5-1962

Estimation of Optimum Plot Size and Shape for Use in Safflower Yield Trails

Alfred Max Wiedemann
Utah State University

ESTIMATION OF OPTIMUM PLOT SIZE AND SHAPE FOR USE IN SAFFLOWER YIELD TRIALS

by

Alfred Max Wiedemann

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Agronomy

UTAH STATE UNIVERSITY
Logan, Utah

1962

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I would like to express my appreciation to the National Science Foundation for providing the funds which made my graduate work and this study possible.

Furthermore, I would like to express my thanks to Dr. L. N. Leininger for his guidance and help in the writing of this thesis; and to Dr. D. R. McAllister for his assistance in planning my work, both as an undergraduate and as a graduate student.

INTRODUCTION

One of the big problems encountered in experimental yield trials of field crops is the variation that occurs in yield estimates regardless of how the trial is handled with respect to variety or treatment. This so-called "natural" variation is the result of such factors as heredity, human error, and environment.

The factor of environment is particularly important, especially as it pertains to the heterogeneous nature of the soil of a given field. Almost any experimental site will vary in fertility from one area to the next, thereby causing a considerable variation in yield from one plot to the next even though elaborate attempts are made to remove all variation.

Variance in yield will fluctuate according to the size and shape of the plots, generally decreasing with increasing plot size. However, not all plot sizes and shapes are equally efficient from the standpoint of cost of operation, so an effort must be made to determine the minimum variance along with the minimum cost.

Each field crop must have this optimum plot size and shape determined for it. Since very little work has been done on safflower in this respect, it will be the purpose of this study: (1) to determine the safflower plot size and shape which will give the least variation possible and still produce the information desired in an experiment where all of the plots are alike with respect to variety and treatment; and (2) to correlate cost figures with plot size and shape to obtain information regarding the most economical plot size and shape consistent with the minimum levels of natural variation desired.

To achieve these purposes three different methods will be used. Two have been quite extensively used in the past by other investigators working on this type of problem with other crops, while the other method has been only recently proposed.

REVIEW OF LITERATURE

The effect of environmental factors such as soil heterogeneity upon experimental field crop trials has been recognized for quite some time. Many early workers were concerned with the reliability of results taken from small field plots. Alwood and Price (1890) recognized that while the objective in experimental work was to use plots as small as possible, more reliable results were obtained when larger plots were used. The American Society of Agronomy (1918, 1931, 1932, 1933) in a series of reports recommended the use of long narrow plots running perpendicular to the fertility gradient of the field, and of a size sufficient to minimize the effects of differences in soil fertility, stand, and in harvesting and threshing.

In one of the first studies to determine the experimental error of field trials, Mercer and Hall (1912), working with mangels, used the concept of probable error to analyze variation in field experiments. Probable error, according to Davenport (1907), is a confidence interval within which a true value has an even chance of occurring. Mercer and Hall determined optimum plot size on the basis of a curve relating plot size and per cent deviation, concluding that one-fortieth of an acre was the best size because at this point the curve flattened out; that is, the per cent standard deviation increased only by very small amounts after this point. However, as Federer (1955) points out, this method has a weakness in that the point of maximum curvature is not independent of the smallest unit selected, or of the scale of measurement used. Biased conclusions could, therefore, result.

Probable error was also used by Love (1919), Kiesselbach (1919), and Day (1920) in determining the extent of experimental error. Day concluded from his work that the greatest accuracy can be obtained from long, narrow plots lying in the direction of the greatest soil variation, and that square plots should be used if the soil variation were not known. He recommended that plots be at least one-twentieth of an acre in size in order to reduce variation to a minimum.

Gerber _et_ _al_. (1926) considered soil heterogeneity as the most important factor in causing yield variation. Working with oats and hay he found a correlation between contiguous plots, but not between replicated plots in the same field, indicating "a field uneven in its productive capacity."

The importance of soil heterogeneity was also recognized by Christidis (1931). He concluded that the use of long plots constituted the only means of reducing the effect of "patched heterogeneity." He proposed a width:

length ratio for plot shape, claiming that the smaller the ratio used, the less would be the variation encountered.

McClelland (1926) working with corn, and Odland and Garber (1928) working with soybeans, both used uniformity trial data in determining optimum plot size. McClelland used basic plots one-one hundred eightieth of an acre in size, combining them in various forms, and determining the per cent error for each combination. He listed this per cent error as the coefficient of variation, and he found a 30 per cent reduction in error in going from a one-thirtieth of an acre plot size to a one-half acre plot size.

Odland and Garber used eight foot rows as the basic units, and the standard deviation as the measurement of variability. They found that 16 foot rows gave the greatest reduction in error. Neither of these two studies considered the cost of operation in determining plot size.

A fertility contour map was used by Immer (1932) to show the soil heterogeneity of a field of sugar beets with which he was working. In conjunction with this, he calculated the efficiency of plots of varying size and shape on the basis of variance per unit area of land. Considering that efficiency in land use decreases with increasing size of the plot, Immer concluded that while the standard error decreased as size of plot increased, the reduction was not proportional to increased size, thereby resulting in reduced efficiency.

Up to this point, most data used to determine optimum plot size were analyzed by studying either probable error, standard deviation, or coefficient of variability in relation to plot size. Smith (1938), using data from a uniformity trial with wheat, proposed a new method of determining optimum plot size. From a total of 1080 basic plots, each one-half by one foot in size, he obtained a measure of the soil heterogeneity by computing the regression of the logarithm of the variance per unit area on the logarithm of plot size. The regression coefficient "b" was considered by him to describe both the soil and plant heterogeneity of the observed field. He then worked out two cost factors, one estimating the part of the total cost proportional to the number of plots in the test area; and the other estimating the part of the total cost proportional to the size of the test area. Using the regression coefficient and the cost factors, he developed a formula which estimates optimum plot size in terms of the basic unit. For the wheat data used in the study, Smith found optimum plot size to be five feet square, with the shape of the plot having no consistent effect upon the variance.

In another approach, Keller (1949) used the comparable variance method of determining optimum plot size. Working with hops, he used 750 hills as the basic plots. The variance between the 750 hills was assumed to contribute 100 per cent information. The between plot variance was calculated for each of the 26 combinations of plots, and this variance was divided by the number of hills per plot so that the variance could be compared with that of the individual hill plots. He found that comparable variance increases and relative information decreases as the size of the plot increases. As the plot size increased beyond five hills, the decrease in relative information became very small, and therefore Keller recommended five hill plots as being the optimum size. He did not consider cost except to note that as the number of hills per plot increased, the cost of collecting the data increased considerably.

Using the method proposed by Smith (1938), Wassom and Kalton (1953) estimated optimum plot size for bromegrass using uniformity trial data. A total of 1296 basic plots, each $3\frac{1}{2}$ by 4 feet in size, were harvested and combined in 23 different ways. The cost factors and the average regression coefficient "b" was determined, and an optimum plot size of 1.86 basic units, or $3\frac{1}{2}$ by $7\frac{1}{2}$ feet, was calculated from the formula derived by Smith. Significant differences in the variances of differently shaped plots were determined through the use of a two-tailed F-test. These tests indicated generally that the variances were smaller when the plot was long in the direction of the fertility gradient.

Brim and Mason (1959) also used the procedure of Smith (1938) in estimating optimum plot size for soybean yield trials. This was estimated as 3.1 times the basic unit, which was 3 by 8 feet in size.

In the only study dealing with safflower, Draper (1959) used basic plots of two sizes: four-foot single rows and five-foot single rows. On the basis of comparable variance, and without regard to cost factors, optimum plot size was 3.33 by 18 feet for the five-foot basic plots; and 3.33 by 12 feet for the four-foot basic plots. Calculating cost factors and utilizing the formula derived by Smith (1938), he found the optimum plot size for safflower to be 3.33 by 25 feet.

In an entirely different approach to the relationship between plot size and soil variability, Hatheway (1961) contends that research agronomists are more interested in the convenience and efficiency of a plot size than they are in its cost. On this basis, he outlines a method of determining plot size if the regression coefficient, the coefficient of variation, the number of replications desired, the level of significance, and the size of the difference that it is desired to detect are all known, or can be readily calculated. This method expresses plot size independent of costs.

METHOD OF PROCEDURE

Agronomic Data

A safflower uniformity trial planted at the Utah State University Field Station, Farmington, Utah, furnished the data for this study. The safflower variety, US-10, was planted in April of 1960 on a plot of land approximately one-half acre in size. The soil in the field was not too uniform, having a clay soil in about the northern third of the field, and a somewhat gravelly soil in the other two-thirds of the field. No fertilizer was applied, and the field was thoroughly watered by furrow irrigation five times during the growing season. The climate and length of growing season were normal for that area of the state.

The dimensions of the field were 114 feet wide and 189 feet long. The rows were planted 22 inches apart with a four-row sugar beet planter which had been adapted for use with safflower seed. The rate of seeding was 15 pounds per acre, and a fairly uniform stand was obtained. There was a total of 62 rows which ran in the long dimension of the field in an east-west direction.

The plots which were to constitute the basic units of the study were not marked off prior to harvest. When the field was ready for harvest in September of 1960, four rows were taken off from each side of the field, and 12 feet from each end to eliminate border effects. The seed from these areas was not weighed.

In harvesting the plots, work was begun from the west end of the field, and proceeded in the following manner. A wire was stretched the width of the field at the edge of the standing safflower. Beginning from the south side, a five-foot stick was laid along each row, and the safflower cut with a hand clipper for that length. The plants were carried to a stationary plot thresher where the seed from each five-foot section of row was threshed, weighed, and recorded separately. Yield was recorded on a field weight basis to the nearest gram. The seed was bulked immediately after its weight was recorded. The row of plots from south to north was designated a range, and as each range was completed, the wire was moved east 5 feet until all 33 ranges were harvested.

Comparable Variance

This procedure gave a total of 1782 one row, five-foot plots which were considered the basic plots for this study. Contiguous plots were then combined from west to east and from south to north (see Appendix, Figure 7, for a diagram showing the layout of the field) in a total of 32 different combinations; and the among plot variances of these different combinations computed. These among plot variances were designated $V_{(x)}$. The among plot variances were then divided by the number of basic units per plot to give the comparable variance, designated as V.

The comparable variances were in turn divided by the number of basic units per plot (x) to give the variance of yield per unit area. This was designated V_x. Combined with the previous method for finding the comparable variance, V_x can be computed directly by the following relationship:

$$V_x = \frac{V(x)}{x^2}$$

The variance of the yield per unit area (V_x) is used in the next section to compute the regression coefficient.

To obtain a measure of relative information, the comparable variances for all plot sizes were compared to the plot size having the smallest comparable variance. This method has been used by several investigators, among them Keller (1949) and Wassom and Kalton (1953).

The Regression Coefficient and Cost Factors

Optimum plot size was also determined taking into account the soil heterogeneity and relative costs. In deriving this method, Smith (1938) showed that an empirical relationship existed between plot size and plot variance. He characterized this relationship with the equation:

$$V_x = \frac{V_1}{x^b} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where V_x is the variance of the yield per unit area among plots which are x units in size; V_1 is the variability among the basic units; and b is a regression coefficient providing a measurement of the soil heterogeneity.

The regression coefficient will vary between zero and plus or minus infinity. Values greater than one are different to interpret, so only those values between zero and plus or minus one, indicating complete correlation and no correlation respectively between plots, are considered useful.

A value close to zero indicates a very uniform field, while a value near one would indicate a field very heterogeneous in soil fertility. The regression coefficient will be constant for any given crop on any given field, but it will vary from crop to crop and from year to year.

When equation (1) is expressed in logarithmic form, it becomes:

$$\log V_x = \log V_1 - b \log x$$

and from this b can be estimated as the linear regression coefficient.

In order to use b in conjunction with relative costs to estimate optimum plot size, two cost factors, K_1 and K_2, must be determined. K_1 is the cost proportional to the number of plots in the test area; and K_2 is the cost proportional to the total test area. These cost factors were determined from information supplied by individuals experienced in working with safflower, and represent the most convenient and usual methods used in safflower yield trials.

The optimum size of plot in number of basic units was then calculated by substituting the calculated values of b, K_1, and K_2 into the formula derived by Smith:

$$x = \frac{bK_1}{(1-b)K_2}.$$

The resulting calculated value of x gave the optimum plot size in number of basic units, without regard to the shape of the plot. The optimum shape was then determined by a comparison of variances of the different plot shapes that could be made up with that number of basic units; and by a consideration of the convenience with which each of the variously shaped plots could be handled.

Convenient Plot Size

The most convenient plot size depends upon factors other than the cost and the regression coefficient done. Utilizing data from the previous sections, convenient plot size was estimated by use of the formula suggested by Hatheway (1961):

$$x^b = \frac{2(t_1 + t_2)^2 \, C_1^2}{r \, d^2}$$

In this formula, x is the optimum plot size expressed in multiples of the basic unit, and b is the regression coefficient that was calculated previously. C_1^2 is the square of the coefficient of variation of plots one basic unit in size. The value d^2 is the square of the difference between treatments or varieties that it is desired to detect, and r is the number of replications desired. The values t_1 and t_2 are read from the t-table, and depend upon the level of significance desired, and upon the degrees of freedom available for estimating error.

The required data was supplied by safflower researchers, and is such that it represents the most common and desireable procedures in conducting safflower yield trials.

Here again plot shape was determined on the basis of variances and convenience in handling, since the calculated value of x gave only the multiples of the basic units to be used without regard to plot shape.

RESULTS AND DISCUSSION

The 1782 basic plots which comprised the entire harvested area of the experimental field each had dimensions of 1.8 feet wide by 5 feet long. These basic plots were added together so as to produce 32 different combinations of row by range. The maximum width used was six rows, or 11 feet, while 11 ranges, or 55 feet, was the maximum length used. Except for the single row plots, only combinations using two, four, or six rows were used, since plots of this width could be conveniently handled with the planting and harvesting equipment available.

These basic plots varied considerably in productivity in that about one-third of the rows on the north end of the field had an average production of twice that of the other rows. This increased yield might be explained by the higher clay content of this section of the field, which in turn could have caused a higher water retention than was possible in the rest of the field where a gravelly or sandy soil predominated. The productivity of the field from east to west, the direction of water flow, was relatively uniform as measured by the total yield of each range.

As a result of this yield differential, a remarkable inconsistency developed as the data were analyzed. The regression coefficient b, which is a measure of soil heterogeneity, was calculated as being 0.1 for this field. This would seem to indicate a field with an almost perfectly uniform soil. At the same time, the coefficient of variation for the basic plots was computed as 39.5 per cent. Even on the maximum sized plots, the coefficient of variation was reduced by only 10 per cent—to 29.5 per cent.

The effect of this disproportionate yield between the two sides of the field was to increase the variance per unit area by a large amount. This, in turn, decreased the total change in the logarithm of the variance, giving a very small regression coefficient. Figure 1 is a scatter diagram showing the regression of the logarithm of the variance of yield per unit area on the logarithm of size of plot.

The difference in yields so inflated the variance per unit area that an accurate estimate of b was not possible. It also caused the unusually high coefficient of variation. On this basis it was decided to exclude the northern third of the field from the analysis. This left a total of 36 rows, or 1188 basic plots, to determine optimum plot size. The same combinations of basic plots were used except that all those involving the last 18 rows were excluded. This excluded area is noted in Figure 7, and in Tables 7 and 8 in the Appendix. Table 9 in the Appendix contains the analysis of the data from the 1782 basic plots.

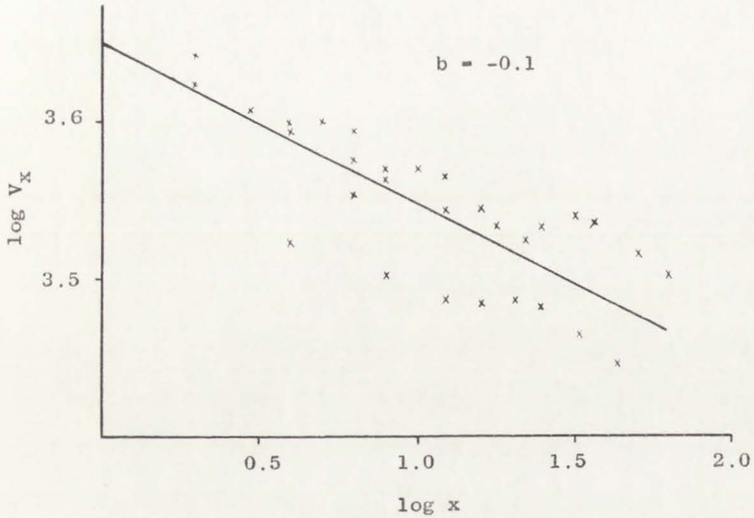

Figure 1. Regression of the logarithm of the variance of yield per unit area on logarithm of size of plot for 1782 basic units

The results of the analysis of the data from the 1188 basic plots will be presented and discussed in four sections: comparable variance; soil heterogeneity and relative costs; convenient plot size; and plot shape.

Comparable Variance

For each of the 32 different sizes of plots, an among plot variance ($V_{(x)}$) was calculated using standard methods. In order to compare these variances on a per plot basis, each among plot variance was divided by the number of basic units making up the plot. This gave the comparable variance (V). To obtain the variance of the yield per unit area (V_x), each among plot variance was divided by the square of the number of basic units making up the plot.

The comparable variance of each plot size was compared to the basic unit as per cent relative information. The variance of the basic units was assumed to contribute 100 per cent relative information. Many of the plots were of such a size and shape that not all of the 1188 basic plots could be used in the combinations. All of the plots not used in these combinations were on the east end of the field. The per cent of the total area used was calculated for each plot size. All of the information derived from these calculations is listed in Table 1, along with the coefficient of variation and the regression coefficient for each plot size.

Table 1. Comparable variance, variance of yield per unit area, relative information, coefficient of variation and regression coefficient for the 32 combinations of plot size and shape of 1188 basic units

No. basic units (x)	Shape (row by range)	No. of plots	Area used (%)	Among plot variance ($V_{(x)}$)	Comparable variance (V)
1	1x1	1188	100	1365	1365
2	1x2	576	97	3844	1922
2	2x1	594	100	3738	1869
3	1x3	396	100	7530	2510
4	1x4	288	97	12035	3019
4	2x2	288	97	11352	2838
4	4x1	297	100	11165	2791
5	1x5	216	91	16796	3359
6	1x6	180	91	20723	3454
6	2x3	198	100	22730	3788
6	6x1	198	100	19536	3256
8	1x8	144	97	34061	4258
8	2x4	144	97	36835	4604
8	4x2	144	97	36396	4550
10	2x5	108	91	52909	5291
11	1x11	108	100	54467	4952
12	2x6	90	91	64813	5401
12	4x3	99	100	73823	6152
12	6x2	96	97	64866	5406
16	2x8	72	97	104304	6519
16	4x4	72	97	122414	7651
18	6x3	66	100	132442	7358
20	4x5	54	91	178421	8921
22	2x11	54	100	165155	7507
24	4x6	45	91	214956	8957
24	6x4	48	97	225112	9380
30	6x5	36	91	332235	11075
32	4x8	36	97	355958	11124
36	6x6	30	91	398729	11076
44	4x11	27	100	574144	13049
48	6x8	24	97	616477	12843
66	6x11	18	100	989994	15000

Table 1. Continued

Variance per unit area (V_x)	Relative information (%)	Coefficient of variation (%)	Standard error	Regression coefficient (b)
1365	100	24.5	37	
961	71	20.5	62	0.51
935	73	20.2	61	.55
837	54	18.9	86	.44
752	45	18.2	110	.43
710	48	17.7	107	.47
698	49	17.5	106	.48
672	41	17.0	129	.44
576	40	15.8	144	.48
631	36	16.7	151	.43
543	42	15.5	140	.51
532	32	15.2	184	.45
576	30	15.9	192	.42
569	30	15.8	191	.42
529	26	16.5	251	.41
450	28	15.3	254	.46
450	25	14.0	255	.45
513	22	15.0	272	.39
451	25	14.1	255	.45
407	21	13.4	323	.44
478	18	14.4	349	.38
409	19	13.4	364	.42
446	15	13.9	423	.37
341	18	12.2	406	.45
373	15	12.7	464	.41
391	15	13.1	474	.39
369	12	12.7	576	.38
348	12	12.3	597	.39
308	12	11.6	631	.42
297	11	11.4	758	.40
268	11	10.1	778	.42
227	9	9.9	994	.43

The comparable variance of the basic plot size was found to contribute the greatest relative information. As plot size increased, the relative information decreased, as did the variance of yield per unit area. As is shown in Figure 2, the decrease in relative information was most rapid up to a plot size of about eight to ten basic units, and changed only a relatively small amount after this point.

Just as the relative information had a rapid initial decrease, so did the variance of yield per unit area, which was very high for the basic plots, decreased rapidly up to a plot size of about eight to ten basic units. After this point, the variance per unit area decreased much more slowly. Figure 3 shows the effect of increasing plot size on the variance of yield per unit area.

This information indicates that a plot size of about eight times the basic unit might be optimum, when both the decrease in relative information, and the decreased variance are considered. While increased plot size would further still reduce the variance, the amount of land required would make the information so obtained more costly.

Soil Heterogeneity and Relative Costs

Another estimate of optimum plot size was made using Smith's regression coefficient—relative cost relationship. Using the formula derived by Smith,

$$\log V_x = \log V_1 - b \log x$$

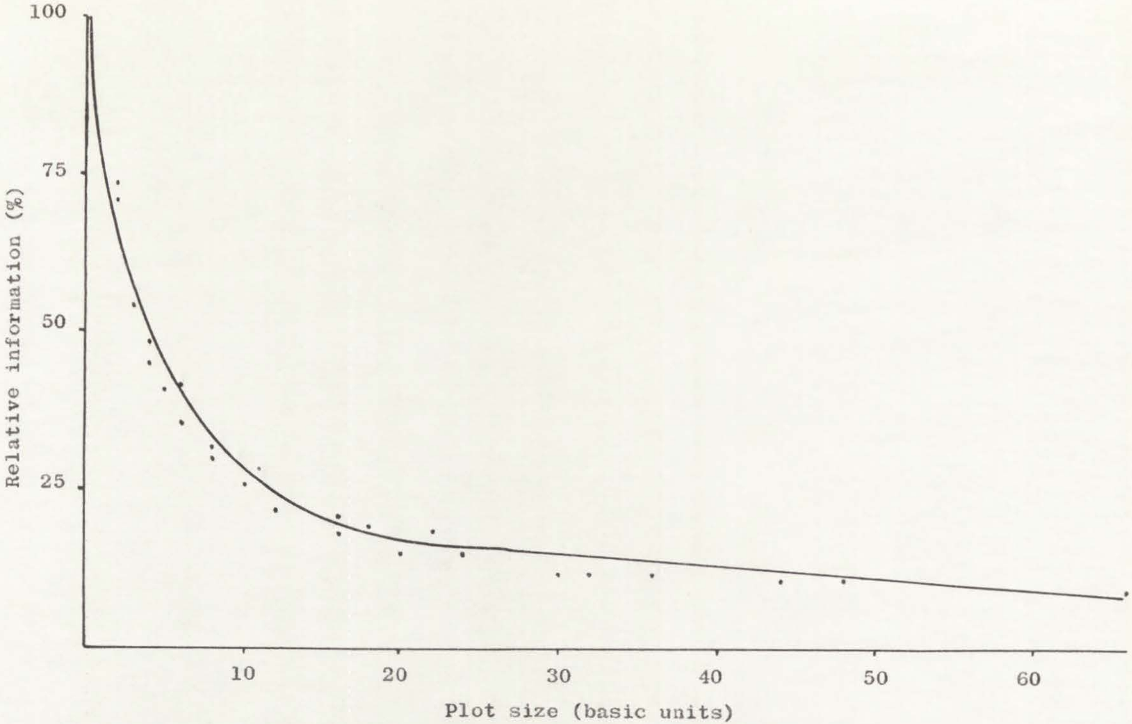

Figure 2. The decrease in relative information with increasing plot size.

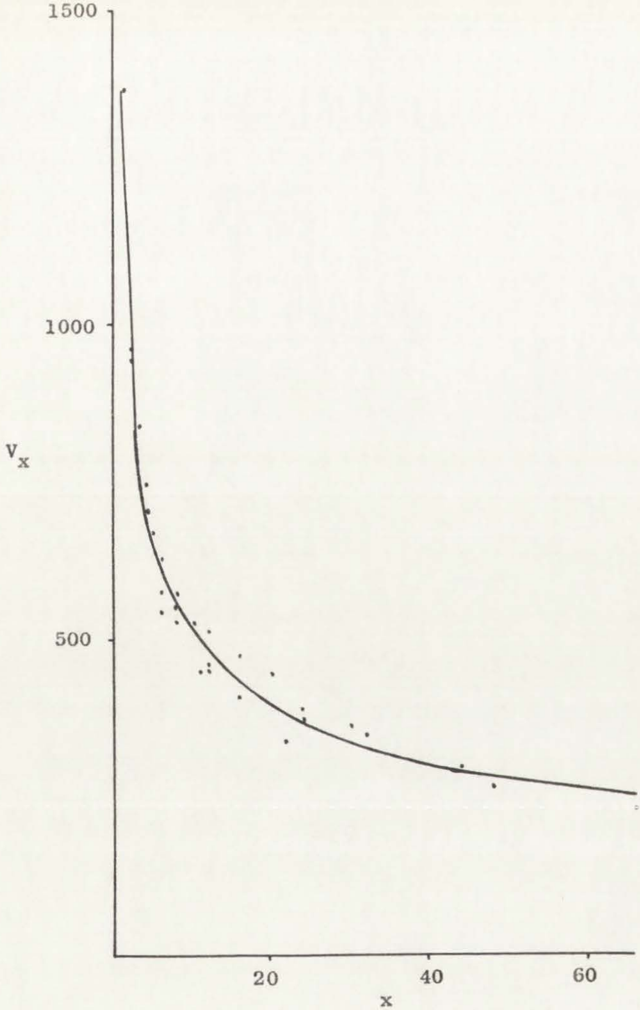

Figure 3. The effect of plot size in basic units (x) on the variance of yield per unit area (V_x).

the regression coefficient b was calculated for each plot size. The average value for b for the 32 plot sizes was 0.43. This value, a measure of the soil's heterogeneity, indicated a field a little above average in uniformity, if the range from 0.4 to 0.7 is considered to be a common one.

The calculated value for b would hold only for that portion of the field that comprised the 1188 basic plots. The graph in Figure 4 is the regression of the logarithm of the variance of yield per unit area on the logarithm of size of plot. The straight line reflects the linear relationship shown in the equation above.

In addition to the regression coefficient, the two cost factors, K_1 and K_2, had to be estimated. Table 2 shows the various operations considered in arriving at these factors. In column 1 the cost of each operation is given in terms of man hours. Machinery costs were not considered in this estimate, although such costs were involved, particularly in the harvesting operation. Furthermore, these costs estimates would apply directly only to the experimental field used in this study.

The per cent of the total cost attributable to each operation is given in column 2. The percentage of column 2 is then broken down into column 3, that cost proportional to the number of plots in the test area (K_1); and into column 4, that cost proportional to the total size of the test area (K_2).

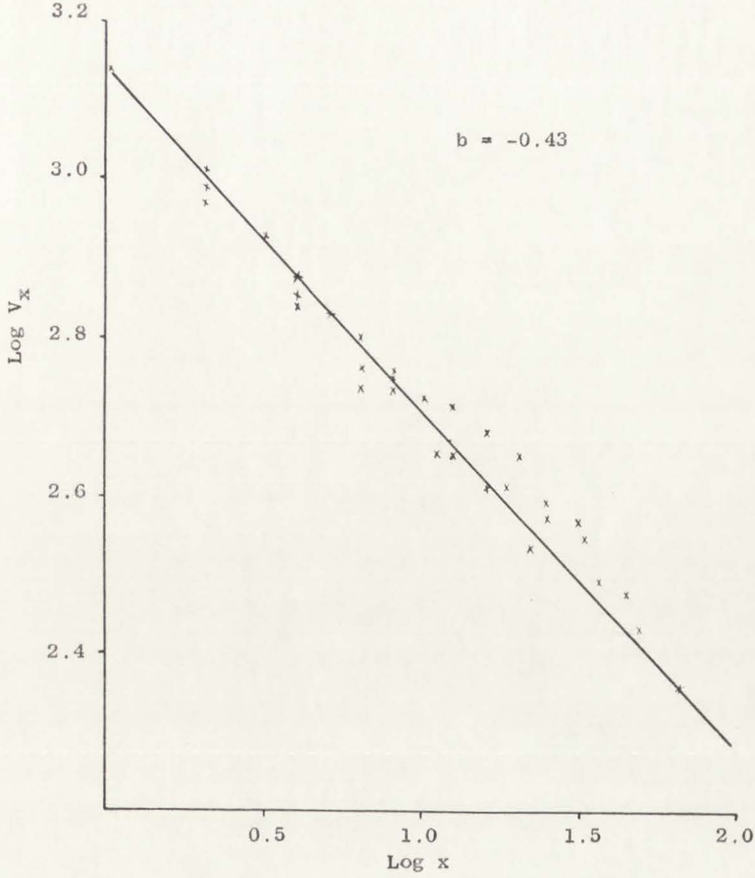

Figure 4. Regression of the logarithm of the variance of yield per unit area on logarithm of size of plot.

Table 2. The estimate of K_1, cost proportional to number of plots in the test area; and K_2, cost proportional to the total test area

Operation	Cost in man hours (1)	Per cent of total (2)	K_1 (3)	K_2 (4)
Land preparation	2	0.5	0.3	0.2
Seed preparation	40	10.7	9.7	1.0
Planting plan	8	2.1	2.1	---
Planting	9	2.4	1.6	0.8
Care of plots	90	24.0	4.0	20.0
Notes	6	1.6	1.2	0.4
Harvesting	120	32.0	30.0	2.0
Statistical analysis	100	26.7	25.2	1.5
Totals	375	100.0	74.1	25.9

The proportions calculated in this table, $K_1 = 74.1$ per cent and $K_2 = 25.9$ per cent would apply particularly to the field of this study, but might also be considered as representative of safflower yield trials using the same general procedure and equipment.

In Table 3, a brief description is given for some items included in the various operations upon which the cost factor estimates were based.

These three calculated values, $b = 0.43$, $K_1 = 74.1$ per cent and $K_2 = 24.9$ per cent, were then substituted into the formula of Smith,

Table 3. A brief description of some of the sub-items included in the major items of cost in safflower yield trials

Operation	Items
Land preparation	Measuring, staking, irrigation furrows (Does not include plowing or discing)
Seed preparation	Counting or weighing, labeling envelopes, packaging, randomizing, putting in proper sequence
Planting plan	Writing, randomizing
Planting	Lay out envelopes, plant seed
Care of plots	Weeding, irrigation, spraying
Notes	Checking, maturity, stand
Harvesting	Cutting border areas, combining, recording, weighing
Statistical analysis	Analysis of data

$$x = \frac{b\ K_1}{(1-b)\ K_2}$$

to obtain an estimate of optimum plot size. The computed value is 2.2 times the basic unit, a figure considerably smaller than that arrived at by considering the variance alone. Smith indicates, however, that the actual plot size could fluctuate both above and below this value without losing what might be considered optimum plot size.

It is evident that as cost proportional to the number of plots increases, the optimum plot size increases. Figure 5 shows the effect of soil heterogeneity, and the

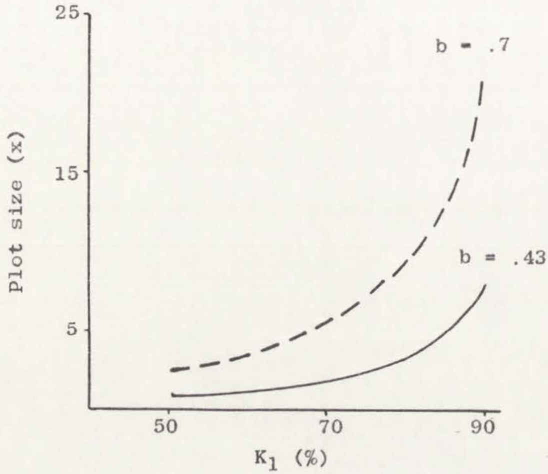

Figure 5. The effect of soil heterogeneity (b) and the part of total cost proportional to number of plots in an area (K_1) on optimum plot size in basic units (x).

part of total cost proportional to number of plots in the test area, on the optimum plot size in basic units. As the value for b approaches unity, the value for x becomes very high.

Convenient Plot Size

Although the method of obtaining what Hatheway calls a convenient plot size is only very recently proposed, it will be included in this study as a matter of interest.

In using the term "convenient plot size" Hatheway refers to a plot size which will tell the experimenter what he wants to know, regardless of the cost that is involved.

By using a formula for number of replications, and Smith's variance relationship, Hatheway derives the formula,

$$x^b = \frac{2\,(t_1 + t_2)^2\,C_1{}^2}{r\,d^2}$$

which gives a convenient plot size in multiples of the plot size currently being used—in the case of this study, the basic plot. All of the variables, except x, are specified or taken from various data.

For the purpose of this study, b will be taken as 0.43, the regression coefficient of the field of 1188 plots. The value, $C_1{}^2$, is the square of the coefficient of variation of the basic plots, or $(24.5)^2$. A precision sufficient to detect a true difference of 15 per cent in 80 per cent of the experiments at a 40 per cent level of significance is specified for the values of d, t_2, and t_1 respectively. The values for t_1 and t_2 for 100 degrees of freedom are read from the t-table as 0.84 and 0.84 respectively. The 100 degrees of freedom is a common number in safflower yield trials. The number of replications is specified as six.

Substituting these values into the above formula, and evaluating by logarithms, a convenient plot size of 8.3 times the basic unit is calculated. While this value could easily be altered by changing any one of the variables in the equation, an attempt was made to use values for the variables that coincided closely with currect practices in conducting safflower yield tests.

One interesting aspect of the use of this formula deserves mention. Hatheway used the relationship derived by Smith, that

$$V_x = \frac{V_1}{x^b}$$

in working out his convenient plot size formula. It could be assumed, since he does not state otherwise, that he attaches the same meaning to the value of b, namely that it is a measure of the soil heterogeneity, and that as values of b near unity, they indicate a very non-uniform soil. Figure 6 shows the relationship between the regression coefficient and plot size using Hatheway's formula.

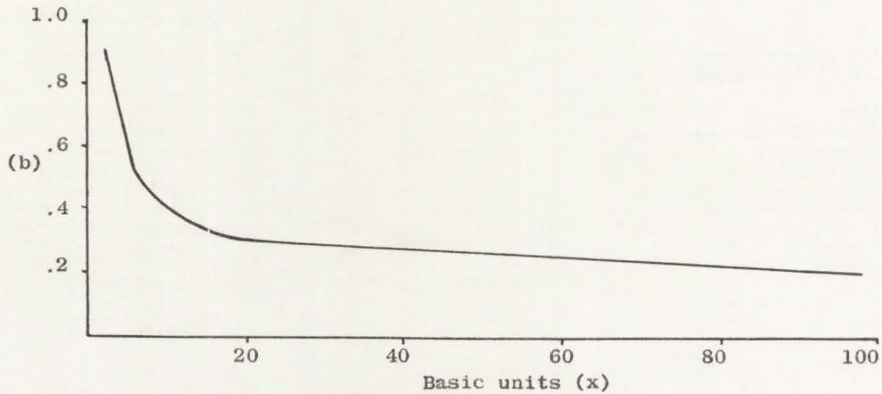

Figure 6. The relationship between the regression coefficient (b), and plot size using the formula proposed by Hatheway

In this case, as the regression coefficient approaches zero, the values for the plot size (x) become very large. This is quite the opposite of what happens with Smith's formula as shown in Figure 5, where plot size becomes very large as the regression coefficient approaches unity. This latter case is what would be expected on the basis of the stated meaning for the regression coefficient b. An explanation is needed for this apparent divergence.

Plot Shape

It was the opinion of Smith that plot shape generally had no consistent effect on the variance. Figure 7 shows the effect of number of rows (plot width) on the variance of yield per unit area for plots of different lengths. The greatest amount of reduction in variance occurred with the one row plots, and a considerable, though lesser, amount with the two row plots. The four and six row plots, while their variances were lower, did not decrease the variance as much as did the other two. The increased size of the plots could be considered as the main reason for this decrease in variance.

In Table 4, a comparison of the variance of yield per unit area is given for long narrow plots; and for the corresponding short, wide plots. It can readily be seen that there is very little difference in variance due to shape of plot.

In considering plot shape, it is important to consider convenience in handling the plots. A self-propelled plot

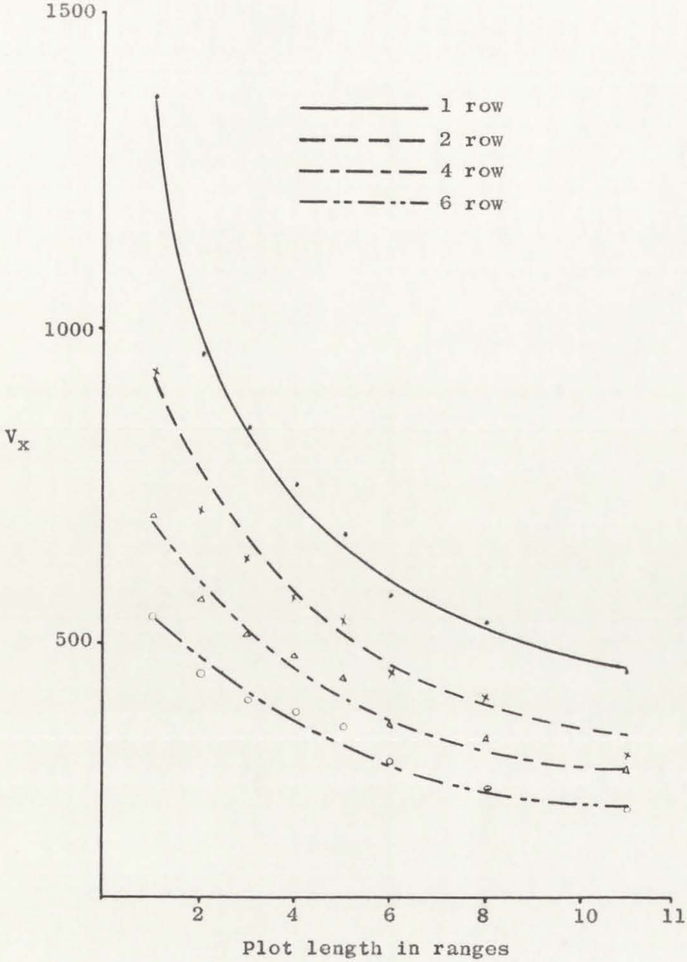

Figure 7. Effect of number of rows on variance of yield per unit area (V_x) for plots of different lengths

Table 4. A comparison of the variances of yield per unit area for narrow, long plots and for short, wide plots

No. basic units	Long, narrow plots		Short, wide plots	
	Shape row x range	Variance	Shape row x range	Variance
1	1 x 1	1365	1 x 1	1365
2	1 x 2	961	2 x 1	935
4	1 x 4	752	4 x 1	698
6	1 x 6	576	6 x 1	543
8	2 x 4	576	4 x 2	569

combine used in harvesting yield trials cuts two rows at a time. It could not be used on a one row plot, and it would be awkward to handle on four and six row plots.

With this factor in mind, plus the fact that variance is only slightly affected by plot shape, it is recommended that plots two rows wide be used.

CONCLUSIONS

Of the three methods used to estimate optimum plot size, two indicated that about 8 times the basic unit would give the information desired. The third, relating soil heterogeneity and relative costs, gave an optimum plot size of about two times the basic unit. As can be seen from Table 1, the variance of yield per unit area for the plots sizes using two basic units is quite high, particularly as compared to the eight unit plots.

However, as Smith pointed out, the plot size calculated from his formula could be as much as 4 times the calculated value, and still be considered an optimum plot size. The plot size calculated by the other two methods falls within this limit.

Considering these factors, it was concluded that as a result of this study, optimum plot size for safflower yield tests was 8 times the basic unit as used in this experiment. Taking into account the recommendation concerning plot shape, this would mean a plot two rows wide by four ranges long, or 3.33 feet wide by 20 feet long.

This size and shape plot was arrived at by taking into account cost factors, soil heterogeneity, the reduction in variance due to increased plot size, and the information that is desired from safflower yield tests. It is a little smaller than the 3.33 by 25 foot plot size recommended by Draper (1959) in his study on safflower.

Since many of the results involve the use of the regression coefficient b in their calculation, a fluctuation of this value could easily cause differences in optimum plot size. Another approach to the problem would be to compute optimum plot sizes for a number of different areas and conditions.

It should be pointed out that the convenient plot size arrived at by the use of Hatheway's formula should not be considered as completely reliable or conclusive. This is so for two reasons. The first is that it is somewhat coincidental to arrive at a plot size which is the same as the plot sizes derived by the other methods, since the values used in Hatheway's formula can be changed at will. The second is that the effect of the regression coefficient on plot size is directly opposite to what would be expected if a high value of b indicates a very heterogeneous soil. The use of Hatheway's formula was included in the study as a matter of interest, and should be considered as such.

The other recommendations and data in this study also can not be considered as all-inclusive. Technically, they pertain only to the field and crop used for this experiment. They can, however, be a recommendation—that a plot 3.33 by 20 feet in size is a good starting point.

SUMMARY

Optimum plot size and shape for safflower yield trials was calculated using data from a safflower uniformity trial planted at Farmington, Utah, in 1960. The area used was harvested as 1782 one row by five-foot basic plots, of which 1188 plots were used in this study. This latter was due to a high yield differential between one-third of the field, and the other two-thirds of the field caused by an uneven moisture retention of the soil.

Optimum plot size was calculated in three ways. Using comparable variances, it was found to be 8 times the basic unit. Taking into account soil heterogeneity and relative costs, two basic units was found to be optimum. By specifying certain levels of information desired, a convenient plot size of 8 times the basic unit was calculated.

It was found that plot shape had little effect on variances, so a width of two rows was indicated, so that the plots might be most efficiently handled.

All factors considered, an optimum plot size and shape for safflower yield trials was found to be 8 times the basic unit, or 3.33 feet wide by 20 feet long.

LITERATURE CITED

Alwood, W. B., and R. H. Price
1890 Suggestions regarding size of plots. Virginia Agr. Exp. Bul. 6.

American Society of Agronomy Committee on Standardization
1918 of Field Experiments. Report. J. Am. Soc. Agron. 10: 345-354.

________. 1931 Report. J. Am. Soc. Agron. 23: 1021-1023.

________. 1932 Report. J. Am. Soc. Agron. 24: 990-992.

________. 1933 Report. J. Am. Soc. Agron. 25: 803-828.

Brim, C. A., and D. D. Mason
1959 Estimates of optimum plot size for soybean yield trials. Agron. J. 51: 331-334.

Christidis, B. G.
1931 The importance of the shape of plots in field experimentation. J. Agr. Sci. 21: 14-37.

Davenport, E.
1907 Principles of breeding. Ginn and Company, New York, New York. pp. 438-441.

Day, J. W.
1920 The relation of size, shape and number of replications of plots to probable error in field experimentation. J. Am. Soc. Agron. 12: 100-106.

Draper, A. D.
1959 Optimum plot size and shape for safflower yield tests. Unpublished M. S. thesis, University of Arizona Library, Tucson, Arizona.

Federer, W. T.
1955 Experimental design. MacMillan Company, New York, New York. p. 65.

Garber, R. J., et al.
1926 A study of soil heterogeneity in experimental plots. J. Agr. Res. 38: 255-268.

Hatheway, W. H.
1961 Convenient plot size. Agron. J. 53: 279-280.

Immer, F. R.
1932 Size and shape of plot in relation to field experiments with sugar beets. J. Agr. Res. 44: 649-668.

Keller, K. R.
1949 Uniformity trial on hops, Humulus lupulus L., for increasing the precision of field experiments. Agron. J. 41: 389-392.

Kiesselbach, T. A.
1919 Experimental error in field trials. J. Am. Soc. Agron. 11: 235-241.

Love, H. H.
1919 The experimental error in field trials. J. Am. Soc. Agron. 11: 212-216.

McClelland, C. K.
1926 Some determinations of plot variability. Am. Soc. Agron. J. 18: 819-823.

Mercer, W. B., and A. D. Hall
1912 The experimental error of field trials. J. Agr. Sci. 4: 107-132.

Odland, T. E., and R. J. Garber
1928 Size of plot and number of replications in field experiments with soybeans. J. Am. Soc. Agron. 20: 93-108.

Smith, H. F.
1938 An empirical law describing heterogeneity in the yields of agricultural crops. J. Agr. Sci. 28: 1-23.

Wassom, C. E., and R. R. Kalton
1953 Estimations of optimum plot size using data from bromegrass uniformity trials. Iowa Agr. Exp. Sta. Bul. 396.

APPENDIX

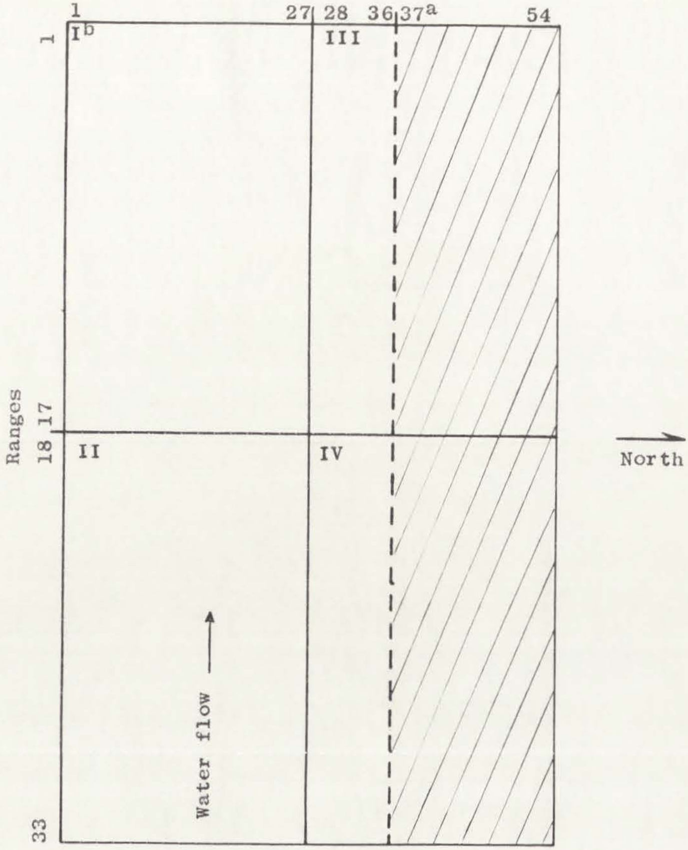

Figure 8. Layout of the uniformity trial field (border areas not shown)

[a]Shaded area is section of plots left out in second analysis

[b]Roman numerals refer to tables on following pages

Table 5. Seed yields per basic plot in grams (section I of Figure 7)

Range number																	
17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Row No.
127	163	151	138	126	125	131	142	150	140	126	148	140	129	115	110	160	1
153	136	120	149	126	212	118	122	184	123	129	145	134	112	112	117	142	2
104	179	145	139	107	126	107	130	155	163	153	184	120	137	127	126	125	3
109	118	128	128	135	119	140	150	144	142	179	100	127	126	125	108	159	4
125	97	118	205	125	127	125	124	157	161	137	160	160	108	123	122	101	5
130	147	140	133	116	103	98	143	163	97	122	197	113	130	102	107	91	6
144	161	146	166	142	119	96	117	153	157	135	161	169	129	92	120	113	7
168	137	129	92	121	151	146	166	136	200	178	126	132	124	131	97	90	8
140	124	105	123	81	103	130	125	116	168	169	169	157	103	112	92	98	9
174	103	83	110	166	112	121	117	110	111	126	177	91	91	109	97	77	10
168	210	133	122	124	127	166	255	151	112	174	134	105	83	93	62	110	11
199	161	163	156	123	140	80	165	212	142	191	131	129	148	80	79	99	12
135	149	130	110	141	145	129	86	128	118	145	135	119	91	104	75	71	13
157	172	164	155	144	118	106	244	146	144	162	143	105	40	97	73	86	14
194	161	128	154	169	163	139	142	172	195	194	155	127	90	83	105	109	15
184	188	150	214	154	188	124	166	124	158	170	143	130	105	163	115	112	16
152	149	130	179	149	208	135	156	129	192	184	161	160	125	104	102	104	17
138	177	198	199	170	267	220	132	164	173	244	143	120	104	97	130	117	18
157	172	164	188	181	222	169	130	192	221	203	230	161	110	123	116	139	19
146	167	182	175	161	194	196	130	103	116	237	160	125	143	114	103	139	20
127	149	168	153	132	161	129	160	166	255	241	198	108	166	98	91	111	21
151	181	181	184	189	168	203	144	147	162	246	156	155	172	91	105	213	22
191	208	134	173	171	167	128	176	188	147	197	213	210	172	114	138	217	23
151	143	168	184	133	177	148	130	157	196	159	179	177	187	107	170	239	24
236	257	124	212	168	137	136	196	207	313	150	177	225	237	127	193	184	25
207	193	153	133	118	91	147	205	146	244	136	156	187	149	169	164	177	26
229	132	139	160	124	186	146	160	143	184	108	138	178	151	193	149	152	27

Table 6. Seed yields per basic plot in grams (section II of Figure 7)

Row	Range number															
No.	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18
1	132	100	106	127	163	186	132	130	108	57	116	112	78	73	113	108
2	136	166	160	191	165	150	167	150	141	170	132	132	150	69	59	84
3	165	194	145	208	136	156	124	125	193	160	156	183	107	131	82	77
4	60	117	96	139	110	117	126	185	142	184	156	204	184	137	135	87
5	118	104	96	128	132	212	151	148	107	122	160	133	169	141	153	101
6	78	56	86	115	135	107	76	112	162	165	161	144	133	149	153	142
7	62	69	56	94	88	126	127	150	149	186	184	147	153	167	142	140
8	102	74	65	78	103	159	168	188	167	161	154	143	169	136	142	123
9	126	114	101	83	124	114	139	144	139	160	174	168	190	159	143	127
10	98	151	138	96	198	177	166	136	174	153	148	160	152	189	153	127
11	233	125	185	175	93	162	150	175	186	149	134	163	180	158	146	120
12	161	141	124	167	168	146	142	119	174	164	184	204	150	178	147	148
13	198	108	131	122	166	166	99	133	127	108	161	120	170	122	132	144
14	148	107	156	169	151	130	129	142	143	182	175	128	155	146	149	126
15	186	118	163	152	156	140	126	159	119	105	137	134	167	175	137	123
16	146	161	126	205	177	132	120	166	157	153	154	157	163	150	163	149
17	159	132	162	161	138	148	138	146	127	134	137	135	161	137	144	134
18	148	173	117	166	152	176	132	184	132	132	121	126	140	163	120	153
19	175	172	217	179	186	139	205	177	193	151	169	186	172	83	169	119
20	107	150	145	214	146	134	130	125	136	148	112	142	130	122	144	191
21	152	154	150	120	182	174	145	158	164	190	123	151	204	121	172	140
22	133	138	101	137	138	112	83	137	109	162	157	111	162	99	135	132
23	148	164	147	144	145	131	112	191	156	178	151	132	119	141	183	164
24	137	147	94	138	123	99	126	156	155	164	125	148	152	130	120	167
25	148	204	137	154	159	147	140	130	209	165	238	173	179	160	142	169
26	192	208	129	158	158	125	135	198	164	125	172	198	160	125	151	198
27	94	141	89	149	128	134	114	168	121	145	112	136	138	100	121	160

Table 7. Seed yields per basic plot in grams (section III of Figure 7)

Range number 17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Row No.
152	114	150	154	144	157	175	200	134	163	169	170	234	124	177	145	154	28
247	145	133	153	148	119	139	198	108	188	164	260	175	153	156	102	149	29
151	176	213	152	144	204	268	266	182	155	273	260	149	263	159	182	208	30
210	193	170	194	213	197	230	255	221	176	146	221	195	190	206	157	188	31
141	142	170	171	121	150	150	200	125	149	181	135	141	184	135	145	154	32
165	135	192	137	169	207	234	201	144	160	155	169	215	167	140	138	134	33
155	137	146	213	107	215	210	193	144	172	114	172	187	147	153	74	135	34
166	184	171	188	173	229	225	233	162	156	153	165	210	170	110	125	125	35
173	162	175	202	212	106	177	204	149	198	175	192	171	145	124	159	140	36
																	[a]
134	162	136	197	214	121	201	183	142	80	154	166	101	111	83	69	99	37
171	207	169	149	230	199	174	269	80	153	155	134	162	122	163	125	163	38
182	170	139	277	202	242	292	177	165	168	168	171	138	146	152	155	162	39
175	157	170	231	261	173	253	311	262	252	220	190	299	183	140	175	221	40
229	210	207	244	272	197	203	159	268	236	240	244	211	201	195	253	163	41
195	216	223	232	269	270	228	113	136	191	195	270	264	366	212	191	136	42
264	354	261	355	340	317	232	225	213	234	181	345	232	255	190	182	213	43
290	285	207	205	274	238	268	200	163	261	328	210	347	282	317	232	197	44
274	305	247	354	290	283	175	166	264	366	288	314	287	366	206	251	185	45
232	313	285	200	396	306	243	239	316	308	333	340	304	342	311	315	242	46
274	279	277	274	353	250	283	359	143	324	329	354	442	350	333	294	299	47
347	311	265	278	310	305	233	363	397	379	302	407	369	336	364	371	289	48
292	307	308	341	305	325	322	322	289	355	434	330	350	316	399	290	349	49
256	392	246	342	252	317	210	312	314	284	333	397	235	281	348	314	293	50
276	202	309	360	314	305	298	272	250	337	325	240	364	320	341	241	241	51
360	346	348	359	444	384	307	444	325	391	537	370	424	266	325	295	348	52
334	267	338	293	318	295	326	218	282	329	266	335	402	418	437	308	353	53
306	291	242	433	378	441	332	398	434	446	300	295	337	357	326	334	390	54

[a]Rows 37 to 54: Plots excluded second analysis

Table 8. Seed yields per basic plot in grams (section IV of Figure 7)

Row No.	Range number 33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18
28	92	109	163	185	119	128	139	157	174	183	204	106	147	144	160	232
29	169	202	144	193	165	161	146	147	163	151	190	156	126	155	143	163
30	174	213	208	207	207	227	222	176	247	224	167	187	206	190	164	222
31	263	223	235	245	219	189	231	267	238	238	225	182	197	163	176	202
32	108	123	178	175	139	218	187	251	132	134	171	143	154	147	149	158
33	180	230	169	163	171	118	201	182	198	149	172	189	173	185	134	134
34	162	118	166	122	164	167	164	221	203	124	196	186	130	172	147	134
35	120	109	130	125	115	101	112	133	124	161	85	118	100	132	196	156
36	172	164	164	127	156	172	98	131	144	128	134	106	178	176	159	132
37[a]	147	117	95	110	135	88	131	114	133	144	116	123	163	111	132	151
38	141	134	92	122	146	106	140	138	127	86	125	143	187	172	144	158
39	158	147	133	92	170	167	140	128	121	164	150	126	142	152	147	228
40	123	115	138	110	175	123	156	148	192	164	218	184	178	214	146	173
41	136	139	126	136	101	133	141	143	145	174	230	196	153	227	162	280
42	85	145	111	122	117	138	140	158	206	142	146	238	166	217	143	268
43	107	133	82	110	125	107	164	160	190	173	191	152	218	147	223	302
44	194	219	170	198	205	124	294	229	241	319	282	245	294	341	317	372
45	174	138	189	128	155	73	222	184	189	203	230	274	233	266	219	271
46	164	263	229	195	104	132	242	358	243	279	300	286	286	284	278	316
47	159	252	245	176	143	141	186	254	220	219	199	237	218	323	287	232
48	158	274	175	177	150	117	202	132	66	103	249	212	236	232	233	324
49	266	282	376	208	209	181	230	311	349	250	206	329	280	302	346	358
50	236	239	203	207	137	181	223	189	202	239	179	262	253	256	245	365
51	222	265	198	232	169	221	187	325	147	324	215	319	344	261	262	429
52	217	338	98	223	147	194	106	292	206	268	356	279	296	359	274	358
53	158	143	148	137	92	146	190	152	210	266	178	218	204	236	244	316
54	176	176	126	175	175	185	130	134	223	305	252	335	245	176	246	369

[a]Rows 37 to 54: Plots excluded in second analysis

Table 9. Plot sizes, comparable variance, variance per unit area, and relative information for plots involving the entire harvested area of 1782 basic plots

Size[a]	Shape row by range	No. plots	Area used (%)	Comp. var. (V)	Var. unit area[b] (V_x)	Rel. info. (%)	Coef. var. (%)
1	1x1	1782	100	4920	4920	100.0	39.1
2	1x2	864	97	8705	4352	56.5	36.8
2	2x1	891	100	8393	4196	58.6	36.0
3	1x3	594	100	12158	4053	40.5	35.4
4	1x4	432	97	15902	3976	30.9	35.0
4	2x2	432	97	15666	3917	31.4	34.8
4	4x1	429	96	13327	3332	36.9	32.8
5	1x5	324	91	19900	3980	24.7	34.2
6	1x6	270	91	23528	3921	20.9	34.4
6	2x3	297	100	22566	3761	21.8	34.2
6	6x1	297	100	21425	3571	23.0	33.4
8	1x8	216	97	29720	3715	16.6	33.9
8	2x4	216	97	29528	3691	16.7	33.8
8	4x2	208	93	25541	3193	19.3	32.1
10	2x5	162	91	37253	3725	13.2	33.6
11	1x11	162	100	38491	3499	12.8	33.0
12	2x6	135	91	44313	3693	11.1	33.5
12	4x3	143	96	36894	3075	13.3	31.6
12	6x2	144	97	42053	3504	11.7	33.0
16	2x8	108	97	56088	3505	8.8	33.0
16	4x4	104	93	48703	3044	10.1	31.3
18	6x3	99	100	61222	3401	8.0	32.6
20	4x5	78	88	61255	3063	8.0	31.1
22	2x11	81	100	73505	3341	6.7	32.3
24	4x6	65	88	72741	3031	6.8	31.0
24	6x4	72	97	81338	3389	6.1	32.4
30	6x5	54	91	104037	3468	4.7	32.4
32	4x8	52	93	93130	2910	5.3	30.7
36	6x6	45	91	124637	3462	3.9	32.4
44	4x11	39	96	123252	2801	4.0	30.2
48	6x8	36	97	158354	3299	3.1	32.0
66	6x11	27	100	210259	3185	2.3	29.8

[a]Number of basic units

[b]Variance of yield per unit area