 ± .07	1.61 ± .05	16.33 ± .54
R.Astrachan	216	10.05 ± .07	1.57 ± .05	15.63 ± .52
Wagener	71	11.51 ± .16	2.02 ± .11	17.55 ±1.02
Wealthy	196	9.72 ± .07	1.52 ± .05	15.61 ± .54
Y.Transprnt.	90	9.41 ± .12	1.65 ± .08	17.49 ± .91
N. Spy	220	11.82 ± .08	1.69 ± .05	14.29 ± .47
McIntosh	215	10.94 ± .08	1.76 ± .06	16.06 ± .53
Delicious	229	10.76 ± .08	1.85 ± .06	17.27 ± .56
R.I.Greening	230	12.67 ± .07	1.62 ± .05	12.78 ± .41
Baldwin	232	13.93 ± .09	2.15 ± .07	15.43 ± .49
King	173	10.91 ± .09	1.81 ± .06	16.61 ± .62

TABLE C. Concluded

1922

Oldenburg	73	9.40 ± .11	1.39 ± .08	14.82 ± .84
R.Astrachan	158	10.72 ± .08	1.45 ± .05	13.52 ± .52
Wagener	35	12.06 ± .15	1.35 ± .11	11.19 ± .91
Wealthy	166	9.05 ± .07	1.32 ± .05	14.64 ± .55
Y.Transprnt.	56	11.41 ± .13	1.41 ± .09	12.37 ± .80
McIntosh	214	11.51 ± .06	1.38 ± .04	12.01 ± .40
Delicious	139	11.02 ± .10	1.71 ± .07	15.52 ± .64
R.I.Greening	115	12.28 ± .11	1.76 ± .08	14.34 ± .65
Baldwin	211	13.27 ± .07	1.43 ± .05	10.77 ± .35
King	72	13.05 ± .10	1.22 ± .07	9.37 ± .53

TABLE D. DIAMETER OF TWO YEAR OLD TREES
1921

Variety	N.	Mean	S. D.	C. V.
Oldenburg	75	18.69 ± .19	2.46 ± .13	13.18 ± .74
Wagenor	100	22.74 ± .24	3.56 ± .17	15.65 ± .76
Wealthy	176	17.04 ± .15	3.01 ± .11	17.70 ± .65
McIntosh	172	20.02 ± .14	2.79 ± .10	13.94 ± .52
Delicious	182	19.92 ± .14	2.73 ± .09	13.72 ± .49
R.I.Greening	178	22.81 ± .17	3.29 ± .12	14.42 ± .52
Baldwin	188	22.39 ± .18	3.62 ± .12	16.17 ± .58

TABLE E. INTERNODE LENGTH OF ONE YEAR OLD TREES

Variety	N.	Mean	S. D.	C. V.
		1921		
Oldenburg	197	24.61 ± .10	2.18 ± .07	11.06 ± .38
R.Astrachan	167	21.08 ± .11	2.08 ± .08	9.88 ± .36
Wagener	71	20.25 ± .16	2.07 ± .12	10.21 ± .59
Wealthy	170	25.01 ± .13	2.52 ± .09	10.08 ± .37
Y.Transprnt.	73	21.85 ± .26	3.28 ± .18	15.01 ± .86
N. Spy	270	27.29 ± .08	1.96 ± .05	7.18 ± .20
McIntosh	177	23.68 ± .11	2.11 ± .07	8.91 ± .32
Delicious	204	22.44 ± .10	2.23 ± .07	9.94 ± .33
R.I.Greening	253	24.65 ± .10	2.50 ± .07	10.15 ± .30
Baldwin	205	30.97 ± .10	2.07 ± .07	6.68 ± .22
King	142	30.31 ± .15	2.69 ± .11	8.87 ± .35
		1922		
Oldenburg	67	27.03 ± .23	2.87 ± .17	10.61 ± .62
R.Astrachan	126	24.26 ± .10	1.72 ± .07	7.09 ± .30
Wagener	35	22.40 ± .15	1.35 ± .11	6.05 ± .49
Wealthy	116	26.11 ± .09	1.45 ± .06	5.56 ± .24
Y.Transprnt.	58	27.25 ± .16	1.86 ± .12	6.82 ± .43
McIntosh	204	26.43 ± .07	1.57 ± .05	5.93 ± .20
Delicious	125	23.84 ± .09	1.48 ± .06	6.19 ± .26
R.I.Greening	103	25.22 ± .11	1.72 ± .08	6.83 ± .32
Baldwin	208	30.88 ± .07	1.49 ± .05	4.83 ± .16
King	73	33.39 ± .14	1.84 ± .10	5.50 ± .31

TABLE F. INDEX OF STOCKINESS

Variety	1916	1917	1921	1922
Oldenburg	126.8	110.8	95.4	105.6
Red Astrachan		105.8	93.3	106.7
Wagener	106.4	93.8	96.7	94.4
Wealthy	137.5	123.7	108.1	115.1
Y. Transprnt.		108.5	103.9	114.9
N. Spy	111.9	101.3	114.6	
McIntosh	133.7	115.4	109.3	120.2
Delicious	127.1	111.9	115.2	119.9
R.I.Greening	111.3	105.5	108.4	102.5
Baldwin	113.3	109.3	115.5	113.5
King	130.5	115.5	121.4	129.3
Average	122.0	109.2	107.4	112.2

TABLE G. MONTHLY TEMPERATURE, PRECIPITATION AND SUNSHINE AVERAGE

Month	Year	Temperature Mean hourly °F	Precipitation Total inches	Sunshine %
May	1916	55.9°	3.21	40%
June		61.1	5.34	34
July		71.6	6.85	40
August		69.5	2.49	60
Sept.		60.8	5.08	68
May	1917	49.3	4.13	70
June		65.3	5.27	55
July		71.7	3.36	62
August		70.9	7.06	67
Sept.		57.0	2.42	64
May	1921	58.9	4.56	67
June		66.9	3.87	69
July		73.4	6.00	62
August		66.9	2.35	74
Sept.		65.6	1.84	67
May	1922	59.8	5.47	74
June		66.5	9.68	58
July		69.4	4.28	67
August		67.3	4.25	60
Sept.		62.8	2.27	62

TABLE H. STRAIGHT LINE PROBLEM SHOWING RELATION BETWEEN DIAMETER & INTERNODE,

Formulae

I $\Sigma n + \Sigma x(m) = \Sigma y$

II $\Sigma x(n) + \Sigma x^2(m) = \Sigma xy$

n = origin m = slope y = observations.

Data

y =	n + (x)m	x^2	xy
II.78	0	0	0
I0.39	I	I	I0.39
I0.89	2	4	2I.78
I0.4I	3	9	3I.23
I2.48	4	I6	49.92
II.48	5	25	56.I5
9.39	6	36	56.34
9.62	7	49	67.34
I3.60	8	64	I08.80
II.98	9	8I	I07.82
III.77	45 m	285	509.77

I I0 n + 45 m = III.77 x 9

II 45 n +285 m = 509,77 x 2

II-I 90 n +570 m = I0I9.54

90 n +405 m = I005.93

I65 m = I3.6I

m = .0824 = slope

I0 n + 3.7I = III.77

I0 n = I08.06

n = I0.8I = Origin of slope

n + 9m = II.55 = end of slope