THESIS

On

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By

Joseph Webster Newell

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APPROVED:

[redacted]

Associate Professor of *Pomology*

[redacted] In charge of Major

Head of Department of *Horticulture*

[redacted]

Dean of the School of *Agriculture*

[redacted]

Chairman of Committee on Graduate Study.

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A STATISTICAL STUDY OF THE BEARING SHOOTS OF THE FILBERT (CORYLUS AVELLANA).

JOSEPH WEBSTER NEWELL.

INTRODUCTION

The filbert, or hazelnut as the wild species are called, belongs to the genus Corylus of the Oak family, Cupuliferae.[11] All of our important commercial varieties may be classified under Corylus avellana, the European filbert.[21] However there are many native American species, the most important and widespread of which are C.americana, C.rostrata, and C.californica.[3]

The filbert is a monoecious plant and the flowers are unisexual.[2] Both the female catkins, commonly known as the fruit-buds or pistillate flowers, and the male catkins develop on the one-year old wood. The development of the catkins and the initiation of the fruit-buds begins in late summer on shoots of the current season's growth.

The staminate flowers develop the most rapidly and when the leaves fall their long pendulous catkins are very noticeable. At the base of each male catkin is a two-cleft calyx partly united with the bracts, or scales.[9] On the inside of each bract there are two bractlets to which several stamens adhere.[11] The male catkins are borne singly, or in groups of two to five, on either the regular fruiting wood or special twigs, which are short and slender. In January and February the axis of the male catkins elongates, the pollen is disseminated by the wind, and the pistillate flowers become pollinated.

The fruit-buds, each of which contains six to fifteen pistillate flowers, are borne laterally on the upper portion of the one-year old shoots.[21] The fruit-buds are usually found at the base of the male catkins, either singly or in groups so close together that the smaller buds sometimes seem to be a part of the larger ones.

In late spring the fruit-bud axis elongates and the nuts are borne terminally in clusters. The number of nuts in each cluster varies from one to nine,[21] depending on variety. Thus the bearing twig of the filbert is comparable to the fruit-spur of the apple and the elongation of the fruit-bud axis to the thickening of the cluster base of the latter fruit.

The two-celled ovary of the pistil contains one ovule in each cell.[9] One of the ovules aborts and the other develops into a nut, which is enclosed by a leafy husk at maturity.[9] These nuts vary in shape from globular or ovoid to oblong, depending on variety.[9]

The filbert was originally brought to this country during colonial days but attained little commercial importance until its introduction to the Northwest. The limiting factors to its eastern development were the rigorous climate and the blight, Cryptosporella anomala, common on the native hazelnut of the east, C.americana, but only seriously injurious to the European filbert.

The mild climate and the absence of the eastern blight on the native hazelnut of this country, C.rostrata or californica, make the Willamette valley and the corresponding territories in Washington the best adapted in the United States to filbert growing.[15] However the greater part of the filbert acreage of the Northwest is confined to the Willamette valley. At present there are between fifteen hundred and two thousand acres of filberts planted in this state. Since less than one hundred of these acres are in bearing the problems of production are in the near future.

Filbert yields, under the most favorable conditions and at the full maturity of the trees, may run over 3,000# to the acre. On the average and over a period of years 1,000# is a safer estimate.[21]

The size of the European importations show that immense quantities of filberts are annually consumed in this country. The Bureau of Commerce and Navigation Reports[4] show that 20,441,538# of shelled and 15,584,418# of unshelled filberts were imported into the United States in 1923. The shelled nuts were multiplied by three in order to compare them with the unshelled. The increasing demand for the filbert, especially in the confectionary trade, indicates a big future for the American grown nut. At present the filbert stands about fourth in commercial importance among the cultivated nuts of the United States, being exceeded only by the walnut, pecan and almond.[4]

As more and more filbert acreage is annually coming into bearing competition is becoming greater so that maximum efficiency in production is more and more essential for profit. Lack of efficient pollination and of a proper system of pruning are among the most important limiting factors in fruit production. The suitable varieties to plant together to secure sufficient pollination have already been determined[21] but, on how to prune the filbert no experimental data has, as yet, been published.

Fuller[9] recommended heading back the strong leading shoots of bearing trees in order to keep them from growing too tall and to force out the lateral twigs as fruiting wood for the ensuing year.[9] Removal of branches was advised where the tree becomes too crowded to admit sufficient light and air to the center.

W. A. Taylor[3] thinks that pruning is of special importance with the filbert. He recommends heading back the strong shoots to promote spur formation and an annual removal of wood that bore the previous year. He prefers a short trunk with a vase-form head of six or more branches.

Schuster[21] says that the young trees should be headed between eighteen and thirty inches; a central leader developed as far as practical; and the scaffold limbs well distributed around the trunk, five to seven inches apart. He recommends a consistent thinning-out program with a heading back of any laterals that tend to take the lead away from the central leader. Heavy yields were obtained from the young bearing trees in the College Orchard by a light thinning to eliminate dense shade and effect a more equal distribution of the bearing wood. Where the trees are slowing down in fruit and wood production, thinning-out and fertilizing are advised rather than a heavy heading-back.[21]

The European system of pruning the filbert is much more severe than ours, amounting to almost a complete renewal of all wood except the scaffold limbs. This is necessitated by the close planting, usually about eight to ten feet apart, and the use of the filbert as an intercrop among orchard trees.[6]

In the summer of 1924, Cooter,[6] present foreman of the College Orchards, visited Geo. Banyard and Sons Nursery at Maidstone Kent, England, where one-hundred-seventy-five acres of filberts have been long in bearing as an intercrop among apple trees. These trees were developed from layered stock which was not allowed to branch until a foot high. Then they were trained to vase-form with a hollow center and the main branches spaced about a foot apart. The latter were headed at five feet from the ground, and pruned so as to leave renewal stubs both outside and in-side the vase, which forms the bearing surface. The trees are pruned back every other year to these renewal stubs. Under this intensive system of care and cultivation, the average yield per acre for trees, in the height of bearing, is around 2,000#.

The filbert resembles the peach in bearing its fruit laterally on wood of the past season's growth. However the open-centered vase-shaped system of training the peach is not so well-suited to the filbert as is the central leader type. The latter gives larger, stronger trees with a greater potential fruiting surface within a smaller radius of the trunk, due to a greater number of scaffold limbs.[10]

As a means of controlling production, the system of pruning is of greater importance than the form of the tree. The object of pruning is to obtain the greatest bearing surface that will function efficiently and produce fruit of good quality. To do this it is necessary to know the characteristics of the most productive shoots so that these may be left in as large a number as will allow the best conditions for their development. The object of this investigation is to study this important subject.

REVIEW OF LITERATURE.

In studying the relationship of the position and vigor of the bearing wood to its productiveness, a general review of the effects of these factors in other fruits was made before undertaking a specific study of the filbert.

Lewis[14] found that it is the medium-sized growth which is the most productive in the peach, the over-vigorous wood tending to excessive terminal bearing.

Clements and Reeves[5] noted that the stronger type of growth of the peach bears its fruit in three-bud formation and is therefore the most desirable. The single fruit-buds were noted as occurring, mostly, on the smallest, weakest shoots.

Edminster[8] investigated the relation between the angle, length, and diameter of shoots, and the development of side-shoots and fruit-spurs from lateral buds. A statistical study was made of 9,000 apple shoots from four varieties.

The idea had frequently been expressed that the most horizontal shoots are the most productive. Edminster's[8] date indicated that, generally, those shoots growing at an angle comparatively close to that of the mean shoot of the variety are the most productive of branch shoots and of spurs.

Also the idea had frequently been expressed that the weaker shoots are the most liable to give rise to fruit-spurs, the strong vigorous growths tending to run to further shoot and wood growth. Edminster[8] found a high degree of correlation existing between the length of the shoot and the percentage of lateral buds breaking and forming spurs. The same was found to be true of diameter, the stoutest shoots being the most productive of side-shoots and fruit-spurs.

Since the most upright shoots proved also to be the longest and thickest, the presence of a positive correlation between shoot angle, length and diameter was demonstrated. However, each of these factors was also proved to be more or less independent of the others. Therefore, when pruning the apple, those shoots should be preserved, so far as possible, that are long, stout, and more or less upright, or, at least, near the mean shoot angle of the variety.[8]

Yeager[24] made a statistical study of the fruit-spur system of the apple, using the Grimes. Among spurs of uniform age there was found to be a marked degree of correlation between length and production. Also there was found to be a high degree of correlation between diameter of spurs and their productiveness. Spurs of the same age borne on branches of large diameter bore a larger amount of fruit than those on smaller branches.

Yeager[24] was led to infer that the position of the spur in the tree had an influence upon its average production. Apparently the higher the spur in the tree, the greater its productivity. The outside of the tree produced more fruit per spur than the inside as well as a much larger proportion of the total amount, although the latter may have been due, at least in part, to the larger proportion of bearing surface to be found on the outside.

His date[24] indicated that the most productive spurs, and the fruit of the best quality were to be found in the south quarter of the tree. This was followed **closely** by the west, east,and lastly north quarters of the tree.

This was explained in various ways. It was said to be partly due to the fact that the youngest spurs were borne on the south side of the tree, for production was found to be negatively correlated with age.[24]

The fact that the north side of the apple trees had the oldest spurs may have been due, at least partly, to the inhibiting effect of a limited light supply on the tendency of the Grimes spurs to go into vegetative growth after a certain number of years of normal functioning.[24]

Also the proportionally greater number of spurs on the north side may have had some effect in lowering the average spur production, and thus decreasing quality. However the better light exposure was doubtless the greatest factor favoring the better quality and productiveness of the spurs on the south side.[24]

Crow[7] discovered that, with the apple, strong fruit-spurs of a certain length, four to nine millimeters, bore nearly all the fruit. The majority of the longer growths consisted of non-fruiting shoots, ten to five-hundred millimeters length, and the shorter growths of weak, unproductive leaf and fruit spurs. Evidently there is an optimum length for fruit production in the apple.

Roberts[19] showed that blossom-bud formation of the apple is related to spur length. The spurs of medium length formed the most blossum buds because they have the greatest amount of food-gathering surface in proportion to length. This was said to be due to the fact that the leaf area increases in proportion to spur length up to the medium length and then the correlation between the two drops, with any further increase because of the increasing length of the internodes.

Roberts[18] also found similar correlations with the sour cherry. Cherry spurs grow only from leaf buds and these are present, in the greatest numbers, on rather long growths. However, a certain length, twelve to fourteen inches, gave the maximum number of leaf-buds.

Painter[17], working with the Montmorency sour cherry verified Robert's[18] conclusions. His results showed that the longer the shoot the greater the percent of fruiting spurs set, up to a certain length, thirteen-and-one-half inches. A vigorous growth, twelve to fourteen inches, seemed to give the highest average set of fruit-spurs for the next season.[17]

OBJECT OF THIS INVESTIGATION.

The object of this investigation was to determine the correlations of the fruit-buds to the number of male catkins and to the length, diameter, and branching angle of the bearing shoots. The object, also, was to determine the effect of the position and latitude of the shoot, in the tree, on fruit-bud formation.

In other words, the questions to be solved are the following. Are the strong, thick shoots more productive than the weak, slender ones? What is the optimum shoot length for fruit-bud formation? Are the upright, or the horizontal shoots the more productive? Where will the most productive shoots in the tree be found--on the perimeter, inside, top, median, or lower part? Also which side of the tree is the most productive? Lastly, how do these various factors differ among the varieties examined?

MATERIALS AND METHODS EMPLOYED.

A statistical study of over 3,000 filbert shoots was undertaken, in the endeavor to answer these questions. Four popular varieties were chosen: Barcelona, Merveille de Bolwyller, Nottingham, and White Aveline. Although each of these varieties are practically self-sterile, they are inter-fertile to a satisfactory degree.[21] The latter three are excellent pollenizers for the first, Barcelona, which is the leading commercial variety in Oregon.[21]

The Barcelona is of spreading habit; vigorous and productive; and bears a medium to large oval nut, one to eight in a cluster. The Merveille de Bolwyller is an upright, close grower; vigorous but a light producer; and bears a large, broad nut. Nottingham is an upright, close grower; vigorous and fairly productive; and bears a long, medium to small, nut. White Aveline is a medium to small tree, of low spreading habit; fairly vigorous, and moderately productive; with a small, long nut.[21]

Three to five typical trees of each variety were selected. They were chosen from among the filbert trees in the South College Orchard, planted about ten years ago. The trees selected were growing under as nearly the same soil, moisture, and fertility conditions as possible. The soil is a heavy clay, lacking somewhat in drainage and fertility.

The following instruments of measurement were used: a metric steel tape for length; a vernier steel calipers for diameter; and a small steel protractor for angle. Length and diameter were recorded in centimeters, or millimeters, and, the angles in degrees. The diameter of each twig was taken at the base. The direction of growth of the old shoot was considered as zero degrees and the angle measured was the degree of departure that the new shoot made from the old. Terminal shoots were considered as growing at an angle of zero degrees, as they continue in the same general direction of growth as the mother shoot.

The data was recorded during the period of Jan. to May 1924. For the purpose of identification, paraffined tags, which had been numbered before dipping, were tied onto the individual shoots. (For illustration see Plate 2) A note-book was used to record the number of the tag; number of fruit-buds and male catkins; and the length, diameter, angle, position and latitude of each shoot. From this data the correlations were determined for the varieties studied.

The object of the statistical methods employed in this study was to put the data obtained into that form which would reveal the maximum number of interpretable facts.

The arithmetic mean was used because it is the best measure of type and marks the central tendency of the data.[13] The standard deviation was employed to determine the degree of dispersion of the data and thus show the dependability of the mean as a measure of type.[13] It is the most used measure of variability as it gives that additional weight to extreme variations so desirable in biometrical work.[1]

Since the coefficient of variability is an index of the degree of variation[1] it was employed to give the different values obtained for the standard deviations an equal significance, in the same set of correlations.[13] Since this coefficient is determined by dividing the standard deviation by the mean,[13] it gives the average percentage of variation of the variable from its mean. The high values obtained for the coefficient of variability in some of the following tables is due to the use of unsmoothed data subject to considerable natural variability and influenced by many extraneous factors.

The Pearson product-moment coefficient of correlation was employed to determine if there was a tendency for a high, or low, positive, or negative, value of the dependent variable to be associated with a high value of the independent variable. The dependent variable,y, was regarded as the function of the independent variable,x, and therefore the latter variable may be considered as a cause and the former as the effect. The object of the correlation coefficient is to show to what extent a certain cause will be accompanied by a certain effect.[13]

Regression lines were used to determine the linearity of regression by the proximity of the lines of best fit to the means of the columns and rows. When there is unity of correlation the regression lines coincide at forty-five degrees from the axes of the table. However, there must be perfectly linear correlation for the lines of regression to thus coincide.[13]

Regression coefficients are an aid in laying off the lines of best fit to the means of the arrays. They may, also, be used to predict the most probable value of one variable to be found with a given value of the other.[13.]

The coefficient of correlation is used more than the correlation ratios in biometrical work, due to the laboriousness involved in the computation of the latter. The coefficient is a kind of average measure of the correlation of two variables, being equal to the geometric mean of the ratios, in the case of perfectly linear regression. It is therefore a conservative measure of correlation and the most convenient method of defining the general tendency in data, since it expresses a property of the Correlation Table as a whole.[13]

However, the correlation ratios are the most satisfactory measure of relationship between the two variables in the case of non-linear regression and a fairly high degree of correlation.[13] Also, they are of value in determining the dependence of one variable upon the other and in showing which of the two is the most affected by variations in the other.[13]

The term, probable error, or probable deviation as it is more properly called, is used to determine the amount which must be added to, or subtracted from, the observed value to obtain two limiting figures of which it may be said that there is an even chance that the true value lies within, or without, these limits.[1] In homogeneous data the observed value will vary within these limits in fifty per-cent of the cases. The probable error is used to show the reliability of the results.

The following formulae, obtained from Kent's elements of Statistics, were employed.[13]

$$C_1 = \frac{f\bar{x}.}{n.}$$

$$C_2 = \frac{f\bar{y}.}{n.}$$

$$Mx. = Bx. + C_1$$

$$My. = By. + C_2$$

P.M. = Product-Moments

SDx. = Square root of

$$\left(\frac{f\bar{x}^2}{n.} - C_1^2\right)$$

SDy. = Square root of

$$\left(\frac{f\bar{y}^2}{n.} - C_2^2\right)$$

$$C.V. = \frac{M.}{SD.}$$

$$r. = \frac{S\overline{xy}.}{n(SDx.)\,(SDy.).}$$

$$c.r_{x.} = \frac{SDxy.}{SDx.}$$

$$c.r_{y.} = \frac{SDyx.}{SDy.}$$

$$P.E.\ of\ M. = \frac{\pm .675(SD).}{\text{Square root of } n.}$$

$$P.E.\ of\ r. = \frac{\pm .675(1-r^2).}{\text{Square root of } n.}$$

$$P.E.\ of\ c.r. = \frac{\pm .675(1-c.r.^2).}{\text{Square root of } n.}$$

KEY TO SIGNS.

C_1 = Correction for Independent Variable.

C_2 = Correction for Dependent Variable.

f. = Number of Frequencies.

x. = Independent Variable.

y. = Dependent Variable.

$\bar{x}$. = Deviation of the Independent Variable from its Mean.

$\bar{y}$. = Deviation of the Dependent Variable from its mean.

n. = Total number of Frequencies.

r. = Coefficient of Correlation.

c.r. = Correlation Ratio. The sub-number stands for the variable, either x or y.

B. = Assumed Base of the variable, either x or y.

M. = Mean of the variable, either x or y.

P.M.= Product-Moments.

S. = Summation.

SD. = Standard Deviation. Sub-number stands for the variable, either x or y.

C.V.= Coefficient of Variability.

SDxy.= Standard Deviation of the x arrays of the y type.

SDyx.= Standard Deviation of the y arrays of the x type.

P.E.= Probable Error, or Probable Deviation.

IS THERE A CORRELATION BETWEEN THE MALE CATKINS AND THE NUMBER OF FRUIT-BUDS?

Woodroof,[23] studying the pecan, found a very low degree of positive correlation between the abundance of the crop of catkins produced and the crop of pistillate flowers, for any particular year.

In order to test the truth of this statement in regard to the filbert the correlation was determined between the two kinds of flowers. Although the few branches where one flower was not associated with the other were eliminated, the fair degree of correlation obtained seems to warrant the conclusion that, where large numbers of male catkins are observed one may be apt to find large numbers of fruit-buds. Therefore the size of the catkinate crop may be regarded as something of an index of the nut crop to be expected. (For an illustration, see Plate 1).

The male catkins were treated as the independent variable,x, the fruit-buds as the dependent variable,y, and the object was to find whether the latter were the function of the former. In other words, are the number of fruit-buds affected by the number of catkins? Three hundred-twenty-two branches on two Barcelonas were counted and the results averaged. (See Table 1.) The lateness of the season made it impossible to work on any other varieties.

The male catkins had a mean of 5.45 ± 0.12; a standard deviation of 3.2; a coefficient of variability of 0.587; and a correlation coefficient of 0.407 ± 0.031. Therefore, in thirty-eight to forty-four cases out of one-hundred, a large number of fruit-buds will be found associated with a large number of male catkins.

Although the non-availability of material limited the study of the relationship between male and female catkins to the Barcelona, the existence of a similar correlation, in the other varieties, might be reasonably expected.

The remainder of this thesis is a study of the female catkins, more commonly called the fruit, or pistillate buds. Naturally, these would be a better index of the size of the nut crop and the productiveness of the tree, than would the male catkins.

TABLE I

CORRELATION TABLE FOR NUMBER OF MALE AND FEMALE CATKINS FORMED ON BARCELONA, --- FALL OF 1923.

Female Catkins (y)	Male Catkins (x)																
y.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	f(y).
11		1					1										2
10						1											1
9										2							2
8	1																1
7			1		2		1	2									6
6		2	2	1		1	1	1	1		2		1		1	1	14
5			2	4	3	2	2	4	2	3	2	1	2		1		28
4		2	2	4		2	4	4	4	1	2	1					26
3	2	9	7	5	5	11	10	8	3	8	2		1	1	1		73
2	4	11	8	14	6	5	7	3	6	4	3				1		72
1	15	31	12	20	6	6	1	2	1		3						97
f(x)	22	56	34	48	22	28	27	24	17	18	14	2	4	1	4	1	322

IS THERE A CORRELATION BETWEEN SHOOT LENGTH AND FRUIT-BUD FORMATION?

One of the most important correlation studies in horticulture is the relation between the length of the fruit producing wood and its productiveness. Most of the pomological fruits hitherto studied have revealed a high degree of correlation between these two factors.

The measurements of the three to five trees of each variety were placed together in the variety correlation tables. Since all of the trees were propagated from layered stock and grown under the same environmental conditions, differences due to individuality are probably, in most cases, at a minimum.

In correlating the two variables, length was treated as the independent variable and the number of fruit-buds as the dependent variable. Shoot lengths were divided into classes with a range of five centimeters. This was considered a convenient and sufficiently accurate method of classification.

From a study of Table V., it may be said that, increases in shoot length will be accompanied by increases in the number of fruit-buds in the following percentages of all cases: for Merveille de Bolwyller, seventy-four to eighty percent; White Aveline, sixty-one to sixty-four percent; Barcelona, sixty to sixty-three percent; and for Nottingham, fifty to fifty-four percent. For all the varieties studied the increases in shoot length were accompanied by increases in the number of fruit-buds in sixty to sixty-five percent of all cases. This indicates a high degree of correlation between these two variables. (See Figure 1.).

In order to determine whether the correlation between the variables is greatest for the short or long shoots, the length arrays of each correlation table were divided into two groups. The first included the mean array and those below, and the second, all the arrays above the mean class. In other words, the short shoots, included those under twenty-five centimeters in the White Aveline; those under twenty centimeters in the Barcelona and Merveille de Bolwyller; and those under fifteen centimeters in the Nottingham.

From the results in Table V., it may be said that, for the shoots in the first group, the short shoots, increases in length will be accompanied by increases in the number of fruit-buds in the following percentages of all cases: White Aveline, fifty-eight to sixty-two percent; Merveille de Bolwyller, fifty to sixty-eight percent; Barcelona, fifty-two to fifty-seven percent; and Nottingham, thirty-six to forty-two percent.

For the shoots of the second group, the long shoots, increases in length will be accompanied by increases in the number of fruit-buds in the following percentages of all cases: Merveille de Bolwyller, forty to forty-eight percent; Nottingham, thirty-six to forty-two percent; Barcelona, thirty-one to thirty-seven percent; and White Aveline, sixteen to twenty-two percent.

The lower correlation coefficients obtained when the table is divided is due to the fact that a ratio, being a quotient, cannot be treated as an average of other quotients.

As the degree of correlation of the short shoots is one-and-four-tenths to three-and-two tenths times that of the long shoots, depending on variety, apparently there is that much greater probability of the short shoots showing an increase in the number of fruit-buds accompanying length increase, than would be the case with the long shoots. If this assumption be correct, then, with the same total shoot length, there is a much greater certainty of having a higher total number of fruit-buds on many short shoots, below the mean length, than on a few long ones.

Figure 2 shows an increase in the distance between the fruit-buds accompanying an increase in shoot length. This is due to the natural increase in the length of the internodes and the consequent decrease in the number of fruit-buds per decimeter.

A comparison of Figure 2 and Table 5 seems to indicate that the differences in the degree of correlation between the short and long shoots is largely dependent upon differences in the rate of increase in the length of the internodes. In those varieties where there is the least difference between the values of the coefficients of the short and long shoots, as in Merveille de Bolwyller and Nottingham, there is only a slightly greater rate of length increase for the internodes of the long shoots, but, where there is a large difference in the value of these coefficients, as in Barcelona and White Aveline, the rate of internode length increase of the long shoots is also much greater.

To test the dependability of the variables upon each other, the correlation ratios were determined, in the case of Barcelona. (See Table VI. and VII.).

The correlation ratio for the independent variable of length was found by computing the standard deviation of the means of the rows and dividing by the standard deviation of length, as found in calculating the correlation coefficient. (See Table VI.).

The correlation ratio for the dependent variable, or the fruit-bud variable, was found by computing the standard deviation of the means of the columns and dividing by the standard deviation of the number of fruit-buds, as found in calculating the correlation coefficient. (See

Table VII.).

The ratio of dependence of shoot length upon the number of fruit-buds proved to be 0.645 $\pm$ 0.012, and the ratio for the dependence of the latter variable upon the former, 0.612 $\pm$ 0.013. Therefore, in sixty-three to sixty-six percent of all cases shoot length increase will be accompanied by increase in number of fruit-buds, and, in sixty to sixty-three percent of all cases an increase in the number of fruit-buds will be accompanied by a similar increase in shoot lengths. In other words, long shoots are about as apt to have large numbers of fruit-buds as large numbers of fruit-buds are apt to be found on long shoots. Both variables are about equally dependent upon each other.

The geometric mean of the two correlation ratios was within two percent of the correlation coefficient. This shows only a small amount of asymmetry in the data.

TABLE II.

CORRELATION TABLE FOR THE NUMBER OF FRUIT-BUDS FORMED ON THE BARCELONA SHOOTS OF DIFFERENT LENGTHS --- FALL OF 1923.

Number of Fruit-buds (y)	Shoot Lengths (x)												
y.	1	2	3	4	5	6	7	8	9	10	11	12	f(y)*
12												1	1
11			1						1		1		3
10											2		2
9					1					1	1		3
8										2	1	1	4
7			1	2	1	2	2	2		5		1	16
6			2	3	1	10	5	4	2	4		1	32
5			1	11	8	10	3	5	10	6	5	3	62
4		1	8	21	20	14	9	1	5	1	2	3	85
3	1	9	28	43	28	22	7	16	10	8	5	6	193
2	19	27	53	56	31	25	6	7	8	5	3		240
1	217	64	75	30	19	5	2	3	3	2		2	422
f(x)*	237	101	169	166	109	88	34	38	39	34	20	18	1053

*For explanation see Key to Arrangement of Table II.

EXPLANATION OF THE COMPUTATION OF THE CORRELATION COEFFICIENT IN TABLE II.

The mathematical method of arranging the classes was followed. The classes of the dependent variable were arranged so that their ascending values read from the bottom up and those of the independent variable to read from left to right.

The measures of value necessary in computing the correlation coefficient were calculated in class values. This simplified the work and eliminated any error due to the different class ranges of the two variables.

In the case of the fruit-bud variable,y, the class values are the same as the real, or actual, values. However, in the case of the length variable,x, the class value is one-fifth of the actual value and must be multiplied by five. Since the first mid-class value, in centimeters, is only one-half of five, two-and-a-half must be subtracted from the above product. To illustrate: the Mean Length(Mx)=4.132 times 5 = 20.66 - 2.5 = 18.16 or 18.2 centimeters; and, the Standard Deviation of Length (SDx) = 2.82 times 5 = 14.1 - 2.5 = 11.6 centimeters.

KEY TO ARRANGEMENT OF TABLE II.

Shoot Lengths (x variable).

Class	Mid-Class Value in cm.	Class-Range in cm.
1	2.5	0 - 4.99
2	7.5	5 - 9.99
3	12.5	10 - 14.99
4	17.5	15 - 19.99
5	22.5	20 - 24.99
6	27.5	25 - 29.99
7	32.5	30 - 34.99
8	37.5	35 - 39.99
9	42.5	40 - 44.99
10	47.5	45 - 49.99
11	52.5	50 - 54.99
12	57.5	55 - 59.99

Number of Fruit-buds (y variable).

The Class numbers are the actual values.

KEY TO LETTERS

x = The Length variable.

y = The Fruit-bud Variable.

f(x) = Summation of Length Frequencies of Shoots.

f(y) = Summation of Fruit-bud Frequencies of Shoots.

TABLE III.

COMPUTATION OF THE CORRELATION COEFFICIENT IN TABLE II

$f(x)$	$\bar{x}$	$f\bar{x}$	$f\bar{x}^2$	$f(y)$	$\bar{y}$	$S\bar{xy}$	$f\bar{y}$	$f\bar{y}^2$
237	-3	-711	2133	422	-1	764	-422	422
101	-2	-202	404	240	0	0	0	0
169	-1	-169	169	193	1	289	193	193
166	0	0	0	85	2	276	170	340
109	1	109	109	62	3	603	186	558
88	2	176	352	32	4	368	128	512
34	3	102	306	16	5	280	80	400
38	4	152	608	4	6	162	24	144
39	5	195	975	3	7	98	21	147
34	6	204	1224	2	8	112	16	128
20	7	140	980	3	9	108	27	243
18	8	144	1152	1	10	80	10	100
1053		140	8412	1053		3140	433	3187

KEY TO TABLE

$f(x)$ - Class Frequencies of Shoot Lengths.

$\bar{x}$ - Class Deviations from Assumed Mean.

$f\bar{x}$ - Product of Class Frequency and Deviation.

$f\bar{x}^2$ - Product of Class Frequency and Deviation squared.

$f(y)$ - Class Frequencies of Fruit-buds.

$\bar{y}$ - Class Deviations from Assumed Mean.

$S\bar{xy}$ - Summation of Product-Moments.

$f\bar{y}^2$ - Product of Class Frequency and Deviation squared.

TABLE IV.

COMPUTATION OF THE CORRELATION COEFFICIENT IN TABLE II(CONT)

$C_1 = \frac{f\bar{x}}{n}$ or $\frac{140}{1053}$ or 0.132 $\quad C_2 = \frac{f\bar{y}}{n}$ or $\frac{433}{1053}$ or 0.409

$C(S\overline{xy}) = (C_1)(C_2)(n) = 56.86$

SDx = Square root of $\left(\frac{Sf\bar{x}^2}{n} - C_1^2\right)$ or $\left(\frac{8412}{1053} - 0.017\right) = 2.8$

SDy = Square root of $\left(\frac{Sf\bar{y}^2}{n} - C_2^2\right)$ or $\left(\frac{3187}{1053} - 0.167\right) = 1.7$

$r = \frac{S\overline{xy}}{n(SDx)(Sdy)} = \frac{3083.14}{1053(2.8)(1.7)}$ or 0.615

P.E.= $\frac{(.675)(1-r^2)}{\text{Square root of } n}$ or $\frac{(.675)(1-.378)}{\text{Square root of } 1053} = \pm 0.013$

Therefore the Correlation Coefficient is 0.675± 0.013

My = 2 ± .41 or 2.41

P.E.= $\frac{(0.675)(SDy)}{\text{Square root of } n}$ or $\frac{(.675)(1.7)}{\text{Square root of } 1053}$ or ±0.035

Therefore My equals 2.41 ± *0.035

Mx = 4 ± .13 or 4.13 which is 4.13 times 5 or 20.65 - 2.5 = 18.2cm.

P.E. = $\frac{(0.675)(SDx)}{\text{Square root of } n} = \frac{(0.675)(2.8)}{\text{Square root of } 1053}$ or ±.059

0.059 times 5 = ± 0.295cm.

Therefore Mx equals 18.2cm ± 0.295cm.

*Plus or minus sign.

KEY TO TABLE IV.

C_1 = Correction for Mean Length (Mx).

C_2 = Correction for Mean Number of Buds (my).

$C(\overline{Sxy})$ = Correction for the Summation of the Product-Moments

C_1^2 = Correction for the Standard Deviation of Length (SDx).

C_2^2 = Correction for the Standard Deviation of Fruit-buds (SDy).

$f\overline{x}$ = Summation of Product of Length Deviations by Class Frequencies.

$f\overline{y}$ = Summation of Product of Fruit-bud Deviations by Class Frequencies.

$f\overline{x}^2$ = Summation of Product of Square of Length Deviations by Class Frequencies.

$f\overline{y}^2$ = Summation of Product of Square of Fruit-bud Deviations by Class Frequencies.

n = Total number of frequencies.

r = Coefficient of Correlation.

P.E. = Probable Error, or Probable Deviation.

TABLE V.

SUMMARY OF THE MEASURES OF VALUE FOR THE VARIABLES OF SHOOT LENGTH AND NUMBER OF FRUIT-BUDS.

V.	Mx.	± P.E.	My.	± P.E.	SDx.	SDy.	CVx.	CVy.	r.	± P.E.	r(la)	± P.E.	r(ua)	± P.E.
B.	18.2	.29	2.41	.036	11.6	1.73	.682	.717	.615	.013	.554	.018	.338	.03
M.	16.2	.21	2.51	.045	5.5	1.80	.428	.717	.770	.028	.590	.094	.436	.04
N.	12.9	.20	2.15	.033	4.9	1.24	.389	.576	.527	.020	.395	.030	.273	.01
W.	21.5	.27	4.97	.069	8.9	2.96	.475	.595	.625	.014	.605	.020	.192	.03
A.	17.2	.24	3.01	.050	7.7	1.93	.494	.651	.635	.044	.536	.040	.309	.03

KEY TO TABLE V.

V. = Variety.

B. = Barcelona.

M. = Merveille de Bolwyller.

N. = Nottingham.

W. = White Aveline.

A. = Average.

$\pm$. = Plus or minus sign.

Mx. = Mean Length of Shoot in centimeters.

My. = Mean Number of Fruit-buds on Shoots.

P.E. = Probable Error, or Deviation.

SDx. = Standard Deviation of Shoot Length in Centimeters

SDy. = Standard Deviation of Number of Fruit-buds.

CVx. = Coefficient of Variability of Shoot Lengths.

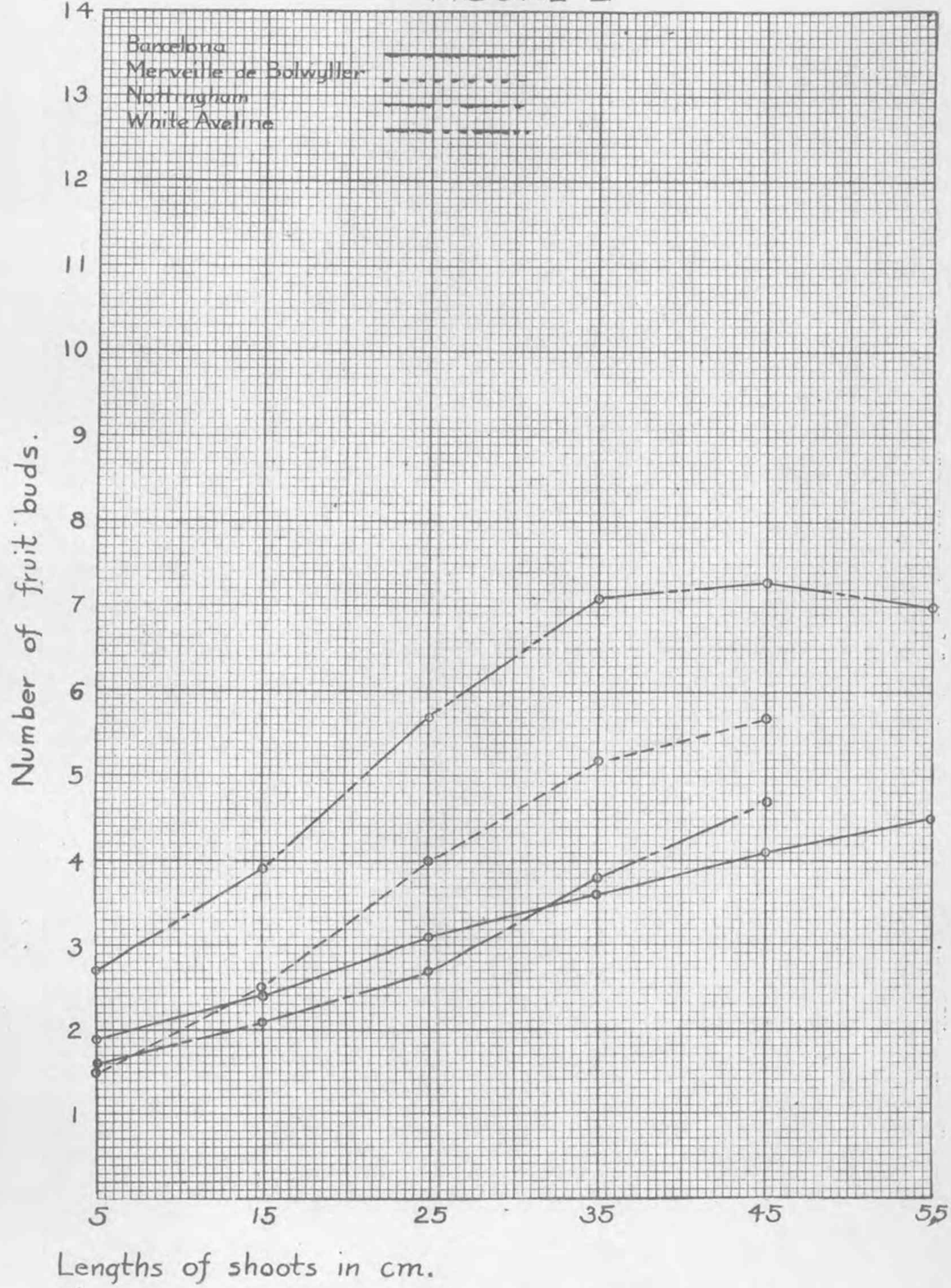
CVy. = Coefficient of Variability of Number of Fruit-buds

r. = Coefficient of Correlation of all Length arrays.

r(la). = Coefficient of Correlation of lower Length arrays

r(ua). = Coefficient of Correlation of upper Length arrays

FIGURE I



EFFECT UPON NUMBER OF FRUIT BUDS, OF INCREASE IN AVERAGE LENGTH OF SHOOTS.

KEY TO FIGURE I.

Heights of the Ordinates.

x.	1.	2.	3.	4.
5	1.9	1.5	1.6	2.7
15	2.4	2.5	2.1	3.9
25	3.1	4.0	2.7	5.7
35	3.6	5.2	3.8	7.1
45	4.1	5.7	4.7	7.3
55	4.5			6.8

EXPLANATION

x.= Mid-Class Lengths of Bearing Shoots, in Centimeters.

1.= Smoothed averages of Numbers of Fruit-buds in the Length Classes of Barcelona.

2.= Smoothed Averages of Numbers of Fruit-buds in the Length Classes of Merveille de Bolwyller.

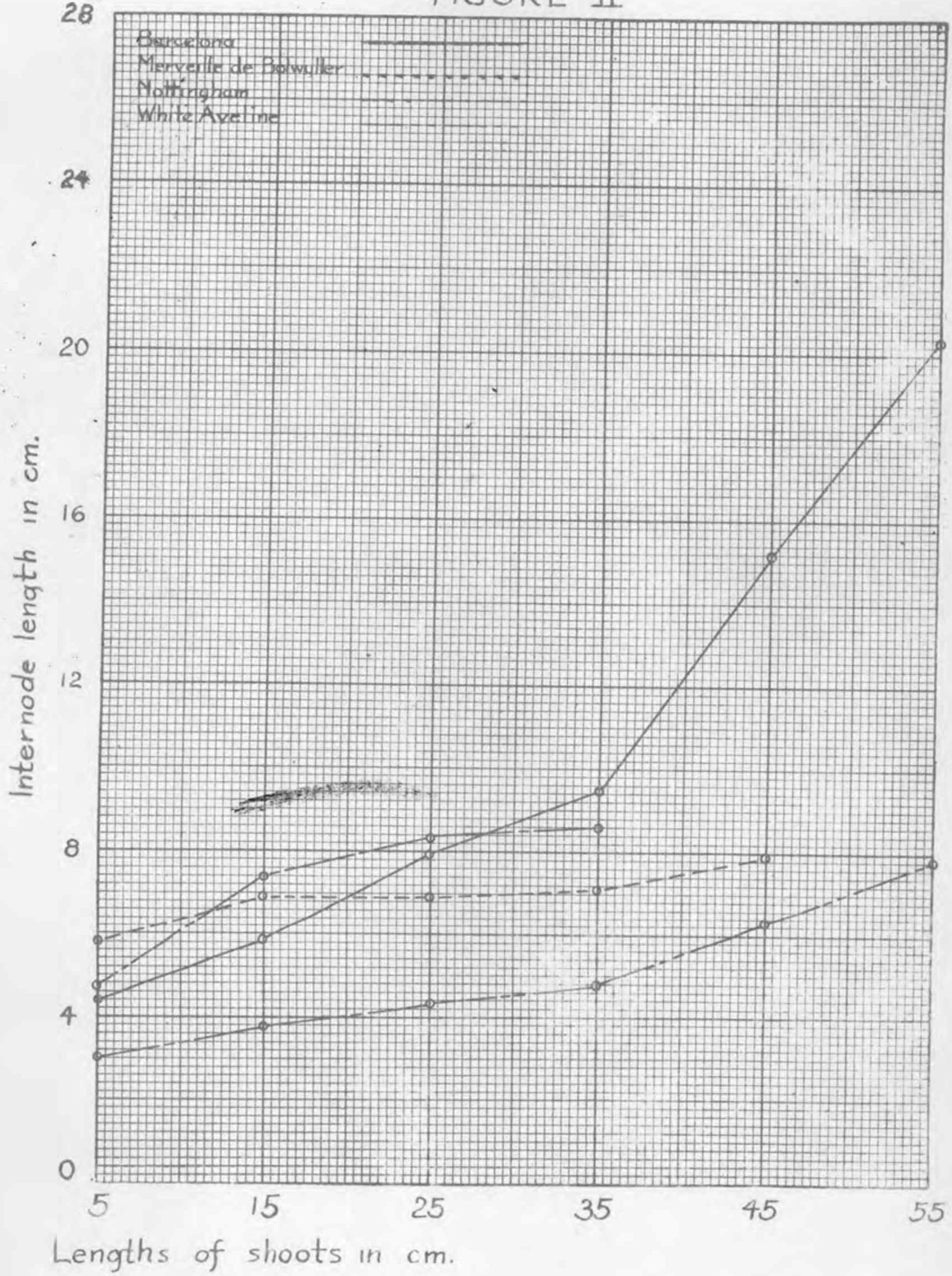
3.= Smoothed Averages of Numbers of Fruit-buds in the Length Classes of Nottingham.

4.= Smoothed Averages of Numbers of Fruit-buds in the Length Classes of White Aveline.

Note - The fruit-bud averages were smoothed according to the formulae: $A = \frac{2A + B}{3}$, $B = \frac{A + B + C}{3}$, $C = \frac{B + C + D}{3}$, in which A, B, C, and D represent the successive averages numbers of fruit-buds. In other words, the true value of each point on the scale is seen to be equal to the Arithmetic Mean of its value and the two adjacent values. Each of the extreme measures is weighted by two and averaged with the adjacent measures. This has no effect on the Arithmetic Mean of the whole distribution and gives a smoother curve. (For detailed explanation see Rugg p.184)[20].

The averages in the following figures were likewise smoothed in order to give a better curve.

FIGURE II



EFFECT UPON NUMBER OF FRUIT BUDS, OF INCREASE IN AVERAGE LENGTH OF SHOOTS.

KEY TO FIGURE 2.

Heights of the Ordinates.

x.	1.	2.	3.	4.
5	4.4	5.9	5.7	3.2
15	5.8	6.9	6.9	3.7
25	7.9	6.9	8.3	4.3
35	9.5	7.1	8.6	4.8
45	15.2	8.0		6.3
55	20.3			7.8

EXPLANATION

x. = Mid-Class Lengths of Shoots, in Centimeters.

1. = Smoothed Average Distances, in Centimeters, between fruit-buds, on Barcelona shoots

2. = Smoothed Average Distances, in Centimeters, between Fruit-buds, on Merveille de Bolwyller Shoots.

3. = Smoothed Average Distances, in Centimeters, between Fruit-buds, on Nottingham Shoots.

4. = Smoothed Average Distances, in Centimeters, between Fruit-buds, on White-Aveline Shoots.

Note. - In order to avoid confusion of lines, unsmoothed values were sometimes used in plotting the ordinates in these figures.

TABLE VI.

COMPUTATION OF THE CORRELATION RATIO FOR THE INDEPENDENT VARIABLE OF SHOOT LENGTH IN BARCELONA.

Type(y)	Mxy	Mx-Mxy	$(Mx-Mxy)^2$	f.	$f(Mx-Mxy)^2$
1	2.19	1.94	3.76	422	1590.00
2	4.22	0.09	0.01	240	2.40
3	5.30	1.17	1.37	193	265.00
4	5.62	1.49	2.22	85	188.50
5	7.22	3.09	9.55	62	591.00
6	6.87	2.74	7.51	32	240.50
7	7.50	3.37	11.36	16	182.00
8	10.70	6.57	43.16	4	172.64
9	8.70	4.57	20.88	3	62.64
10	11.00	6.87	47.19	2	94.38
11	7.60	3.47	12.04	3	36.12
12	12.00	7.87	61.94	1	61.94
				1053	3487.12

Sdxy = Square root of $\left(\frac{f(mx-Mxy)^2}{n.}\right)$ or $\left(\frac{3487.12}{1053}\right) = 1.82$

Correlation Ratio of (x) = $\frac{SDxy}{SDx} = \frac{1.82}{2.82} = .645$

P.E. = $\frac{(.675)(1-c.r.^2)}{\text{Square root of n.}} = \frac{(.675)(.584)}{\text{Square root 1053}} = \pm 0.01215$

Therefore the Correlation Ratio equals 0.645 $\pm$ 0.01215

Note: - See Kent's Elements of Statistics pp.130-1 for detailed explanations.

TABLE VII.

COMPUTATION OF THE CORRELATION RATIO FOR THE DEPENDENT VARIABLE OF FRUIT-BUDS IN BARCELONA.

Type(x)	Myx	My-Myx	$(My-Myx)^2$	f.	$f(My-Myx)^2$
2.5	1.09	1.32	1.74	237	412.00
7.5	1.48	0.93	0.86	101	86.80
12.5	1.97	0.44	0.19	169	32.10
17.5	2.66	0.25	0.06	166	9.97
22.5	2.81	0.40	0.16	109	17.45
27.5	3.42	1.01	1.02	88	89.80
32.5	3.83	1.42	2.02	34	68.70
37.5	3.47	1.06	1.12	38	42.50
42.5	3.64	1.23	1.51	39	59.80
47.5	4.52	2.11	4.45	34	151.50
52.5	5.10	2.71	7.34	20	146.80
57.5	4.45	2.04	4.16	18	748.00
				1053	1192.22

Sdyx = Square root of $\left(\frac{f(My-Myx)^2}{n}\right)$ or $\left(\frac{1192.22}{1053}\right)$ (Square root) or 1.06

Correlation Ratio of (y). = $\frac{SDyx}{SDy} = \frac{1.06}{1.73} = 0.612$

P.E. = $\frac{(.675)(1-c.r^2.)}{\text{Square root n.}} = \frac{(.675)(.63)}{\text{Square root 1053}} = \pm 0.01335$

Therefore the Correlation Ratio equals 0.612 ± 0.01335

Note: - See Kent's Elements of Statistics pp.130-1 for detailed explanations.

KEY TO TABLE VI.

Mxy.	=	Means of all Length arrays of Fruit-bud type(y).
Mx-Mxy.	=	Deviation of Means of Length arrays from Average Mean.
f.	=	Class Frequencies.
n.	=	Total number of Frequencies.
x.	=	The Length Variable.
SDxy.	=	Standard Deviation of Means of Length arrays.
SDx.	=	Standard Deviation of Length.
P.E.	=	Probable Error.
c.r.	=	Correlation Ratio.
$\pm$	=	Plus or minus sign.

KEY TO TABLE VII.*

Myx.	=	Means of all Fruit-bud arrays of Length type(x).
My-Myx.	=	Deviation of Means of Fruit-bud arrays from Average Mean.
y.	=	The Fruit-bud Variable.
SDyx.	=	Standard Deviation of Means of Fruit-bud arrays.
SDx.	=	Standard Deviation of Number of Fruit-buds.

*Signs explained in above Key not included.

Note = Table of Powers and Roots in Kent's Elements of Statistics (Appendix B) used in Computation of Correlation Ratios in Tables VI and VII.

IS THERE A CORRELATION BETWEEN SHOOT DIAMETER AND FRUIT-BUD FORMATION?

If increase in shoot diameter is affected by length increase, there is no need to determine the correlation of the diameter and the number of fruit-buds. Both would be effects of the same cause. In other words, variations in shoot diameter and the number of fruit-buds would depend primarily upon variations in shoot length. Therefore the answer to the above question depends largely upon whether, or not, there is a correlation between the length and diameter of the bearing shoot.

Since the object of the correlation is to show if length increase is the cause of diameter increase, the former was taken as the independent variable and the latter as the dependent variable. The shoots were grouped into class ranges of five centimeters for length and half millimeters for diameter. Since the classes of the two variables are of unequal metrical value, the coefficient of correlation was computed from the class numbers, instead of the actual values. (See Table VIII). As with the previous correlation study, the true values for any of the measures of type may be readily determined by simple calculation (See Key to Arrangement of Table VIII).

The results in Table IX. are based upon data from only one tree of each variety. The steep and regular lines of diameter increase accompanying that of length, in all the varieties, shows a high degree of correlation. (See Figure 3).

From a study of the correlation coefficients in Table IX., it may be said that increases in shoot length will be accompanied by increases in shoot diameter in the following percentages of all cases: Barcelona, eighty-eight percent; White Aveline, eighty to eighty-three percent; Nottingham, seventy-nine to eighty-two percent; Merveille de Bolwyller, seventy-three to seventy-seven percent; and, averaging all four varieties, in seventy-seven to eighty-three percent of all cases.

These coefficients, which are extremely high for natural phenomena, indicate a very close association between the length and the diameter of the filbert shoot. The low coefficient of variability gives additional emphasis to the close relationship between these two variables.

Since the number of fruit-buds and the diameter of the shoot are dependent variables of one cause, shoot length, the deduction, which would naturally follow, may be stated in the form of the following syllogism; The Length of the Shoot was found to be correlated with its Diameter. The Number of Fruit-buds were found to be correlated with the Length of the Shoot. Therefore, the Number of Fruit-buds are correlated with the Diameter of the Shoot.

An attempt was made to determine if there were any causal connection, or independent correlation, between the two effects of the same cause, the variables of shoot diameter and fruit-buds. In other words, will thick shoots of the same length bear more, or less, fruit than the thinner ones, other conditions being as nearly equal as possible.

A study of the diameter and fruit-bud variations in all the shoots of an arbitrarily chosen length, such as twenty centimeters, and borne in favorable positions of light exposure, revealed no degree of independent correlation between these two factors. On the contrary, the manner of variation of the number of fruit-buds borne on shoots of an equal length suggests the presence of other factors, more influential than the shoot's diameter.

TABLE VIII

CORRELATION TABLE FOR THE LENGTH AND DIAMETER OF BARCELONA SHOOTS.

Shoot Length.(x).

Short Diameter (y). y.	1	2	3	4	5	6	7	8	9	10	11	12	f(y).
12												2	2
11											1		1
10			1						2	2		2	7
9					1	2	1	1	1	1			7
8					3	4	1	1					9
7		1	1	2	4	3	2	1					14
6			3	18	14	14	1						50
5	1	5	12	17	7	2							44
4	6	10	28	14	3								61
3	20	28	16	2	1								67
2	96	16	3	1					1				117
1	63	4				1							68
f(x).	186	64	64	54	33	26	5	3	4	3	1	4	447

KEY TO ARRANGEMENT OF TABLE VIII.

Shoot Length Variable(x)			Shoot Diameter Variable(y)		
C.	M-C.	C-R.	C.	M-C.	C-R.
1	2.5	0- 4.99	1	.175	.15-.199
2	7.5	5- 9.99	2	.225	.20-.249
3	12.5	10-14.99	3	.275	.25-.299
4	17.5	15-19.99	4	.325	.30-.349
5	22.5	20-24.99	5	.375	.35-.399
6	27.5	25-29.99	6	.425	.40-.449
7	32.5	30.34.99	7	.475	.45-.499
8	37.5	35-39.99	8	.525	.50-.549
9	42.5	40-44.99	9	.575	.55-.599
10	47.5	45-49.99	10	.625	.60-.649
11	52.5	50-54.99	11	.675	.65-.699
12	57.5	55-59.99	12	.725	.70-.749

EXPLANATION.

f(x). = Summation of Length Frequencies of Shoots.

f(y). = Summation of Diameter Frequencies of Shoots.

C. = Class Values.

M-C. = Mid-Class Values in Centimeters.

C-R. = Class-Range Values in Centimeters.

TABLE IX.

SUMMARY OF THE MEASURES OF VALUE FOR THE VARIABLES OF SHOOT LENGTH AND DIAMETER.

Variety.	My	P.E.	SDy	CVy	r	P.E.
Barcelona	30.5	±.35	11.	.361	.881	±.002
Merveille de Bolwyller	34.2	±.37	9.7	.284	.746	±.021
Nottingham	35.4	±.40	8.3	.235	.805	±.012
White Aveline	43.2	±.54	11.6	.268	.815	±.016
Average	35.8	±.41	10.2	.287	.812	±.013

KEY TO TABLE IX.

My = Mean Diameter in millimeters.

P.E. = Probable Error of Mean

SDy = Standard Deviation of Diameters, in millimeters.

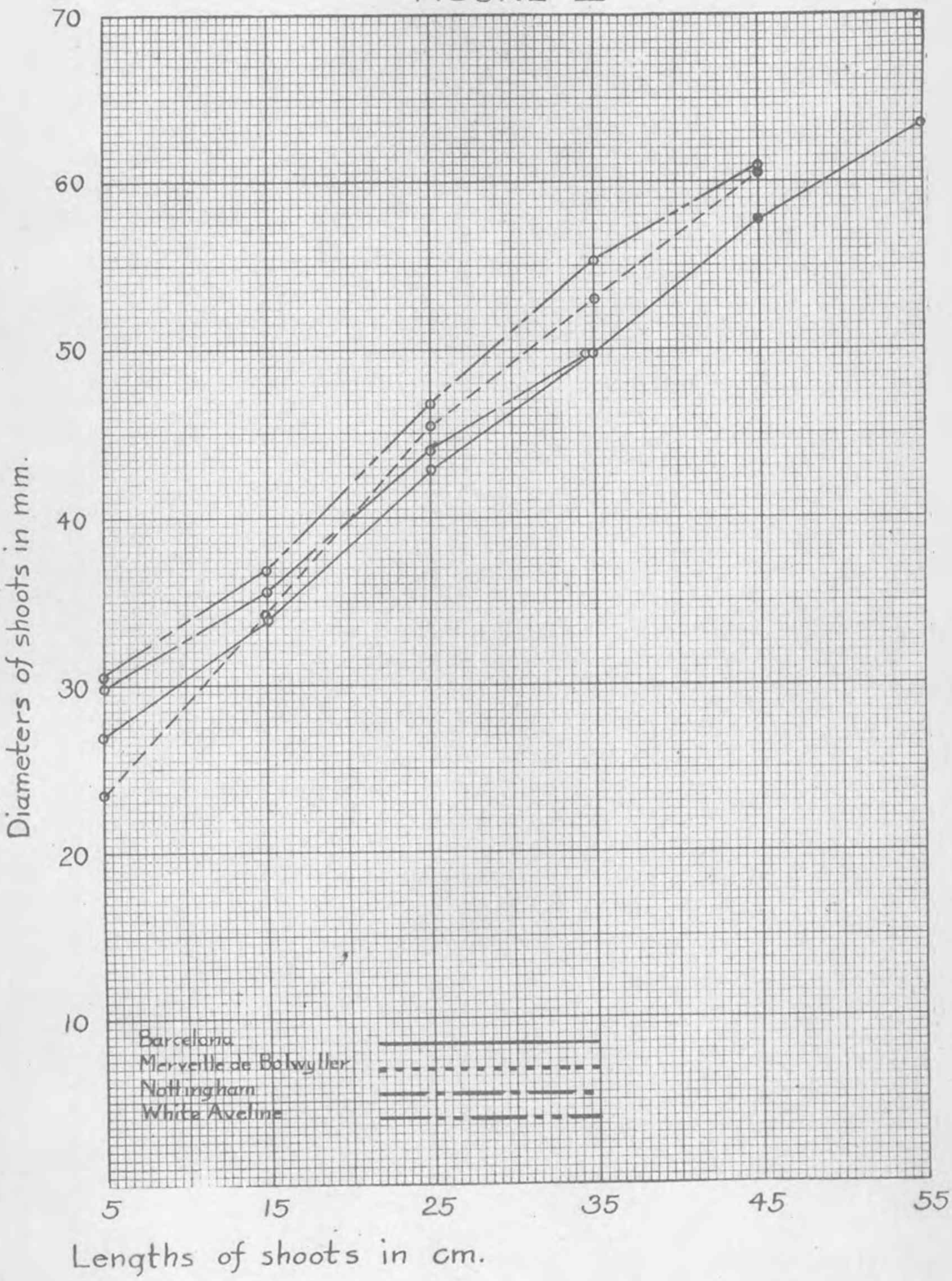
CVy = Coefficient of Variability of Diameters.

r = Coefficient of Correlation of Diameter and Length.

± = Plus or minus sign

Note - The values for the variable of Length have been given in Table V.

FIGURE III



EFFECT OF INCREASE OF AVERAGE LENGTH OF SHOOTS UPON THEIR DIAMETER

KEY TO FIGURE 3.

Heights of the Ordinates.

x.	1.	2.	3.	4.
5	27.2	27.0	29.9	30.5
15	33.8	34.0	35.4	36.8
25	42.9	42.0	44.0	46.8
35	49.7	53.1	49.7	55.3
45	57.8	60.5		60.8
55	63.5			

EXPLANATION.

x.= Mid-Class Lengths of Shoots, in Centimeters.

1.= Smoothed Averages of Shoot Diameters of Barcelona, in Millimeters.

2.= Smoothed Averages of Shoot Diameters of Merveille de Bolwyller, in Millimeters.

3.= Smoothed Averages of Shoot Diameters of Nottingham, in Millimeters.

4.= Smoothed Averages of Shoot Diameters of White Aveline, in Millimeters.

IS THERE A CORRELATION BETWEEN THE ANGLE OF A SHOOT AND FRUIT-BUD FORMATION?

Variations in the number of fruit-buds and the shoot diameter have been found to be independent effects of variation in the shoot length. What is the relation vetween these factors and the angle at which the fruiting wood departs from the mother shoots?

The regression lines, L_1 and L_2, plotted for the Barcelona, in Figure 4, are a typical example of the lack of correlation found between the variables of shoot angle and length. These "two lines of best fit" to the means of the arrays are perpendicular to each other and closely parallel to the axes of the table, as formed by the average means of the two variables, Mx and My. The regression lines for Merveille de Bolwyller were very similar to the Barcelona, but in the case of the White Aveline and Nottingham the lines of regression actually coincided with the axes - showing an even greater similarity of distribution of all parallel arrays.

The character of the regression lines, in the case of all varieties showed that the mean of the array did not depend upon the type, and that there is a similarity of distribution for all parallel arrays. Therefore there is no correlation between shoot angle and length, at least for the varieties studied.

In determining the correlation between shoot angle and the number of fruit-buds, the former was treated as the independent, and the latter as the dependent, variables. The slight degree of variability in the number of fruit-buds accompanying angle variations necessitated grouping the latter into large classes, with a range of twenty degrees. However, the correlation coefficient was computed from the class numbers.

Table XI. shows that the highest average number of fruit-buds were borne on shoots in the zero to twenty degree class, but, among the other classes, increases in shoot angle were generally accompanied by only slight decreases in the average number of fruit-buds. For example, the number of fruit-buds on the shoots in the zero to twenty degree class showed the following percentages of increase over the average of all of the rest of the classes; White Aveline, one-hundred-eight percent; Barcelona, seventy-eight percent; Merveille de Bolwyller, fifty-two percent; and Nottingham, twenty-eight percent.

Since those shoots growing at an angle from zero to twenty degrees are mostly terminals, or at least upper laterals, the higher average number of fruit-buds formed is probably due to better illumination and more nutrition. Apparently, whatever correlation there is between shoot angle and the number of fruit-buds is principally due to the favorable position, on the exterior of the tree and on the terminal portion of the mother branches, of those shoots making the least departure from the direction of growth of the parent shoot.

Figure 5 shows that there is a low to negligible degree of negative correlation between the variables of shoot angle and fruit-buds. The results in Table XII. may be illustrated by saying that increases in shoot angle will be accompanied by decreases in the number of fruit-buds in the following percentages of all cases: Merveille de Bolwyller, thirty-eight to forty-three percent; Barcelona, twenty to twenty-four percent; Nottingham, twelve to eighteen percent; White Aveline, seven to nine percent; and, on the average, only nineteen to twenty-six percent. Therefore the degree of correlation is, in most cases, almost negligible.

TABLE X.

CORRELATION TABLE FOR THE ANGLE AND NUMBER OF FRUIT-BUDS ON MERVEILLE DE BOLWYLLER SHOOTS.

Shoot Angle(x)

Number of Fruit-buds(y) y.	10*	30	50	70	f(y).
10	2	1			3
9	1	3		1	5
8	7	4			11
7	5	4			9
6	13	5	3	1	22
5	26	13	7		46
4	26	37	12	1	76
3	23	59	29	8	119
2	45	87	44	30	206
1	57	160	119	24	360
f(x).	205	373	214	65	857

KEY TO TABLE X.

x = The Angle Variable.

y = The Fruit-bud Variable.

f(x) = Summation of Angle Frequencies of Shoots.

f(y) = Summation of Fruit-bud Frequencies of Shoots.

*The true mid-class values in degrees are given for the angle variable, x. Class values of fruit-bud variables are the true class values, also.

TABLE XI.

MEAN NUMBER OF FRUIT-BUDS OF ANGLE ARRAYS.

Variety.	10*	30	50	70	90
Barcelona	2.92	2.50	2.10	1.95	1.56
Merveille de Bolwyller	3.16	2.28	1.85	1.95	
Nottingham	2.29	2.27	1.94	1.74	1.43
White Aveline	9.95	4.70	4.56	5.00	
Average	4.58	2.94	2.61	2.66	1.49

* Mid-class values in degrees.

TABLE XII.

SUMMARY OF THE MEASURES OF VALUE FOR THE VARIABLES OF SHOOT ANGLE AND NUMBER OF FRUIT-BUDS.

Variety	Mx.	P.E.	SDx.	CVx.	r.	P.E.
Barcelona	39.0	.515	24.0	.615	-.221	±.02
Merveille de Bolwyller	33.3	.400	17.4	.523	-.410	±.02
Nottingham	30.9	.520	19.4	.627	-.147	±.03
White Aveline	36.6	.400	18.2	.496	-.085	±.02
Average	36.9	.446	19.3	.522	-.090	±.02

KEY TO TABLE.

Mx. = Mean Angle in Degrees.

P.E. = Probable Error, or Deviation.

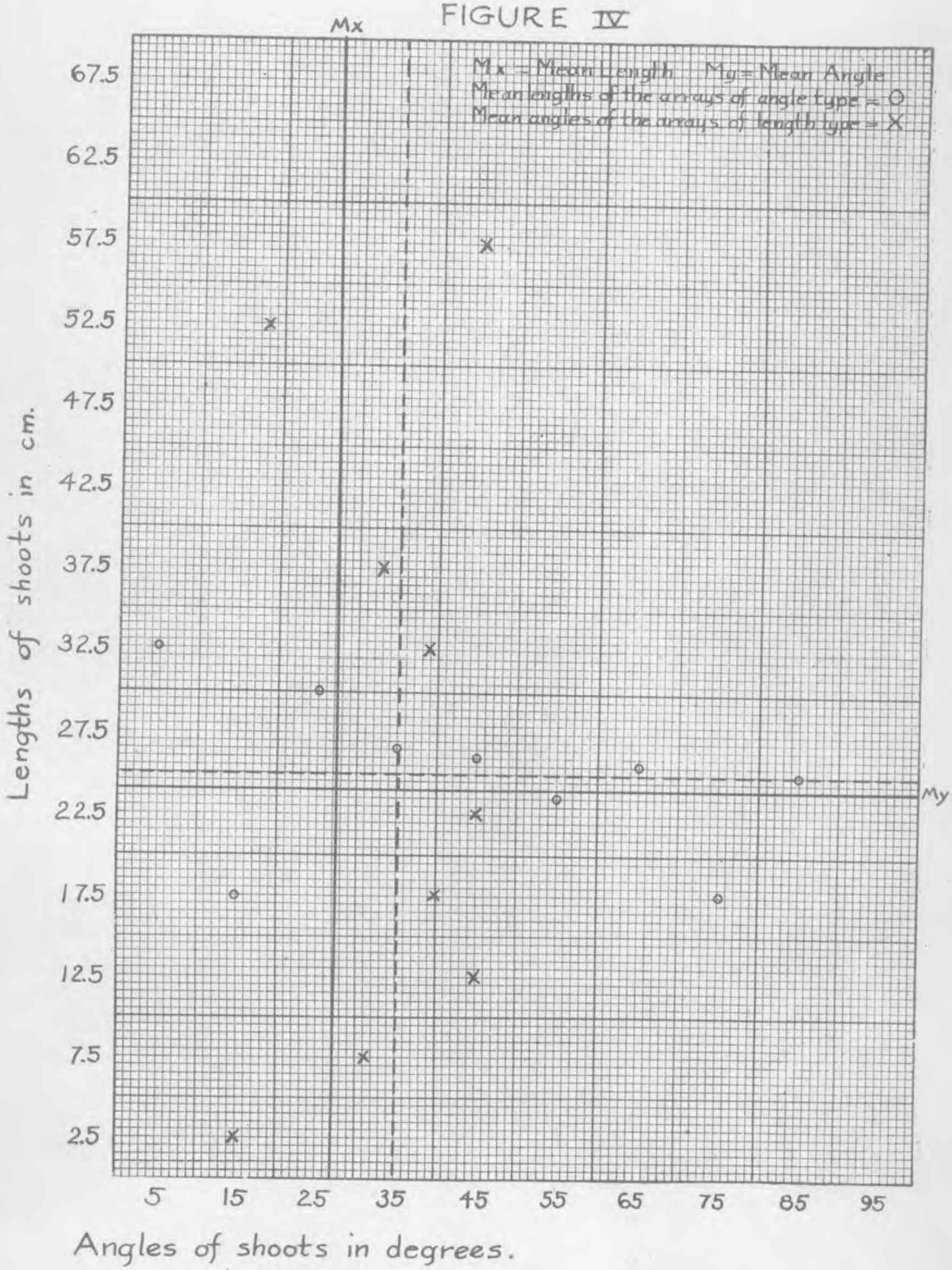
SDx. = Standard Deviation of Angles, in degrees.

CVx. = Coefficient of Variability of Angle Variable.

r. = Coefficient of Correlation of the two Variables.

±. = Plus or minus sign.

FIGURE IV



REGRESSION CHART SHOWING LACK OF CORRELATION BETWEEN ANGLE AND LENGTH OF SHOOT IN BARCELONA

KEY TO FIGURE 4.

Tx.	Myx.	Tx.	Myx.
5	32.5	55	23.5
15	17.5	65	25.5
25	30.0	75	17.5
35	26.5	85	25.0
45	26.0		

Ty.	Mxy.	Ty.	Mxy.
2.5	15.0	32.5	39.0
7.5	27.0	37.5	33.0
12.5	45.0	42.5	35.0
17.5	40.0	47.5	27.0
22.5	45.0	52.5	18.0
27.5	35.0	57.5	45.0

EXPLANATION

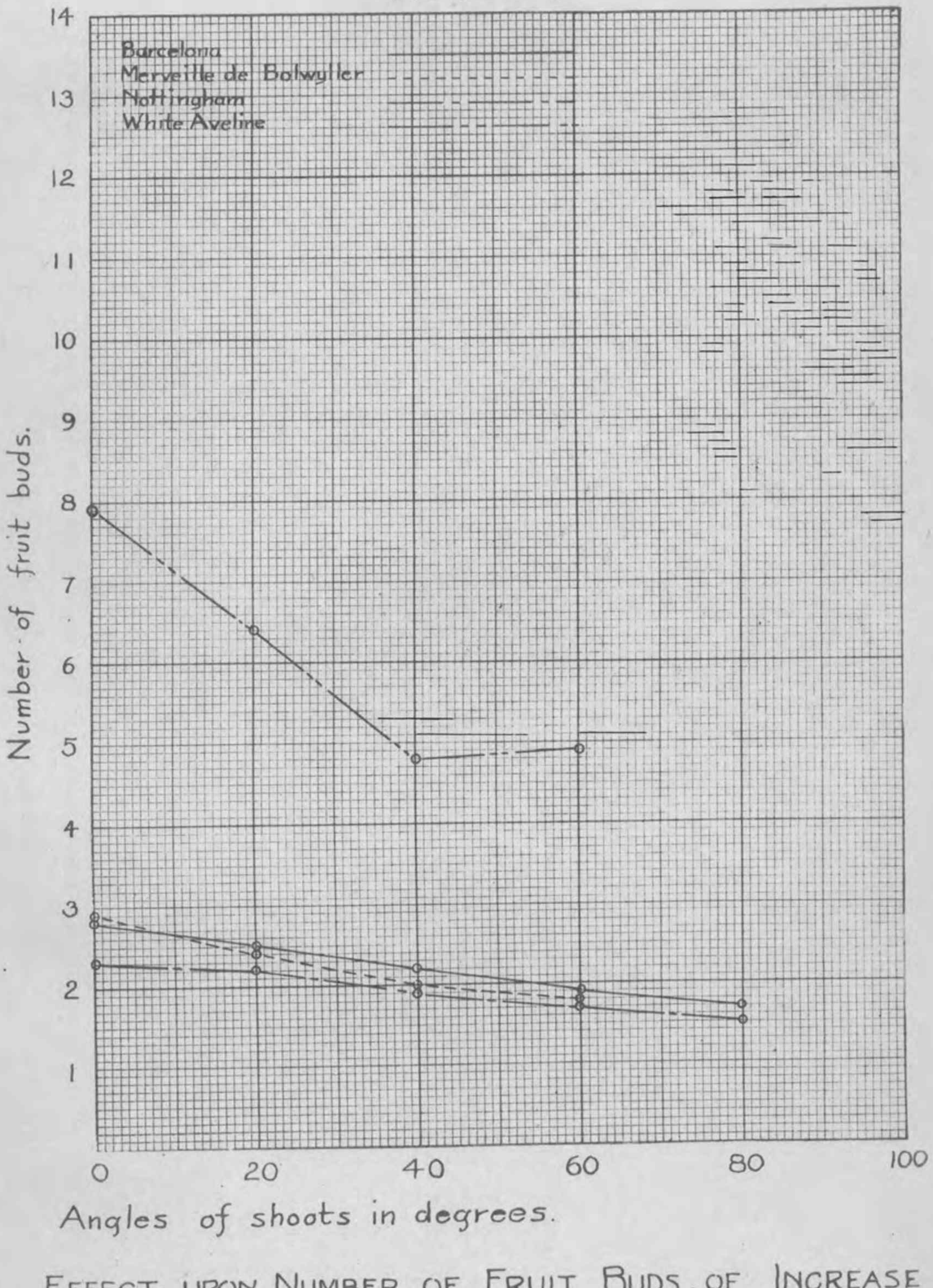
Tx.= Type x, or, the Mid-Class Angle Values, in degrees.

Myx.= Means of the y arrays of the x type, or, the Mean Shoot Lengths for each Angle array.

Ty.= Type y, or, the Mid-Class Length Values, in Centimeters.

Mxy.= Means of the x arrays of the y type, or the Mean Shoot Angles for each Length array.

FIGURE V



EFFECT UPON NUMBER OF FRUIT BUDS, OF INCREASE IN AVERAGE ANGLE OF SHOOTS.

KEY TO FIGURE 5.

Heights of the Ordinates.

x.	1.	2.	3.	4.
10	2.8	2.9	2.3	7.9
30	2.5	2.4	2.2	6.4
50	2.2	2.0	2.0	4.8
70	1.9	1.9	1.7	4.9
90	1.7		1.5	

EXPLANATION

x.= Mid-Class Angles of Bearing Shoots in Centimeters.

1.= Smoothed Averages of Numbers of Fruit-buds in the Angle Classes of Barcelona.

2.= Smoothed Averages of Numbers of Fruit-buds in the Angle Classes of Merveille de Bolwyller.

3.= Smoothed Averages of Numbers of Fruit-buds in the Angle Classes of Nottingham.

4.= Smoothed Averages of Numbers of Fruit-buds in the Angle Classes of White Aveline.

WHAT IS THE EFFECT OF THE POSITION IN THE TREE ON FRUIT-BUD FORMATION?

Yeager[24] found that the higher the apple spur was borne, in the tree, the greater the average production, and, that the exterior of the tree produced more fruit-buds per shoot than the interior. The effect of the position in the tree on fruit-bud formation was studied in a similar manner for the filbert.

Each tree was divided into five positions as shown in Tables XIII and XIV. The exterior of the tree was divided into three parts: the top, which included all the shoots borne over the top and a third of the way down; the upper perimeter, which included all shoots borne on the middle third of the tree; and the lower perimeter, including all shoots borne on the lower third of the tree. The interior of the tree was divided into two parts: central interior, which included all the upper inside shoots; and the lower interior, including the lower inside shoots.

Table XIII. shows that the most fruit-bearing shoots, with the largest total shoot growth and the greatest number of fruit-buds, are usually borne above the middle of the filbert tree, and on the exterior. In the case of the White Aveline, the greater total shoot growth found on the lower perimeter is unaccompanied by the two other factors, and is probably due to the more shrub-like character of this variety and a tendency to round out near the bottom.

The shoot averages obtained for the shoot length and the number of fruit-buds are recorded in Table XIV. These results show, with a few exceptions due to the natural variability of the data and to various extraneous factors, that the exterior of the tree produces a far longer average shoot than the interior, and that the higher the shoot the longer. Consequently, the same relationship is to be found with the average numbers of fruit-buds.

Since the average shoot lengths for each position are different, there is no basis of comparison as to the specific influence of the position of the shoot on fruit-bud formation. Therefore, the average number of fruit-buds obtained for the average shoot length of a position was compared with the varietal average, for that shoot length and the deviation recorded.

The results in Table XIV. show that the increases in average shoot lengths were accompanied, in most cases, by increases in productiveness. The lowest average shoot lengths, such as those in the interior of the tree, had the greatest negative deviation from the varietal average, for the number of fruit-buds. Although such factors as natural variability, varietal, and individual characteristics, method of pruning, etc., exert considerable effect upon the character of any such data as this, the general conclusion seems warranted, that the upper part of the tree is the most productive. Probably the principle reason for this is that the better illumination favors increased photosynthesis, although other factors, such as nutrition for instance, have been shown to play an important part in fruit-bud formation.[12.]

TABLE XIII.

TOTALS OF SHOOTS, LENGTHS, AND FRUIT-BUDS FOUND IN DIFFERENT POSITIONS IN THE FILBERT TREES.

	(Barcelona).			(Merveille de) (Bolwyller.)			(Nottingham).			(White Aveline).		
Position	Sx.	Sy.	n.	Sx.	Sy.	n.	Sx.	Sy.	n.	Sx.	Sy.	n.
Top Third.	5160	653	223	3892	606	222	3861	556	221	4202	1198	172.
Upper Perimeter.	5735	816	289	3493	575	218	3856	516	232	2431	1209	252.
Lower Perimeter.	4364	543	226	1985	264	113	1862	225	130	4932	974	217.
Central Interior.	2008	389	195	1169	168	93	690	80	45	4676	527	138.
Lower Interior.	845	127	79	320	41	30	179	23	18	1429	251	81

KEY TO TABLE.

Sx. = Summation of Total Lengths of Shoots in Centimeters.

Sy. = Summation of Total Number of Fruit-buds.

n. = Number of Shoots in each position.

TABLE XIV.

EFFECT OF POSITION IN THE FILBERT TREE ON FRUIT-BUD FORMATION

	(Barcelona).			(Merveille de) (Bolwyller.)			(Nottingham).			(White Aveline).		
Position	Mx.	My.	ȳ.	Mx.	My.	ȳ.	Mx.	My.	ȳ.	Mx.	My.	ȳ.
Top Third.	23.2	2.9	+.1	17.5	2.7	+.40	17.5	2.5	+.4	24.5	7.0	+1.6
Upper Perimeter.	19.8	2.8	+.1	16.0	2.6	+.30	16.6	2.2	+.1	18.5	4.8	+0.5
Lower Perimeter.	19.3	2.4	-.3	17.6	2.3	-.04	14.3	1.7	0	22.7	4.5	-0.9
Central Interior	10.3	2.0	0	12.5	1.8	-.05	15.3	1.8	-.3	17.6	3.8	-0.5
Lower Interior	10.7	1.6	-.4	10.7	1.4	-.40	9.9	1.3	-.1	17.6	3.1	-1.2

KEY TO TABLE.

Mx = Mean Length of Shoot in Centimeters.

My = Mean Number of Fruit-buds per Shoot.

ȳ. = Positive(+) and Negative(-) Deviations of Mean Number of fruit-buds from Varietal Average for the Mean Length.

WHICH SIDE OF THE TREE IS THE MOST FAVORABLE FOR FRUIT-BUD FORMATION?

Yeager[24] found that the most productive apple spurs and the best fruit were borne in the south quarter of the tree, followed by the west, east, and north quarters. The effect of latitude on fruit-bud formation was studied in a similar manner for the filbert. The term, latitude, is used in a restricted sense as a synonym for the side.

The data from all the trees were used. Only shoots on the upper perimeter where there is good light exposure, were selected.

Barcelona was the only variety in which the differences in fruit-bud formation are consistent with differences in latitude. Table XV. shows that this variety had the most fruit-bearing shoots, the largest total shoot growth, and the greatest number of fruit-buds on the north side of the tree, followed by the south, west, and east sides. Table XVI. shows that the longest average shoot and the largest average number of fruit-buds are also to be found on the north side, followed by the other quarters in the above order.

However, deviations from the varietal average number of fruit-buds, for the different average lengths of Barcelona shoots, show that the shoots on the north side of the tree are the least productive for their length. In other words, on comparing shoots of equal length with the varietal average as to their number of fruit-buds: forty percent more than this average will be found in the south quarter; ten percent more in both the east and west quarters; and thirty percent less in the north quarters.

The results in the case of the Barcelona seem to verify, at least to some extent, those of Yeager[24], in showing that on the south side, where there is the greatest light supply, there are the best conditions for fruit-bud formation. In this case, however, the greater vegetative growth on the north side has overcome this handicap by having a sufficiently greater average shoot length. Evidently the slightly more limited light supply of the north side favored vegetative growth more than it inhibited fruit-bud formation.

A study of the other three varieties reveals no variations that could be attributed to differences in illumination. Apparently these differences have not been sufficient to overcome accidental variations, or the natural variability, and the various other extraneous factors.

The effect of light intensity is illustrated by the experiments of Vinson[22] who found that shade grown plants had longer internodes, slenderer stems, larger, thinner leaves, and less productiveness, with the exception of the raspberry, than those grown in open sunlight. In other words, shade favored long vegetative growth and inhibited fruit-bud formation.

The only justifiable conclusion, from the results in Tables XV. and XVI., is that the differences in illumination between the filbert shoots, on the different sides of the tree, were usually insufficient to cause any consistent variation in shoot length, or productivity.

TABLE XV.

TOTALS OF SHOOTS, LENGTHS, AND FRUIT-BUDS FOUND ON THE NORTH, EAST, SOUTH, AND WEST SIDES OF THE FILBERT TREES.

	(Barcelona).			(Merveille de) (Bolwyller.)			(Nottingham)			(White Aveline)		
Latitude	Sx.	Sy.	n.	Sx.	Sy.	n.	Sx.	Sy.	n.	Sx.	Sy.	n.
North.	1658	203	65	921	171	57	764	122	46	1258	312	58
East.	1138	172	61	740	112	42	1226	166	75	1119	317	50
South.	1240	261	111	1219	188	72	965	118	57	865	231	43
West.	1337	180	59	607	105	36	814	103	50	938	229	36

KEY TO TABLE.

Sx. = Summation of Total Lengths of Shoots in Centimeters.

Sy. = Summation of Total Number of Fruit-buds.

n. = Total Number of Shoots in each Position.

TABLE XVI.

EFFECT OF LATITUDE OF SHOOTS ON FRUIT-BUD FORMATION.

Latitude.	Mx.	My.	$\bar{y}$.	Mx.	My.	$\bar{y}$.	Mx.	My.	$\bar{y}$.	Mx.	My.	$\bar{y}$.
North.	25.5	3.1	-.3	16.2	3.0	+.6	16.6	2.7	+.6	21.7	5.4	0
East.	18.7	2.8	+.1	17.6	2.7	+.3	16.3	2.2	+.1	22.4	6.3	+0.9
South.	11.2	2.4	+.4	17.0	2.6	+.2	17.0	2.1	0	20.1	5.4	0
West.	22.7	3.1	+.1	16.8	2.9	+.5	16.3	2.1	0	26.0	6.4	+1.0

KEY TO TABLE.

Mx = Mean Length of Shoot in Centimeters.

My = Mean Number of Fruit-buds per Shoot.

$\bar{y}$. = Positive(+) and Negative(-) Deviations of Mean Number of Fruit-buds from Varietal Average for the Mean Length.

Note. = Only Shoots in the same relative position, on the Upper Perimeter, were compared. This eliminated any difference due to Position.

PRACTICAL APPLICATION.

The results of the foregoing analysis of statistical data, from typical trees of a few of the most popular varieties, leads to the following recommendations for the pruning of healthy young filbert trees of bearing age.

The shoot length has been shown to be a better single index of the number of fruit-buds than the shoot diameter. Therefore, when thinning, choose shoots more on the basis of their length than their diameter.

Short shoots, under twenty centimeters or eight inches in length, should be chosen in preference to the longer shoots because the shorter internodes give a larger amount of leaf area per unit of growth. Hence the buds of the short shoots receive the most nourishment and form the highest percentage of fruit-buds. Harvey and Murneek[12] have said that the most important factor involved in fruit-bud formation is generally assumed to be the nutritive supply to the bud primordia.

There should be enough thinning to keep all parts of the tree open sufficiently to give the optimum amount of illumination to the bearing wood. This will overcome any specific influence due to the angle of departure of the young shoot from the mother branch. Apparently light was the primary cause of any correlation obtained between the shoot angle and the number of fruit-buds.

The fact that the most productive wood is found on the outside of the tree, in the best lighted parts, demonstrates the need of illumination in fruit-bud formation. This could be attained by developing a loosely built tree in which the upper third is by far the thinnest; the central third somewhat denser but thin enough to allow sufficient light to reach the lower branches; and the lower third as compact as possible, without competition among the individual shoots.

Long[16] says that building a tree loosely and keeping it vigorous and properly thinned-out is of first importance in maintaining active fruiting-wood.

A consistent thinning-out program followed from year to year seems the best adapted to profitable productiveness in the filbert. Heading-back and removing large branches should be avoided, as far as possible, because of the encouragement to unproductive sucker-like shoots, with long internodes. Only where the laterals are tending to take the lead away from the central leader, or, are interfering with cultivation, should there be much, if any, heading-back.

Since all picking is from the ground and the weight of the crop does not tax the branches, the natural development of the tree may be allowed, so long as the lower wood remains productive and can be sufficiently illuminated. Hence if the trees are planted the right distance apart, twenty-five to thirty feet, they may be allowed to grow and spread almost at will.

Even where the tree is slowing up in productiveness fertilization might be a better practice than any great amount of heading-back.

SUMMARY OF RESULTS.

The results of this investigation may be briefly summarized, as follows:

1. There was a fair degree of positive correlation between the male catkins and the number of fruit-buds, per shoot, in the case of Barcelona.
2. In all varieties, there was a high degree of positive correlation between the shoot length and the number of fruit-buds, per shoot.
3. In all varieties, the correlation between the shoot length and the number of fruit-buds, per shoot, was higher for the short shoots, under twenty centimeters, or eight inches, than for the long shoots - in most cases considerably higher.
4. The correlation ratios for the Barcelona show that the variables of shoot length and the number of fruit-buds, per shoot, are about equally dependent upon each other. Increases in the one are about as

liable to be accompanied by increases in the other as vice-versa.

5. In all the varieties, the extremely high degree of positive correlation between the shoot length and the diameter, accompanied by the lack of any independent correlation with the number of fruit-buds, per shoot, shows that the diameter of a shoot is a very good index to its length.
6. There was no correlation between the length of a shoot and its degree of departure from the mother branch.
7. In all cases, except the Merveille de Bolwyller, there was an almost negligible degree of negative correlation between a shoot's angle and its number of fruit-buds.
8. Better illumination resulted in the upper third of the tree being the most productive.
9. In all cases, except Barcelona, the variations in illumination and shade found on the different sides of the trees were insufficient to cause any consistent variability in the number of fruit-buds formed on the shoots.

(For a summary of the correlation coefficients, see the following table.

TABLE XVII.

SUMMARY OF CORRELATION COEFFICIENTS.

Variety.	A.S.	S.S.	L.S.	A.	M.C.	L. & D.
Barcelona.	.615±.013*	.554±.018	.338±.03	-.221±.02	.407±.03	.881±.002
Merveille de Bolwyller.	.770±.028	.590±.094	.436±.04	-.410±.02		.746±.021
Nottingham.	.527±.020	.395±.030	.273±.01	-.147±.03		.805±.012
White Aveline.	.625±.014	.605±.020	.192±.03	-.085±.02		.815±.016
Average.	.634±.014	.536±.290	.309±.02	-.090±.02		.812±.013

*Plus or minus the Probable Error.

KEY TO TABLE XVII.

A.S. = Correlation of Fruit-buds and Shoots of all Lengths.

S.S. = Correlation of Fruit-buds and Short Shoots.

L.S. = Correlation of Fruit-buds and Long Shoots.

A. = Correlation of Fruit-buds and Shoot Angle.

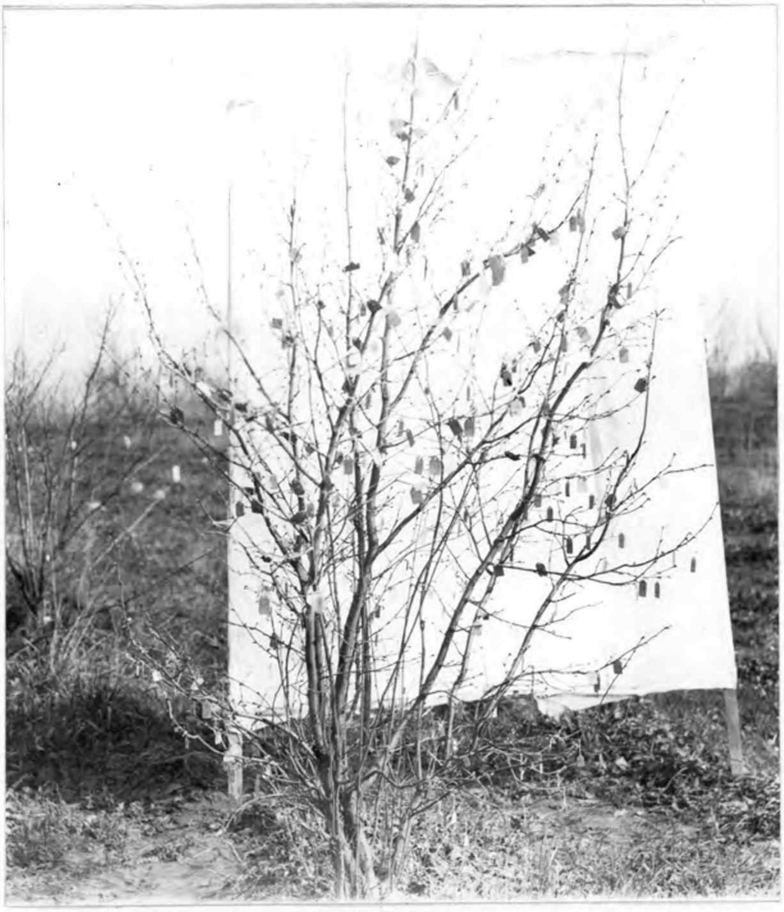
M.C. = Correlation of Fruit-buds and Male Catkins.

L. & D.= Correlation of Shoot Length and Shoot Diameter.

PLATE I

Filbert tree in the winter_time, showing the male catkins.

PLATE II



Filbert tree, showing the paraffined marking tags used to identify the shoots.

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