ADJUSTING YIELDS TO THEIR REGRESSION ON A MOVING AVERAGE, AS A MEANS OF CORRECTING FOR SOIL HETEROGENEITY [1]

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GENERAL CONSIDERATIONS

The recent tendency has been to eliminate the use of check plats as a means of correcting for soil heterogeneity in comparisons of varieties or selections under field conditions. Thus, the committee on standardization of field experiments of the American Society of Agronomy reports:[2] "*Check plats.*—Adequate replication of varieties or treatments removes the necessity of including check plats."

The author is in entire accord with this view if the word "check" is used in the ordinary sense and "adequate" is defined properly. It is felt, however, that replication adequate to remove the advisability of having some measure of the variation in soil productivity from point to point is impractical under many conditions. Moreover, reducing the variability by doubling the number of replications does not necessarily make the data obtained as significant as if the same reduction were achieved by adjusting the yields to a check occurring in alternate plats. In the author's experiments with corn, therefore, the frequency of the checks has been increased, when possible, until they occurred in alternate plats and at the same time the number of replications has been kept as large as conditions permitted. For any fixed experimental facilities the size of the plats, the number of replications, and the frequency of check plats are the elements that determine the number of strains that can be compared. If corrections for soil heterogeneity could be made without the use of check plats, a material gain in accuracy should be possible.

With this in mind, a planting arrangement was devised for an experiment in which each of the strains to be compared was used as a check in one series of replications, thereby constituting that many extra replications of each strain. The data obtained under this arrangement were fairly satisfactory as a whole, but the method was limited in its application and there were other objections to it. Some of the concepts on which it was based were not fundamental and modification of certain phases made it more satisfactory and permitted a wider application. As some of the principles involved appear not to have been used in connection with varietal and strain comparisons, and appear to promise something of value, it seems advisable to present them at this time.

Before considering the method itself, it is desirable to discuss briefly the principles upon which it is based. This can be done more conveniently in connection with certain hypothetical experiments, the object of which is to determine the relative productiveness of two varieties or strains of corn in a given field for a single season. In these experiments

[1] Accepted for publication Nov. 19, 1923.

[2] WIANCKO, A. T., ARNY, A. C., and SALMON, S. C., report of committee on standardization of field experiments. *In* Jour. Amer. Soc. Agron., v 13, p. 372. 1921.

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each variety is grown in 100 relatively long narrow plats arranged as shown below. The mean yields in each will be taken as 75 and 70 bushels per acre, respectively, with a probable error of ± 0.707 bushel in each case. It is assumed that errors due to differences in stand or to competition between varieties do not enter into the experiments. The planting arrangement in each case follows:

Experiment 1. The ends of the plats of one variety abut upon the ends of the plats of the other.

Experiment 2. The plats of the two varieties alternate.

Experiment 3. The two varieties are included among 100 in a varietal comparison, all of the varieties being replicated 100 times, with the replications systematically distributed.

THE SIGNIFICANCE OF THE PROBABLE ERROR

The significance of the data in relation to the probable error may be considered first. In each experiment the difference between the yields of the two varieties is 5 ± 1 bushels, and the odds are more than 1,300 to 1 that this difference is not due to chance. The presumption as to causal relations, however, differs markedly in each case. Thus, in experiment 1, one would hardly care to attribute the difference in yield to a varietal difference, whereas in experiment 2, such an assumption is entirely warranted. It is clear that the probable error in either case measures the same thing. The difference in the presumption as to the causal relations rests, of course, upon a knowledge that the yields of both varieties, in so far as they are affected by soil productivity, represent random samples of essentially the same soil mass in Experiment 2, but not in Experiment 1.[3]

The conditions in Experiment 3 do not permit such definite conclusions as to causal relations. The probable error again measures the portion of the difference that reasonably may be assigned to variations in the random sampling of the varieties and the soils in which they grew. Here, however, the yields as influenced by soil productivity do not sample entirely different soil masses, as in Experiment 1, nor do they sample what is essentially the same soil mass as was the case in Experiment 2. In so far as it is probable that 100 plats of one variety distributed over a 30-acre field[4] would not encounter soil conditions materially different, as an average, from those encountered by 100 plats of another variety distributed over the same field, it is logical to assume that the difference in this experiment was due to a difference in the varieties. Such an assumption is based, however, upon the judgment as to equal chances, and not upon the probable error per se.

The above consideration has been made somewhat detailed, not because it presents a new concept, but to emphasize clearly and distinctly that interpretation as to causal relations in field experiments expressed in terms of the probable error really involves two elements of judgment. These are (1) the probable reliability of the two means from the standpoint of the random sampling of the varieties and the soil in which each grew and (2) the conclusion that there was no systematic

[3] It is conceivable that a difference obtained as in Experiment 2 might be due to something other than an inherent varietal difference, such as some previous fertilizer or cultural treatment that was similarly alternated and the alternations of which chanced to coincide with those of Experiment 2. The possibility of such an occurrence without the knowledge of the investigator, however, scarcely needs to be considered. A more probable cause of error in the assignment of causal relations would be a difference in seed value not inherent in the varieties. The consideration of this kind of error is entirely beyond the scope of the present paper.

[4] Something over 30 acres would be required for 100 replications of 100 varieties where each plat consisted of 10 hills 3.67 feet apart.

difference in the conditions of soil productivity under which the two varieties were grown. When the number of replications is large in proportion to the number of strains compared, the correctness of the latter conclusion obviously may be warranted. As the number of replications decreases relatively to the number of strains involved, however, the justification for such a conclusion becomes constantly less. Thus, when 100 strains are systematically replicated 4 times, any 2 strains may not have been grown within 10 plats of each other in the whole experiment.

THE COEFFICIENT OF CORRELATION

When the relation between two variables is rectilinear, the coefficient of correlation measures their tendency to concomitant variation. A significant coefficient of correlation shows a relation between the variables, but tells nothing of the cause of that relation. One may be the cause or effect of the other, the relation may be purely mathematical, as between a product and its factors, or both variables may be affected by one or more common causes. Frequently, however, other information is available on which to base interpretations. Thus, a positive correlation between the yields of the adjacent odd and even rows in Experiment 2 logically leads to the conclusion that the yields of both varieties were being influenced from row to row by variation in the soil conditions so gradual that when it affected one row, it also affected the adjacent row more or less. Similarly, systematic competition would tend to lower a positive correlation due to soil variation, and might even result in a negative correlation.

For a good discussion of the interpretation of data on the basis of correlation values plus such other information as to the relations as may be available, the reader is referred to the works of Sewall Wright.[5, 6]

Letting X and Y represent the odd and even rows of Experiment 2, the significance of the coefficient of correlation is made more evident by its relation to the standard deviation of the differences. Thus, the standard deviation of the differences, $X-Y$, is given by the equation, $\sigma^2_{X-Y} = \sigma^2_X + \sigma^2_Y - 2r_{XY}\,\sigma_X\,\sigma_Y$. When $r=0$, $\sigma^2_{X-Y} = \sigma^2_X + \sigma^2_Y$. Substituting probable errors for standard deviations, the latter is the equation largely used for the probable error of a difference between means. This is correct in field experiments only when there is no correlation between the yields of the two items in the different replicates. It results in too small an error if there is a negative correlation and too large an error if r is positive. Competition thus tends to lower, and a gradual change in soil productivity tends to raise, the probable error computed in this way. It is the portion of the error due to the term, $2r_{XY}\,\sigma_X\,\sigma_Y$, in the formula for the squared standard deviation that is eliminated by obtaining the successive differences between X and Y and determining their probable error directly.

REGRESSION

It is in connection with the theory of regression that the coefficient of correlation attains its importance in the present paper. Using X and Y as in the previous paragraph, the regression of X on Y is given by the expression, $r_{XY}\,\frac{\sigma_X}{\sigma_Y}$. In other words, for each unit of deviation of Y from

[5] WRIGHT, SEWALL. CORRELATION AND CAUSATION. *In* Jour. Agr. Research, v. 20, p. 557-585. 1921. Literature cited, p. 585.

[6] ———. THE THEORY OF PATH COEFFICIENTS. *In* Genetics, v. 8, p. 239-255, 8 fig. 1923. Literature cited, p. 255.

its mean, X on an average deviates $r_{XY}\frac{\sigma_X}{\sigma_Y}$ times one unit, from its mean. The deviation is in the same direction if the regression is positive ($r=+$), or in the opposite direction if it is negative. Similarly, $reg_{YX}=r_{XY}\frac{\sigma_Y}{\sigma_X}$. Thus, when any row X deviates from its mean by x units, the magnitude $x\left(r_{XY}\frac{\sigma_Y}{\sigma_X}\right)$ is the predicted deviation of the associated Y row from its mean. Letting the actual deviations of rows Y from their mean be represented by y and the predicted deviations by y_1, the y_1's are the closest estimates of the y's that it is possible to obtain, knowing the x's and assuming a rectilinear relationship.

Let $y-y_1=y_2$, the error of estimate or residual. There are, of course, N y_2's in N paired observations. Their mean is zero and their standard deviation is given by the equation $\sigma_{y_2}=\sigma_Y\sqrt{1-r^2_{XY}}$. This is the "standard error of estimate," and its value is less for the y_1's than for any similar values predicted on the basis of x.

ADJUSTING YIELDS TO CHECKS

The assumption underlying the methods that have been generally used in adjusting the yields of test plats to those of nearby checks has been equivalent in effect to assuming an entirely arbitrary correlation between the two kinds of plats. Let c_1 and c_2 be the yields of two adjacent checks, C the mean yield of all checks, and Y and Y_a the actual and adjusted yields of the test. Then, adjusting for the checks on each side according to the equation, $\frac{2Y}{c_1+c_2}C=Y_a$, is equivalent to adjusting on the basis of an assumed regression coefficient of $+1$. When only every third or fifth plat is a check and the regression is supposed to decrease proportionately with the distance from the checks, the assumption is even more arbitrary. That such methods of adjustment frequently have reduced the variability of the test plats materially is ample evidence of the fundamental soundness of some means of correcting for soil heterogeneity.

Without a detailed review of the literature, Stadler's [7] discussion of the value and limitations of adjusting to checks may be cited as approximating in general the conclusions of other investigators. These may be summed up briefly in the statement that adjusting sometimes is beneficial and sometimes it is not. Stadler also discusses some of the conditions under which adjustment was more and less effective in his experiments. These may be grouped into conditions that would tend to increase and those that would tend to decrease the significant correlation between the check and the test plats. It is clear that the practice of adjusting to check plats is unwarranted when there is no correlation between the yields of the tests and the checks. It is equally clear that an adjustment to the checks on the basis of the actual regression of the test plats on the check plats is warranted and of value. On this basis it would be desirable to have frequent check plats in every experiment and to use them for adjusting the yields only in those cases in which there was a significant correlation between their yields and those of the test plats. Because of the area required, this is not practical unless the

[7] STADLER, L. J. EXPERIMENTS IN FIELD PLOT TECHNIC FOR THE PRELIMINARY DETERMINATION OF COMPARATIVE YIELDS IN THE SMALL GRAINS. Mo. Agr. Exp. Sta. Research Bul. 49, p. 72, 1921.

"check plats" also constitute replications. The planting arrangement to be described was an effort to obtain this result.

THE METHOD USED

THE PLANTING ARRANGEMENT

The planting arrangement was used in connection with corn breeding experiments conducted by the Office of Cereal Investigations of the United States Department of Agriculture, at Burdette, Ark., in 1921. The detailed data have been published,[8] and need not be repeated. It should be noted, however, that the field in which this experiment was located was so lacking in uniformity that it was used only because of circumstances amounting practically to necessity.

The planting arrangement and methods of computation are indicated in Table 1, which gives the order of planting for the first 10 rows of series 1 to 5. The different lots are referred to by the strain numbers given in Table 2.

TABLE I.—*Abstract of data from the comparison of generations in a selection experiment at Burdette, Ark., in 1921, illustrating the order of planting and the method of computing the percentage yields*

Row No.	Series 1.							Series 2 to 5.			
	Strain number.	Actual yields, pounds.[a]			Percentage yields.			Strain numbers in series:			
		Individual rows.	2-alternate-row plats.	3-row plats.	Individual rows.	2-alternate-row plats.	3-row plats.	2	3	4	5
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
1	10	9.8	....	....	[b]95.1	....	....	10	10	10	10
2	1	14.4	21.2	35.6	[b]113.3	[b]92.1	[b]99.7	2	3	4	5
3	1	11.4	27.0	38.4	89.7	106.2	100.7	1	1	1	1
4	1	12.6	23.8	36.4	99.2	100.0	99.7	2	3	4	5
5	2	12.4	28.0	40.4	111.7	110.2	110.6	2	2	2	2
6	1	15.4	26.5	41.9	121.2	112.2	115.4	2	3	4	5
7	3	14.1	25.6	39.7	112.8	100.7	104.7	3	3	3	3
8	1	10.2	24.0	34.2	80.3	104.8	96.0	2	3	4	5
9	11	9.9	20.8	30.7	95.1	81.8	85.7	11	11	11	11
10	1	10.6	20.5	31.1	83.4	89.5	87.3	2	3	4	5

[a] On basis of corrected stand. [b] Not used in correlations as there were no comparable 5-row plats.

Each strain was grown in a single row between one-row check plats. The rows were 10 hills long with two plants in each hill. A single comparison of all of the strains with the alternating check plats constituted a series which was replicated 10 times. A different strain, however, was used as the check in each unit. Thus, strain No. 1 was the check in the first unit or series, strain No. 2 was the check in series 2, and so on, each of the seed classes, strains 1 to 10, inclusive, being used as a check in one of the series. Series Nos. 1 to 5, inclusive, were grown end to end, and series 6 to 10 were adjacent to Nos. 1 to 5. A test plat of strain No. 11 was planted in each of the 10 series, but this strain was not used as a check.

[8] RICHEY, F. D. EFFECTS OF SELECTION ON THE YIELD OF A CROSS BETWEEN VARIETIES OF CORN U. S. Dept. Agr. Bul. 1209. (In press.)

The use of the small plats, containing approximately 0.0029 of an acre, made it possible to have a large number of replications of each strain. Twelve of these replications were distributed in alternate rows across one series and 10 were distributed lengthwise of the experiment. The strain occurring in alternate rows in any one series served as a check on soil variation within that unit and the strains as a whole distributed lengthwise of the field served as controls on differences between the series. Looked at in this way, therefore, there were alternate check plats throughout the experiment without any increase being required in total area. Moreover, each strain competed with every other strain the same number of times.

TABLE II.—*The mean actual and adjusted yields and the average values of the corresponding 3-row plats of 11 strains of corn compared at Burdette, Ark., in 1921*

Strain No.	Designation.	Average of 22 replications.[a] Actual yields.		Adjusted yields, basis of— 2-alternate-row plats.	Adjusted yields, basis of— 3-row plats.	Average of 3-row plats.
		Pounds.	*Bushels.*	*Bushels.*	*Bushels.*	*Per cent.*
1	*2*	*3*	*4*	*5*	*6*	*7*
1	Whatley Prolific	12.7	73.48±1.50	72.61±1.21	72.66±0.76	101.21
2	St. Charles White	11.1	64.22±1.45	63.99± .98	63.96± .73	100.88
3	St. Charles White × Whatley, F_1	12.5	72.32±1.45	73.25± .98	72.85± .67	99.18
4	Whatley × St. Charles White, F_1[b]	12.5	72.32±2.43	72.90±1.56	72.45± .99	99.32
5	Selection No. 201 F_2	11.2	64.80±1.62	67.81±1.04	66.77± .72	97.78
6	Selection No. 201 F_3	10.2	59.01±1.16	56.35±1.04	56.94± .75	103.44
7	Selection No. 201 F_4	11.5	66.54±1.62	68.73±1.27	67.69± .80	98.10
8	Selection No. 201 F_5	11.4	65.96±1.21	64.51±1.04	64.80± .72	101.75
9	Selection No. 201 F_6	11.5	66.54±1.68	66.88±1.10	66.59± .74	100.02
10	Selection No. 201 check	10.3	59.59±1.68	58.49±1.21	58.65± .77	101.41
11	Selection No. 201 F_1 (1914 seed)	10.4	60.17±3.53	64.11±2.72	62.43±1.92	94.73
	Average of the probable errors[c]	......	1.757	1.287	.870	[d]100.07

[a] Only 10 replications of strain No. 11.
[b] Selection No. 201 is the cross, Whatley × St. Charles White, made in 1914 and the filial generations descended from it.
[c] $P. E. = 0.6745\sqrt{\frac{\Sigma d^2}{n(n-1)}}$
[d] Average of all 3-row plats.

ADJUSTING THE YIELDS

The mean yield of each strain was computed first. These means are given under the heading, "Actual yields" in columns 3 and 4 of Table II. As has been noted, the field in which the comparison was made did not even look uniform, and, although the different lots were well distributed over the area, it was uncertain whether they had equal opportunity. It was assumed that the ratio of the yield of two alternate rows to the mean yield of the strains grown in them would be a good index of the productivity of the soil between them. Accordingly, the yield of each row was adjusted to this ratio. Thus, the yield of 15.4 pounds for row

6, series 1 (Table I) was divided by 1.122, the ratio of the yield of rows 5 and 7 (26.5 pounds) to the sum of the average yields of strains 2 and 3 for the entire experiment (23.6 pounds) which were grown in rows 5 and 7 of series 1. The yield of each row was adjusted similarly and the adjusted yields then were averaged. The means are given under the heading "Adjusted yields, basis of 2-alternate-row plats" in column 5 of Table II, for comparison with the actual yields.

EFFECTS OF CORRECTION

Inspection of Table II shows that all of the means have been modified one way or the other. Many of the modifications are so slight as to be entirely negligible, whereas others appear to have some significance. There is a consistent difference, however, in the probable errors of the two sets of means, those of the relative yields being lower in every case. The mean of the probable errors for the actual yields, 1.757 bushels, is reduced to 1.287 for the relative yields, a reduction of 0.47 bushel or 26.75 per cent. This represents a real gain in the degree of accuracy with which comparisons can be made between the strains.

As will be shown later, the assumption of a 1:1 ratio between the variations in yield of the plats of two alternate rows and that of the row between them was not warranted entirely. It was sufficiently accurate, however, to eliminate one-fourth of the variation as evidenced by the smaller probable errors.

EXTENSION OF METHOD

As previously noted, the method used was not entirely satisfactory. In the first place, the extreme variability of the soil made the use of such short rows questionable. These conditions combined to make the plat yields fluctuate rather widely with the result that sometimes a yield, actually too low as judged by its ratio to the mean for the strain, was decreased still further because the adjacent rows yielded more than their mean. Part of this may have been due to competition, but much of it was a result of random fluctuation. Finally, a planting arrangement in which the replicates were distributed more uniformly would have been better. Objections inherent in the calculations are subject to elimination. Other methods, therefore, were tried, and their effects noted.

OTHER BASES FOR ADJUSTING

If the mean actual yields of the different strains represented approximately their respective productiveness, it was reasonable to assume that the ratio of the actual yield of a plat of any given number of rows to the computed average yield of a group of rows of equal number and kind would be an approximate index of the productivity of the soil in which the given plat was grown. On this hypothesis, indices of productiveness were computed for plats of three and five adjacent rows, in addition to those for the plats of two alternate rows already considered. In order to make the indices continuous, the moving average commonly used in time series was utilized. The method of computation may be indicated from the data in Table I for the 3-row plats. Thus, the 3-row index (column 8) centered on row 7, series 1, was obtained by dividing the total yield of 39.7 pounds (column 5) for rows 6 to 8, inclusive, by 37.9 pounds, the total yield of two average rows of Strain No. 1 plus one average row of Strain No. 3 (Table II, column 3).

The quotient, 104.7 per cent, is the percentage yield, or index of productiveness for a plat centered on row 7. It should be noted that these indices were not computed by averaging the percentage yields of the individual rows.

THE EFFICIENCY OF THE DIFFERENT CHECKS

The efficiency of the plats of different sizes as a basis for adjustment was studied through their correlation and regression relations to the percentage yields of the individual rows, and through the reduction in the variability of the latter which was accomplished by adjusting to the different kinds of checks.

For convenience, the individual rows will be considered as variable *A*, the plats of two alternate rows as variable *B*, and the 3 and 5 row plats as *T* and *C*, respectively. The constants reported for these plats were computed from correlation tables in which the class interval was 5 per cent with class centers at . . . 95.05, 100.05, 105.05, etc. The table for r_{AT} is shown in figure 2.

The coefficients of correlation of *A* with *B*, *T*, and *C*, and the regression of *A* on these variables, the gross standard deviations of the different kinds of plats, and the net standard deviations of *A* for constant *B*, *T*, and *C* are shown in Table III. All of these indicate the superiority of the 3-row moving average for adjusting yields. The net standard deviation of *A* with one variable constant is the same as the standard error of estimate for the coefficients of regression of *A* on that variable and shows the amount of variation that will remain in *A* after adjusting it on the basis of that regression. The relative fit of the 3 and 5 row plats to the individual rows for series 1 and 6 and series 2 and 7 is shown graphically in figure 1. The fit of the plats of two alternate rows is not shown, but may be estimated readily from the individual row values.

The reliability of the correlation coefficients and the constants derived from them rests upon the assumption that the relations between the variables are rectilinear. That the latter assumption is warranted as regards the relations of the individual rows with the 3-row plats is shown clearly in figure 2, in which the means of *A* for the corresponding values of *T* are shown by the plus sign (+). The regression line for *A* on *T* also is shown in figure 2.

TABLE III.—*Coefficients of correlation of A with B, T, and C; coefficients of regression of A on B, T, and C; gross standard deviations, in percentages, of A, B, T, and C; and partial standard deviations of A for constant B, T, and C, for a single row and for the mean of 4, 10, and 22 rows*

Variable.	Coefficients of— Correlation, *A* with variable in column 1.	Coefficients of— Regression *A* on variable in column 1.	Percentage σ of variable in column 1.	Percentage σ_A for the mean of the number of rows stated, when the variable in column 1 is made constant. 1 row.	4 rows.	10 rows.	22 rows.
1	2	3	4	5	6	7	8
A	....	....	16.805	....	[a] 8.403	[a] 5.315	[a] 3.583
B	0.6995±0.0230	0.830	14.170	12.009	6.005	3.798	2.560
T	.8616± .0116	1.027	14.100	8.530	4.265	2.698	1.819
C	.8266± .0143	1.117	12.440	9.458	4.729	2.992	2.016

[a] Gross σ_A.

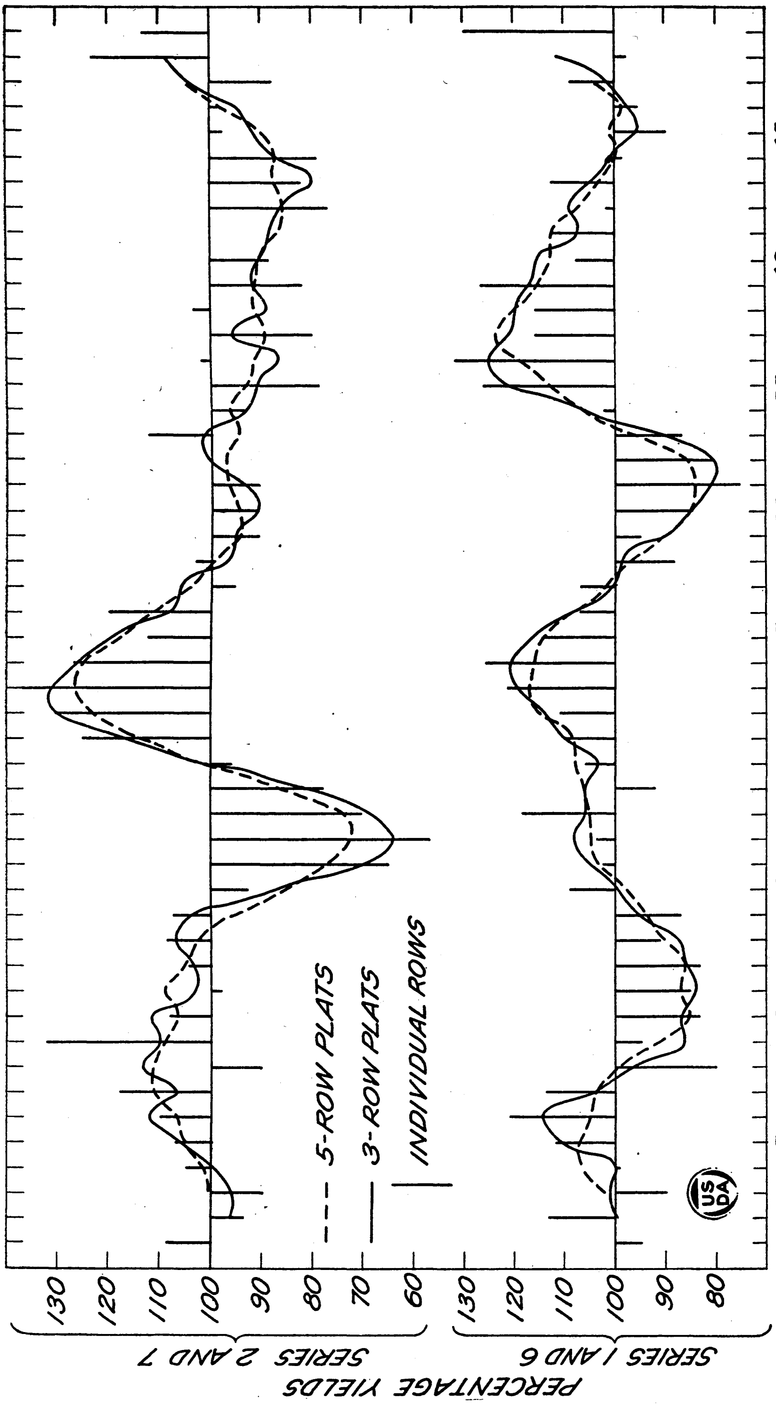

FIG. 1.—Graph showing the percentage yields of individual rows, 3-row plats, and 5-row plats in series 1 and 6, and 2 and 7.

Adjusting yields to 3-row plats of which the rows to be adjusted are components may seem objectionable. In the experiment under consideration, however, inspection of figure 1 shows that the individual variation of *A* is of relatively little importance in determining *T*. It is the variation in *A* concomitant with that of the row on each side that is important, and *T* is superior to *B* because more of the independent

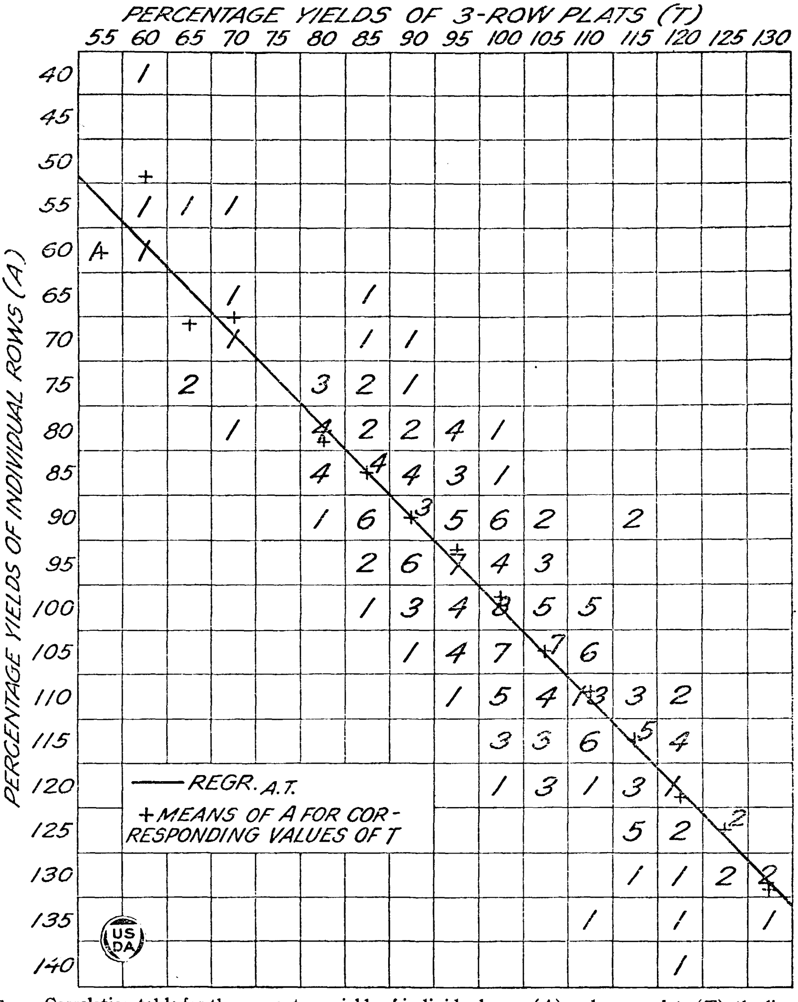

FIG. 2.—Correlation table for the percentage yields of individual rows (*A*) and 3-row plats (*T*); the line of regression of A on T; and the mean values of A for each corresponding value of T.

variation of the individual rows is equalized when three rows are averaged than when two are averaged. *T* is superior to *C* as a check because it responds more quickly, and more nearly approximates the extremes of *A*.

THE METHOD OF ADJUSTING

In adjusting the yields, each actual yield is divided by the corresponding predicted percentage yield. The latter are obtained from the regression equation, in this case, $a = 1.027t$, in which *a* and *t* are the deviations from their respective means, or this equation may be converted to absolute values, $A = 1.027\ T - 0.027$. The predicted A's then may be calculated for the corresponding values of T. Thus, for row 6, series 1, $T =$ 115.4 per cent, or 1.154. $1.154 \times 1.027 = 1.185$, $1.185 - 0.027 = 1.158$, the predicted yield of row 6. The actual yield, 15.4 pounds, divided by 1.158 = 13.3 pounds, the adjusted yield of row 6. The "Adjusted yields, basis of 3-row plats" in column 6 of Table II are the averages of the yields corrected in this way. Here again the means are modified slightly, but the gain in reliability as measured by the decrease in the probable errors is about half. Moreover, the method used here is based upon the determined regression and involves no arbitrary assumption, which was not the case for the data in column 5.

In practice it will be easier and sufficiently accurate to obtain the predicted percentage yields graphically from the regression line drawn as in figure 2, but to a reasonably large scale.

OTHER CONSIDERATIONS

The planting arrangement used in the experiment described is in no way fundamental to the method of adjustment proposed. In fact, it would have been better from the standpoint of theory if the replicates of the different items had been distributed more widely. Neither is it necessary to have as many replicates as in this case. It is necessary to have plats of such size and frequency as will give a reasonable approximation of the productiveness of each seed class. The replicates should be distributed systematically to cover the experimental field as uniformly as possible, and in such a way that the sequence is not the same in the different series. Thus, representing the seed classes by 1, 2, 3, 4, etc., the first may be planted 1, 2, 3, 4, etc., the second, 1, 3, 5, 7, etc., the third, 1, 4, 7, 10, etc., and the fourth, 1, 5, 9, 13, etc., or any similar system that will give a different sequence in each series. The index of productiveness for each 5-row group under such a system would be in terms of the average of 20 rows located in different parts of the field, and the final mean of four adjusted replicates would be weighted according to the yield of as many as 80 rows in a large experiment properly arranged. Moreover, although not all strains will be used equally in correcting each of the others unless the number of replications is the same as the number of strains in the experiment, nevertheless the basis will be an average of a large number of strains in each case, thus reducing the chances of distortion due to the specific response of a single variety.

It is recognized that the extreme variability of the soil in the experiment discussed in some ways made the data particularly amenable to the correction used. On the other hand, probably many experimental fields are equally, though not similarly, variable. The rapidity of the variation in the case considered, as brought out in figure 1, made conditions decidedly adverse for adjustment. It was this rapid variation that made the 3-row plats better than the 5-row plats for predicting. A field with a gradual change in productiveness from one side to the other, but with negligible fluctuations around this trend, would be ideally suited to adjustment on the basis of a moving average, although in such a case the optimum number of rows to be averaged probably would be larger.

The important points are that adjustment on the basis of the determined regression is not arbitrary and that no extra land or field labor is required. The computations of the indices and correlation are simple, and, if the latter is not significant, no adjustment of individual yields need be made. The following values show the average percentage reduction in the probable errors resulting from adjustment when the correlation between tests and checks is as stated:

$r=$	Reduction in variability= $100 \times 1-\sqrt{1-r^2}$	$r=$	Reduction in variability= $100 \times 1-\sqrt{1-r^2}$
	Per cent.		*Per cent.*
0.4	8.4	0.8	40.0
.5	13.4	.866	50.0
.6	20.0	.9	56.4
.707	29.3	1.0	100.0

It is evident that correlations of less than 0.6 will reduce the variability so little that adjustment of individual yields may hardly be worth while.

In the case of relatively low correlations, however, the moving average may be used as a criterion in another way. Individual yields may be modified by adjusting so as to change the mean as well as the standard deviation. Thus, if one strain occurred only on relatively poor soil in each of four replications, the four yields might be identical, but all relatively too low. This fact should be brought out by the average of the indices of productiveness for the four soils in which this strain was grown. Therefore, if individual adjustments are not made, the averages of the indices may be obtained and taken into account in drawing conclusions from the data. As an example of this use, the average percentage values of the 3-row checks for each of the strain numbers are given in Table III, column 7. These seem to be a fair measure of the reliability of the comparison, and if the difference between two strains were materially greater than the difference between the corresponding indices more significance could be attached to it.

CONCLUSION

The fundamental concepts on which the proposed method is based are: (1) That the mean yield of any one seed class is a fair measure of its productiveness, (2) that the deviations of the individual replicates from this mean are due in part to soil variation, (3) that deviations of the yields of successive groups of contiguous rows from the computed production of an equal number of average rows of similar kind are due in part to soil variation, and (4) that the correlation of the percentage yields of such groups with the percentage yields of the individual rows upon which the groups are centered measures their tendency to concomitant response to the soil variation. Granted these, and they seem entirely sound, the adjustment of yields on the basis of their regression on a moving average follows logically.