METHODS OF PREDICTING AGRONOMIC CHARACTERS IN DOUBLE CROSS MAIZE HYBRIDS

by

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B. S., University of Nebraska, 1937

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1939

TABLE OF CONTENTS

INTRODUCTION

Among the plants of distinctly American origin, maize, *Zea mays* L., has occupied an important position. This large cereal grass has contributed much to American agriculture and is symbolic of corn belt agriculture. Its diverse plant type, its wide range of adaptation and other qualities make maize desirable for research studies.

Corn research carried on by many investigators has developed both theoretical and practical knowledge of value to agricultural science. Intensive research in the field of genetics has been well rewarded in the discovery of 400 or more genes located upon ten linkage groups. Many of these genic factors have been associated with plant characters and abnormalities, and their analyses have given a clear understanding of their inheritance and relationship.

Cytological examination has given an insight into the mode of inheritance. The correlation of genetic evidence with cytological evidence has added much information and has given proof of genic arrangement and linkage relationships, and a clear picture of chromosomal homology and related chromosomal abnormalities.

Agronomic investigation through plant breeding efforts based upon much of the theoretical evidence previously secured, has resulted in recent years in the phenomenal growth in acreage of hybrid corn. The advantages of this "newly crossed" corn to practical agriculture are so obvious and have been repeated so often, it seems unnecessary to restate them. It is a deserving culmination of patient research, so outstanding in nature that already it is revolutionizing seed production and distribution.

The superiority of tested, well adapted hybrids over adapted varieties might well have been the goal of many early investigators in corn improvement. The reasons for the concentrated efforts of Love (1912), Ewing (1910), Collins (1916), Love and Wentz (1917), Olson, Bull and Hayes (1918), Hutcheson and Wolfe (1918), Kempton (1924) and others to locate higher yielding strains of corn through parent-progeny correlations at once becomes obvious and certainly justifiable. Relationships between various plant characters and between plant characters and yield by this method have been obtained and the field fully explored. These methods have given a quantitative measure of the existing relationship and a conception of the possibilities which might result through recombination of desirable factors.

Similarly the method of mass selection and the ear-to-row method have been used in corn improvement work. Although progress was made by mass selection in securing better adapted varieties, little increase in yield was obtained. The ear-to-row method used extensively at the Ohio and Illinois Experiment Stations in the early twenties, produced classical examples of modification by selection of the chemical composition of corn, as well as the selection of high eared and low eared strains of corn, but again no distinct advancement toward increased yields were obtained. The limited progress in obtaining higher yielding varieties by the method of mass selection and by the ear-to- row method can be understood after studying the principles of Mendelian inheritance.

Mendelism, together with additional genetic and cytological evidence, has suggested a far more convincing and fundamentally sound approach as a basis for corn improvement than methods previously mentioned. Shull (1909) first suggested the utilization of selection within selfed lines of corn and the utilization of the phenomenon of hybrid vigor. The most noticeable effect of self-fertilization is the marked decrease in vigor in the early generation of selfing of normal plants as well as the segregation of abnormal plant types with various deleterious characters. The reduction in vigor of growth is accompanied by a decrease in productivity.

This early apparent disadvantage of low yielding, weak inbred lines has been eliminated through their utilization in double-cross combinations as well as in single crosses, three-way crosses, top-crosses, and synthetic varieties. At the present time, however, the double-cross hybrid is produced to the apparent exclusion of all others in the commercial production of hybrid seed corn. The other methods of combining inbred lines, although not common in commercial practice, do have a place in experimental hybrid production, and may be utilized more widely in the event new, more vigorous, and higher yielding inbreds be found, or existing inbreds improved by convergent improvement methods now underway.

Selection within selfed lines necessitates testing large numbers of inbred progeny for yielding ability, for desirable agronomic characters, and for the elimination of progenies or individuals unsuited for later crossing. Much of this discarding can be made on the basis of the method suggested by Davis (1927) which involves an inbred-variety combination, commonly called the top-cross, and provides a method by which a large number of lines may be tested. Jenkins and Brunson (1932) explain that inbred lines which are seemingly desirable from top-cross data are carried into further generations by selfing, and that crosses can be made between unrelated lines, preferably after the fifth generation of selfing, and tested for yield and other agronomic characters. Lindstrom (1931a) obtained significant increases in yield from the use of inbred sires on the commercial varieties of sweet and dent corn. Experimental data show variations between inbred sires for ear type, disease resistance (smut), lodging and uniformity of maturity. Davis (1934) stated that inbred-variety crosses give fairly reliable indications of the comparative yielding capacities of the inbred lines in the second-generation of selfing. At the present time the method of top crossing is used rather widely in testing of inbred lines in the early generations of selfing.

The testing of a large number of possible combinations from new inbred lines over a period of years requires skill in handling as well as patience of the investigator. Not only is proper planning necessary, but the selection of lines for crossing to produce single crosses, and the selection of single crosses to produce double-cross combinations which seem to have the greatest possibilities is very important in a successful breeding program.

In order to facilitate the elimination of hybrid combinations of questionable value, several methods have been formulated. The methods suggested by Jenkins (1934), and those suggested by Doxtator and Johnson (1936) based upon and similar to the former's methods, have been of greatest value. Single crosses in all possible combinations provide data for estimation of the double-cross performance for three of the proposed methods suggested by Jenkins (1934) and inbred variety crosses provide data for a fourth method.

The importance of the selection of promising single crosses to be used in new double-cross combination and the elimination of poor single crosses of questionable breeding value warrants an intensive study of their breeding behavior and performance as expressed in yield or other heritable agronomic characters. It seemed desirable, therefore, to begin a study devoted to the critical examination and breeding behavior of important agronomic characters of single crosses and to evaluate these characters in such a way that the methods of estimation previously mentioned might be used in determining their probable performance in double-cross combinations. The apparent need of a more accurate statistical analysis in evaluating methods of estimation also seems necessary. Correlation coefficients, while measuring relationships between methods, do not measure their reliability as a means of estimating double-cross performance.

The objectives of this research, therefore, are: to critically examine the data secured on agronomic characters of single crosses, to calculate their estimated breeding behavior in double crosses, together with a comparative statistical measure of their reliability, and to compare this estimated breeding behavior with their actual performance.

REVIEW OF LITERATURE

Parent-Progeny Relations

The study of parent-progeny relations in early varietal improvement work, primarily because of their importance in discovering higher yeilding varieties with desirable agronomic characters, was once thought to be full of promise. The basis for such a study is somewhat obscured today as a result of the acceptance of the inheritance of characters, either quantitative or qualitative, based upon Mendelian principles. Early investigators, however, understood and saw the evident need of improved varieties. Their study of parent-progeny relations was an outgrowth of this apparent need. Studies of this type are especially abundant in early corn improvement literature.

Shortly after the beginning of the twentieth century great emphasis was placed on selection of ears for show type. Investigation later brought out many shortcomings. Yield could not be increased by such a method of selection, and this gave an impetus to research in corn improvement which was based for the most part upon a study of agronomic characters related to yield. Correlation coefficients were generally used as a measure of this relationship.

Correlations between various characters may originate from fluctuations in the characters concerned and variations of this type could easily result from changing environmental conditions as suggested by Ewing (1910). He concluded "that very little improvement could be made by the method of correlation, but that it was of some value to know the regression of one character relative to a correlated character when the other is under selection through a number of successive generations."

Smooth ears proved to be higher yielding than ears of the rough type (Montgomery, 1909). Seed selection of smooth ears, because of better environmental adaptation, rather than ears of the rough type was then considered the proper method of maintaining a good adapted open-pollinated variety.

McCall and Wheeler (1913) published a short summary of their work on such relationships and found that neither length, weight, circumference, or ear density was correlated with yield.

According to Cunningham (1916) too much emphasis was placed upon ear characters as related to yield. He suggested, however, a smooth type of corn would generally outyield a rough type of the same variety. No significant correlations between ear characters and yield were obtained by Love and Wentz (1917) but were not of sufficient size to be of value, and they concluded that the ear-to-row progeny test for selection of high yielding strains was most desirable. Again Olson, Bull and Hayes (1918), in a thorough study of the selection of show type ears showed conclusively that such selection was of no practical value and believed that close selection for any set of characters might prove detrimental because of inbreeding. As a result of these investigations, a broad system of breeding corn varieties was suggested.

A relation between yield and length of ear, and yield and weight of ear was found by Hutcheson and Wolfe (1918) and by Biggar (1919), but no relation was found between number of rows and yield or shelling percentage and yield. Results obtained by O'Kelly and Hull (1932) agree with other conclusions that no improvement in corn could be made by the association of plant characteristics and yield.

A positive correlation between yield and breaking strength of the cob was found by Winter (1926). A positive correlation was also obtained between either a pink or a red coloration of the lignified portions of the cobs and average yield while a negative correlation existed between brown coloration of the lignified portions of the cobs and average yield.

Yield and prolificacy were found to be highly correlated by Brunson and Willier (1929), thus the more prolific strains of corn tend to produce offspring which are more productive.

In a summary of correlation studies between ear characters and yield, Etheridge (1921) acknowledges the existence of correlations, though they are not an index or a relative measure of yield. Therefore, it is believed that any conception of yield must be based upon a multiple factor hypothesis and cannot be measured through correlation analysis of ear characters alone. The effect of environment upon yield must also be considered in this connection, and its importance at once becomes obvious.

Other plant characters in relation to yield of corn have been studied by a number of investigators. Smith and Walworth (1926) in a study of seminal root development in corn in relation to vigor or early growth and yield concluded that there was a measurable and distinct difference between various ears as well as in various varieties in the number of seminal roots. They obtained a high correlation between a high seminal root number and yielding ability of the strain and also found some evidence of the association of a high seminal root production with early vigor and growth.

Work on the relation of yield to the number of seminal roots by Collins (1927) did not verify the study made by Smith and Walworth (1926). No evidence of an association was obtained. A correlation of 0.208 for a low number of seminal roots and yield, and a correlation of -0.593 for a high number of seminal roots and yield was found, thus reversing or nulifying the conclusions of the former. Mangelsdorf and Goodsell (1929) found no relation between yield and the number of seminal roots. Evidence obtained by them did show that the number of seminal roots was positively and significantly correlated with vigor of seedlings in germination tests, but negatively and significantly correlated when planted directly into the soil. It was also found that number of seminal roots was an independent character and not associated with most agronomic characters.

Corn improvement based on Mendelian methods moved rather slowly, greatly overshadowed by the tremendous research program underway with correlation analysis and its possible value in breeding work. A renaissance in corn improvement was necessary. Once Mendelian principles were accepted as the most logical method of breeding, advancement was rapid.

Shull (1909) first suggested the utilization of selfed lines in practical corn breeding by outlining (1) methods of finding the best pure lines, and (2) methods for the utilization of pure lines in the production of seed corn. The phenomenon of hybrid vigor which is involved in such a method of improvement was first explained by Bruce (1910) and Keeble and Pellew (1910) and later expanded by Jones (1917).

Research on parent-progeny relations, based on the proposed method for corn improvement, was started to determine the relation of inbred lines and their crossed progeny. Hayes (1926) stated that present day problems of corn improvement are concerned largely with the reactions of selfed lines and of crosses between them. Statements of this type are particularly abundant in later literature, emphasizing primarily the relationship of various inbred characters to the productive capacity of their F_1 hybrids, a feature in which investigators were mainly interested.

Kiesselbach (1922) found a general relation between the yield of inbred lines and their cross-bred progeny. Some exceptions were found, however. Richey and Mayer (1925) found that there was little if any relation in yield of inbred lines to their bross-bred progeny, and that the final test of inbred lines must be determined by the performance of their crosses. It is of practical importance, however, to use and secure inbred lines which are high yielding.

In correlation studies with characters of the inbred lines with the same characters of their F_1 crosses, Jorgenson and Brewbaker (1927) obtained positive and significant correlations for yield 0.50 ±0.07, length of ear 0.58 ±0.07, diameter of ear 0.63 ±0.06, number of kernel rows per ear 0.78 ±0.03, height of stalk 0.47 ±0.07, and weight of seed 0.39 ±0.09. All characters with the exception of number of kernel rows per ear are expressions of vigor. Nilsson-Leissner (1927) in a similar study also obtained positive correlations for the characters studied, and also found that some inbreds were superior to others as parents of crosses. He concluded that in general high correlations have been found between yield and other characters that are expressions of vigor in the selfed lines and the same characters in the F_1 crosses between them and, when considered on the basis of present conceptions of heredity and hybrid vigor, could be expected.

Jenkins (1929) made an exhaustive correlation study of characters of inbred lines, of characters of F_1 crosses, and of characters between them. The highest simple correlations within inbred lines were for ear characters, as might be expected. All were positive and significant, the highest being a correlation between yield and shelling percentage of 0.39. The multiple correlation between yield and the twelve characters studied was found to be 0.69 ±0.03. A larger number of simple correlations were found to be significant in the F_1 crosses than in the inbred lines. The highest correlations of yield with another character, again an ear character, was with ear length, a correlation of 0.42. Multiple correlations of the characters of the F_1 crosses were highest for yield correlated with the ear characters. Multiple correlation between yield and the ten characters studied was 0.71 ±0.02. In a study between characters of the inbred parents and those of their F_1 crosses positive and significant correlations were obtained in every case. The highest correlation obtained was for percentage of erect plants. Other high correlations were obtained for number of kernel rows per ear, nodes per plant, nodes below the ear, and percentage of nodes below the ear. Yield gave the lowest correlation. Characters in the inbred parents which were most highly correlated with yield in their F_1 crosses, were nodes per plant, yield, nodes below the ear, plant height, date of tasseling, and length of ear, all being characters associated with size and vigor. Jenkins (1929) also adds that the high yielding crosses did not occur by chance combinations, but were the progeny resulting from the crossing of certain outstanding inbred lines.

The chlorophyll content of the leaves was used as an index of the productive capacity of selfed lines of corn and their hybrids by Sprague and Curtis (1933). Results show that total chlorophyll was more highly correlated with yields of total dry matter and grain, leaf area and chlorophyll concentration than any other factors. In addition it was found that chlorophyll content was genetically recessive, dominant, partly dominant or cumulative in relation to other selfed lines. Selection and mating of selfed lines on the basis of chlorophyll concentration or color is described as the best breeding practice to obtain prepotent lines and high yielding hybrids and also might be an index of parent-progeny relations.

Consideration must be given to parent-progeny relationships, and their differential resistance to the attack of certain insects. The wide spread infestation, the destructive nature, and the large monetary loss caused annually by the European corn borer, Pyrausta nubilalis is particularly well known in the eastern corn belt. The increase in interest in this field can partially be explained by the obvious nature of the injury to the plants, as well as the consequent or probable later effects of the injury on the plant.

There is probably no other single insect that causes such obvious injury to corn as does the grasshopper. There is some evidence to indicate that there is a differential resistance of corn varieties, of top crosses, and of hybrids to injury by this insect, Brunson and Painter (1938). They state that varieties and inbred lines of corn showing greatest resistance originated in areas where grasshoppers are a natural element of the environment, and they suggest that natural selection has operated to intensify the resistance of corn to grasshoppers and to other natural insects.

Other less important insects also cause damage to the corn crop. These insects are the chinch bug, the southern corn root worm, the corn ear worm, and the white grub. A number of corn hybrids are known to be resistant to attack by chinch bugs, and a study has indicated that the probable resistance may be due to the presence of certain inbred lines in the constitution of the hybrids, Dungan et. al. (1938b). Resistance to attack by the southern corn root worm has been reported in the Illinois Corn Performance tests by Dungan et. al. (1938a), although no mention was made of resistant inbreds or single crosses.

In studies of the relative resistance of corn to ear worm attack by Painter and Brunson (1939) it is shown that there is a wide range of differential class injury between the inbred lines of corn as determined by their single cross performance. Production of single crosses carrying a high degree of resistance to corn ear worm by crossing resistant inbred lines may be possible, as well as predetermining the suitability of their use in producing various double crosses by their parent-progeny relationship.

Painter and Brunson (1939) have secured highly significant correlations between the class of injury of each succeeding year showing apparent resistance or susceptibility to attack. It is quite probable, therefore, that inbred lines differ in their resistance to attack by the corn ear worm and that this resistance is hereditary.

Morphological characters, especially the length of husk, have been studied to secure resistant corn varieties. Collins and Kempton (1917) found a high correlation between prolongation of husks and low damage, as well as a correlation of 0.66 ±0.09 between the average damage of parent and progeny. Evidence secured by McClelland (1929) indicates that little or no protection is offered by long shucks in a season when the attack is universal. It is probable, however, that morphological characters are concerned in resistance to ear worms.

In occasional years damage to corn caused by white grubs, _Phyllophaga spp._, may be found in local areas. The damage to corn, primarily, consists of cutting off many of the brace and feeding roots of the corn plant, the amount of damage depending upon the maturity, as well as what reduction of yield or what amount of lodging occurs. If infestation becomes particularly heavy during the latter part of the season, little difference in yield will result; however, under this condition lodging may become extraordinarily serious. Such variations in resistance to lodging are clearly apparent to the most causal observer. Dungan et. al.(1938b) have made comparative studies of the resistance of various single crosses to white grubs and upon examination found one single cross, Tr x L317, particularly susceptible while others were much more resistant to attack. Selection of inbred lines upon a basis of a parent-progeny relationship could well give added impetus as well as encouraging results in later hybridization.

In Kansas drought is perhaps the greatest limiting factor in crop production. Crop plants must cope with the particularly adverse conditions of high temperatures, high evaporation, low humidity, hot winds, and erratic rainfall in their growing season. Particular attention must be given to these environmental factors in relation to the adaptation of new varieties of crop plants, as well as a fundamental consideration in a crop improvement program. Jenkins (1932) called attention to the differential resistance of inbred and crossbred strains of corn to drought and heat injury, and suggested that much might be accomplished in breeding for drought resistance in corn.

A method for studying resistance to drought has been proposed by Hunter, Laude and Brunson (1936) in which comparative determinations of resistance to heat between inbred lines or crosses are made. They believe that there is a relation between this type of seedling heat resistance and field resistance to heat and drought. Heyne (1938) has shown that there is evidence of inherited resistance and susceptibility to these factors. Inbred lines susceptible to heat and drought when crossed probably will produce hybrids which are susceptible. If these relationships exist it is extremely important to differentiate inbred lines accordingly, and to discard or refrain from using them unless they are particularly desirable in other characters. Possibilities of determining probable resistance or susceptibility by such a study is a reasonable assumption, and the relationship of the parent to probable progeny performance used as a basis for determining the expected results in the succeeding progeny is logical.

Breeding for resistance to lodging is stressed in corn improvement and probably ranks second to yield in importance among the desirable features of hybrid corn. Strains or inbred lines with high root lodging resistance or resistance to stalk breaking can be obtained by the inbreeding and selection methods commonly used. These selected strains when crossed can be expected to produce crosses which are comparatively resistant to the various types of lodging. In a comparison of parental selfed lines and their F_1 crosses, Hayes and McClelland (1928) found a high correlation coefficient between the average lodging of the parents and their F_1 crosses. These correlations in three different varieties were $+0.72 \pm 0.07$, $+0.77 \pm 0.05$, and $+0.65 \pm 0.07$ respectively, from which it is justifiable to assume that the ability to withstand lodging is dependent to a marked degree on inherited genetic differences.

The common ear and stalk rots may influence lodging by infecting stalks of the growing plant, spreading through the tissues and weakening them so that later in the season near maturity excessive stalk breaking may occur in susceptible strains. Jugenheimer has obtained evidence of inherited differences within inbred lines and crosses between them, in resistance to _Diplodia zeae_ and its effect upon lodging, over a wide range of conditions. Resistant strains x resistant strains appear to be resistant, resistant strains x susceptible strains appear to be intermediate or partially resistant, while susceptible strains x susceptible strains are susceptible to the disease.

Histological studies of inbred lines made by Hunter and Dalbey (1937) give evidence of a relationship between anatomical structure of the stalk and resistance to lodging. In plants remaining erect, bundle sheaths and the subepidermal sclerenchyma layers were several cells thick and stained deeply. The cells were also more angular and had smaller intercellular spaces between them in the resistant strains.

Evidence has already been presented in regard to lodging caused by insect attack. Few, if any, intensive studies have ever been conducted on the problem, for the most part due to the variability and spasmodic occurrence of the attack of some insects. Some evidence has been obtained and a measurable resistance to attack by insects and subsequent lodging especially to the white grub, *Phyllophaga spp.*, has been found (page 17) in certain hybrid combinations.

Probable differential resistance to lodging may, therefore, be determined by several methods to which consideration must be given in a corn improvement program. All features of lodging resistance should be used as a basis in the selection and isolation of productive inbred lines and crosses. This necessitates a critical examination of available material, as well as a careful choice of lines to use in subsequent combinations.

Genetic Aspects

Parent-progeny studies of characters such as height of plant, height of ear, length of shank, number of nodes, smut resistance, resistance to damage by corn ear worm, size of ear, yield of grain, resistance to firing and resistance to lodging necessitates the use of the multiple factor hypothesis for interpretation. Development of these "size characters" probably is dependent upon the interaction of two or more genetic factors the expression of which is also associated intimately with the conditions of the surrounding environment. "Size characters" are expressions of degree rather than of kind.

Nelsson-Ehle (1908) presented the first evidence of the inheritance of characters of this type in color studies of oats and wheat for interpretation of the inheritance of quantitative characters. His work with a cross between a red seeded variety and a white seeded variety is a classical example of such inheritance and clearly shows the cumulative effect depending upon the dosages contributed by the genes.

Proof that such genes exist has been obtained by Sax (1923) in work with beans in which characters of pigmentation, pattern and eye-color, and self-color were studied.

In crosses of large pigmented beans x small white beans involving several thousand progenies, the white segregates were always smaller than pigmented, patterned or self colored segregates. There was evidence to show that a gene which is linked with pigmentation is responsible for the increase in seed weight.

Lindstrom (1926) has obtained evidence of a major gene for fruit size in the tomato and has determined its linkage relations with several nearby genes, and in addition has shown that other genes influencing fruit size are found in at least two other chromosomes. Specific genes controlling the number of rows on a maize ear have also been reported by Lindstrom (1931b).

The cumulative effect of quantitative factors is commonly known as blending inheritance. Characters of a cross in the F_1 generation usually are intermediate in nature, segregation and recombination occur in the F_2 generation and transgressive segregation follows in the F_3 progeny. Exceptions are found, however, in the cases of the F_1 generation particularly, due to the phenomenon of heterosis. Hybrids from such crosses often exceed their parental size. The effect of heterosis is also cumulative, and dependent upon the number of heterozygous factors involved. Hybrid vigor may be expressed not only as increased size and yield, but also as disease and insect resistance, as drought and lodging resistance, as well as other manifestations. The effects of heterosis are rather difficult to express quantitatively, and the term hybrid vigor is used commonly in its description.

On such a quantitative hypothesis it may be assumed that inbred lines, after a number of years of selfing, become homozygous for evident characters and when crossed produce progeny of the same genetic constitution each time the cross is made. Single crosses thus have separate and distinct individualities representing a particular combination. It has been possible to measure the character expressions of inbred lines in their single cross progeny by methods already mentioned, the characters being influenced to some extent by the prepotency of the lines.

On the same basis a double cross combination, produced by crossing two single crosses, would have the same genetic constitution as represented by the parent single crosses. Characters measured in double crosses should, therefore, have some relation to the characters of their component parents, unless the phenomenon of hybrid vigor or heterosis entirely eliminates or masks similarities between them, or the characters have been masked by conditions of the immediate environment. Normally, however, it should be possible to measure a number of these characters, to analyze them statistically and to determine their relationship.

In addition it appears within the realm of possibility, at least to a greater or lesser degree, to predetermine certain characteristics of double cross hybrids from their parental single crosses. Quantitatively it also seems logical to believe, that there should be an independent factorial complex influencing various characters of the plant. An intensive study and analysis by proper methods of some of the quantitative characters of the maize plant in single cross combinations though limited in expression by environmental fluctuations, should give a conception of expected related characters in double cross hybrids.

Suggested Methods for Estimating Performance

One of the problems that is constantly confronting the corn breeder is the choice of inbred lines and single crosses, which in combinations will be productive and also have desirable agronomic characters. The enormous number of available inbred lines, and their subsequent possible combinations in single and double crosses, make it quite impossible to attempt to test each of them adequately. There is a need of a simple method of eliminating many of the less promising combinations in respect to yield as well as to desirable agronomic characters.

One of the most promising methods suggested for the elimination of inbred lines in early generations of selfing is a method involving an inbred-variety cross proposed by Davis (1927). Jenkins and Brunson (1932) state that fifty per cent of the lines tested in this way may be eliminated without losing superior germ plasm, the remaining lines being tested further for their future possibilities in crossbred combination. Such early elimination of unpromising material greatly enhances the efficiency of the breeding program.

Jenkins (1934) made a study of various methods of estimating the performance of double crosses in corn from known single cross data. He used four methods of estimation as follows: Method A. - An estimate obtained from a computation of the mean values for any character in all of the six possible single crosses among the four inbred parents of the double cross; Method B. - An estimate obtained from the mean value of each character of the four single crosses which are not represented by the double cross combination; Method C. - An estimate of the mean value among all the possible combinations in which each of the four lines was a parent, thus determining the apparent prepotency of the lines; and Method D. - The estimate calculated from the mean values for the inbred-variety crosses of its four parental lines. Correlation coefficients between performance of the double crosses and the estimates of their performance by the four methods outlined for various characters which he obtained are given in Table 1.

Table 1. Coefficients of correlation between the performances of double crosses and the estimates of their performance as obtained by four different methods.

Character	Methods of Estimation			
	A	B	C	D
Burned leaves	0.60	0.65	0.57	0.57
Ear height	0.38	0.42	0.32	0.31
Plants erect	0.77	0.70	0.75	0.64
Moisture	0.69	0.61	0.72	0.49
Shelling percentage	0.70	0.78	-0.06	0.70
Acre yield	0.75	0.76	0.73	0.61

Significant r = 0.39

In a study of the scatter diagrams of each method for yield, he concludes that the information obtained from comparisons of inbred-variety crosses may be utilized to good advantage in estimating the performance of double crosses among these lines.

The Method B, suggested by Jenkins (1934), was used by Doxtator and Johnson (1936) to predict double cross yields in corn and was utilized to determine the best possible double cross combination from four inbred lines of known value. Data on yield were only secured, the predicted yield being determined from the mean yields of the four single crosses not used as parents. The results obtained indicate that highly significant differences in yielding ability can be found in the double crosses originating from the different single crosses produced from four inbred lines. By using single cross data by the method suggested, the highest yielding double cross combinations may be predicted with a fair degree of accuracy.

MATERIAL AND METHODS

Germ Plasm

Plant improvement in which the tool of crossing is used to produce material from which later selections are made, ordinarily follows one of two methods. These are, first, many crosses can be made between the hundreds of plants available to the breeder, the crosses being made at random and indiscriminately, and second, planned crosses between plants which carry desired agronomic characters or have known prepotency for yield. In the field of corn breeding crosses are usually made between inbreds and between single crosses which have known superiority, and many inbred lines are discarded by preliminary top cross testing or discarded because of abnormal and deleterious characters.

After such elimination of inferior stocks, hundreds of crosses can be made between superior inbred lines and the resulting single crosses can be recrossed giving many possibilities, so many in fact, that it becomes quite impossible to obtain performance data upon all of them. If it would be possible to eliminate the production of, and the testing of inferior combinations, the efficiency of a hybrid corn project could be greatly increased. Methods for such elimination have been suggested by Jenkins (1934). These methods have been outlined previously, and have been followed to a great extent in this investigation. Because of the importance of the problem and the availability of material, work was begun in the fall of 1937.

Among the crosses produced by the project of Corn Investigations, Kansas State College, six inbred lines of quite dissimilar nature were found to have been crossed in all possible combinations, as well as several of the possible double cross combinations between the single crosses. The inbred lines involved are white, and originated from the Pride of Saline variety. They are designated by the following pedigrees: PS26, PS41, PS44, PS54, PS55, and PS63. Each had been inbred for at least six generations or more and apparently were homozygous for observable characters, before being crossed to produce all possible single cross combinations.

The single crosses are listed in Table 2, each line being crossed with every other line five times.

Table 2. Fifteen possible single cross combinations involving six inbred lines.

Inbred lines	Inbred lines					
	PS 26	PS 41	PS 44	PS 54	PS 55	PS 63
PS 26	---	X	X	X	X	X
PS 41	---	---	X	X	X	X
PS 44	---	---	---	X	X	X
PS 54	---	---	---	---	X	X
PS 55	---	---	---	---	---	X
PS 63	---	---	---	---	---	---

A few double cross combinations involving the single crosses listed in Table 2 were made during the season of 1937. It was, therefore, necessary to supplement the supply by greenhouse plantings during the winter of 1937-1938. Plantings of the single crosses to produce the desired combinations were made at Manhattan, Kansas, and a larger duplicate planting was also made at the Arlington Farm greenhouse, of the United States Department of Agriculture, at Arlington, Virginia. Excellent sets of seed were obtained in the Manhattan greenhouse, but because of the limited space available not enough seed for the test was produced. Most of the crosses at the Arlington greenhouse were failures, necessitating the removal of many of the double crosses from the test because of lack of seed. The 45 possible double cross combinations, along with the double crosses studied in this investigation and additional observational double crosses for which not enough seed was available for inclusion in the experiment are listed in Table 3.

Table 3. Forty-five possible double crosses between 15 single crosses including 29 double crosses studied and seven double crosses grown for observation.

Single crosses	Single crosses 26 x 41	26 x 44	26 x 54	26 x 55	26 x 63	41 x 44	41 x 54	41 x 55	41 x 63	44 x 54	44 x 55	44 x 63	54 x 55	54 x 63	55 x 63
26x41															
26x44															
26x54															
26x55															
26x63															
41x44			X*	X*	X										
41x54		X*		X*	X*										
41x55		X*	X*		X*										
41x63		X*	X^o	X^o											
44x54	X*			X	X*			X*	X*						
44x55	X		X*		X^o		X*		X^o						
44x63	X*		X	X			X*	X*							
54x55	X*	X*			X	X*			X^o			X			
54x63	X*	X*		X^o		X*		X*			X*				
55x63	X*	X^o	X			X*	X*			X					

X = Possible double cross.
X*= Possible double cross studied.
X^o= Possible observational double cross.

The planting plan for the six inbred lines studied is given in Table 4.

Table 4. Planting plan of the six inbred lines.

Pedigree	Row Number in Replication					
	1	2	3	4	5	6
PS 26	14	24	34	42	54	62
PS 41	15	26	32	41	55	66
PS 44	11	21	33	45	56	65
PS 54	13	23	36	46	51	64
PS 55	12	25	35	43	53	61
PS 63	16	22	31	44	52	63

The planting plan of the single crosses studied is given in Table 5.

Table 5. Planting plan of the 15 possible single crosses involving six inbred lines and Pride of Saline variety.

Pedigree	Row Number in Replication					
	1	2	3	4	5	6
PS26 x PS41	106	210	311	405	505	601
PS26 x PS44	103	206	312	412	506	608
PS26 x PS54	109	215	305	407	512	616
PS26 x PS55	101	214	315	411	508	605
PS26 x PS63	115	216	307	403	515	602
PS41 x PS44	102	201	309	414	513	610
PS41 x PS54	107	207	314	415	501	606
PS41 x PS55	114	213	306	402	510	615
PS41 x PS63	113	208	310	404	507	603
PS44 x PS54	110	209	301	409	514	609
PS44 x PS55	111	212	308	401	511	613
PS44 x PS63	112	204	303	410	516	614
PS54 x PS55	104	211	313	408	502	607
PS54 x PS63	108	205	316	416	509	612
PS55 x PS63	116	202	304	413	504	604
P. of S.	105	203	302	406	503	611

The planting plan of the double crosses studied in this investigation is shown in Table 6.

Table 6. Planting plan of the 29 double cross hybrids and Pride of Saline variety.

Pedigree	Row Number in Replication					
	1	2	3	4	5	6
(PS26xPS41)x(PS44xPS54)	1012	2021	3014	4025	5027	6030
(PS26xPS41)x(PS44xPS63)	1007	2007	3008	4017	5014	6027
(PS26xPS41)x(PS54xPS55)	1029	2013	3009	4030	5030	6015
(PS26xPS41)x(PS54xPS63)	1001	2030	3010	4019	5004	6020
(PS26xPS41)x(PS55xPS63)	1027	2005	3016	4023	5020	6001
(PS26xPS44)x(PS41xPS54)	1028	2004	3029	4022	5026	6022
(PS26xPS44)x(PS41xPS55)	1021	2006	3004	4015	5028	6023
(PS26xPS44)x(PS41xPS63)	1025	2026	3012	4002	5018	6025
(PS26xPS44)x(PS54xPS55)	1005	2018	3028	4003	5001	6014
(PS26xPS44)x(PS54xPS63)	1015	2015	3022	4018	5011	6029
(PS26xPS54)x(PS41xPS44)	1019	2016	3001	4014	5024	6013
(PS26xPS54)x(PS41xPS55)	1017	2010	3030	4029	5017	6018
(PS26xPS54)x(PS44xPS55)	1024	2023	3011	4004	5005	6026
(PS26xPS55)x(PS41xPS44)	1002	2027	3027	4016	5016	6008
(PS26xPS55)x(PS41xPS54)	1006	2017	3015	4021	5006	6006
(PS26xPS63)x(PS41xPS54)	1010	2003	3003	4010	5009	6017
(PS26xPS63)x(PS41xPS55)	1011	2020	3023	4008	5012	6003
(PS26xPS63)x(PS44xPS54)	1016	2009	3002	4027	5008	6019
(PS41xPS44)x(PS54xPS55)	1009	2024	3025	4012	5007	6011
(PS41xPS44)x(PS54xPS63)	1020	2025	3017	4001	5019	6021
(PS41xPS44)x(PS55xPS63)	1026	2029	3013	4006	5025	6004
(PS41xPS54)x(PS44xPS55)	1014	2008	3021	4009	5029	6002
(PS41xPS54)x(PS44xPS63)	1018	2028	3007	4011	5021	6028
(PS41xPS54)x(PS55xPS63)	1004	2011	3024	4020	5013	6012
(PS41xPS55)x(PS44xPS54)	1030	2002	3005	4024	5010	6007
(PS41xPS55)x(PS44xPS63)	1003	2001	3018	4026	5023	6016
(PS41xPS55)x(PS54xPS63)	1013	2012	3026	4028	5002	6009
(PS41xPS63)x(PS44xPS54)	1022	2014	3020	4007	5015	6005
(PS44xPS55)x(PS54xPS63)	1023	2022	3019	4013	5003	6010
Pride of Saline	1008	2019	3006	4005	5022	6024

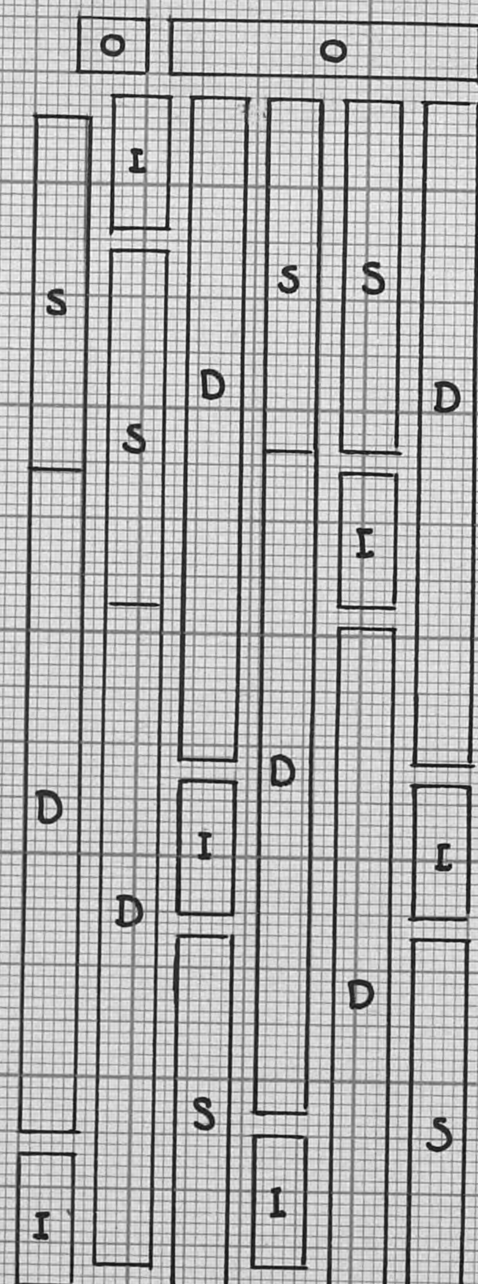
Field Technique and Notes

Three groups were included in the experiment, viz., inbred lines, single crosses, and double crosses. Each group was replicated six times in 2 x 5 hill plots, each particular group being randomized for position within each of the six series, as well as each entry of every group being randomized within that group. Each group of inbred lines, single crosses and double crosses was set off from the adjacent group by comparable borders on every side within and between each series to eliminate border effect, so that statistical analysis could be used effectively. A map of the field is shown in Figure 1.

The soil type of the field on which the planting was made is classified as Wabash silty loam. At the time of planting the field appeared to be uniform, but as the season advanced considerable heterogeneity was evident, thereby causing some abnormal differences between the groups in the different series, as well as reducing the significance for each combination by limiting its ultimate expression for certain agronomic characters.

All entries were planted on the same day, April 30, and in the fall were harvested on November 10.

Detailed notes on the following plant characters and



Replications 6 5 4 3 2 1

Figure 1. The field planting plan of the inbred lines, the single crosses, the double crosses and the observational double crosses studied.

O = Observational studies
D = Double crosses
S = Single crosses
I = Inbred lines

Two border rows between groups

items were taken during the growing season and during the fall.

1. Stand. Two by ten hill plots were planted at the rate of four kernels per hill and thinned later to two plants per hill. Good stands were secured throughout the entire experiment with the exception of some of the inbred plots, in which some of the seeds apparently did not germinate or the plants were so weak they succumbed before they were able to maintain themselves. Missing hills and stand counts were taken after growth was well underway.
2. Suckers. All inbreds used in the experiment were practically free from suckers. Very few suckers were found on either the single crosses or double crosses.
3. One-fourth pollen and one-half silk. Notes on pollen shedding and silking were taken every day as far as possible.
4. Height of plant and height of ear. Height of plant and height of ear were measured soon after the plants reached full maturity. Measurements were taken to the nearest inch in both instances. The measurements were taken from

the surface of the soil near the base of the plant to the top of the tassel, and to the node from which the ear shank arose, respectively.

5. Length of shank. This measurement was taken from the nodal origin of the shank to the base of the ear, and measured to the nearest one-half inch.
6. Dropped ears. Counts of ears broken from the shanks were taken just prior to harvesting the plot.
7. Total nodes and nodes below the ear. Leaves were notched at the five-leaf stage soon after germination, and each additional five-leafed stage thereafter. It was possible to count the total nodes at a later date by counting the notches in the leaves as well as determining the nodes above and below the ear. Leaves were clipped on two series only, giving two replications of each group and each combination. Comparable data were also taken in the greenhouse on the single crosses used to produce the needed double cross combinations.
8. Leaf counts and leaves below the ear. Leaves were counted on the entire experiment, counting

being more rapid than leaf clipping and coming during the early fall after the pollinating season was closed.

9. Smut. Notes on smut were taken during the latter part of the month of September. Good notes were obtained for four classes of smut; tassel, leaf, ear, and culm smut. Plants were recorded for the type of smut which seemed to be the most serious. Later calculations included all smutted plants.

10. Firing notes. During the latter part of the growing season due to a lack of moisture and several days of hot, dry wind a differentiation for firing or leaf burning occurred. Several strains were nearly totally damaged while others appeared to be resistant to a greater degree. Each plot in the experiment was graded for firing. The following grades were used to measure the leaf surface burned:

Grade	0	No burning	
"	1	1 - 20%	of leaf surface burned
"	2	21 - 40%	" " " "
"	3	41 - 60%	" " " "
"	4	61 - 80%	" " " "
"	5	81 - 100%	" " " "

11. Yield. Yield in bushels per acre was calculated for each plot on the basis of 15.5 per cent moisture from pounds of ear corn per plot. Differences in the quality of the corn were fairly obvious but no attempt was made to include it in this study. All of the ear corn for each plot was removed from the field and stored for notes to be taken during the winter months.

12. Corn ear damage. Injury by corn ear worm was prevalent during the season. Because of the unique arrangement of plots, the relationships between the entries, and the need of this type of data, it seemed particularly desirable to take these notes. All corn ear worm notes were taken in cooperation with Dr. R. H. Painter of the Department of Entomology, and were taken during the winter months from the stored plot yields. Approximately 6,000 ears were read for injury and by later calculation the class of injury was obtained.

13. Ears per cwt. A count of the number of ears was available from the corn ear worm reading. The ears per hundred pounds were calculated to

determine the relative ear size. The formula for the calculations based on 15.5 per cent moisture follows:

$$\text{Ears per cwt.} = \frac{\text{No. of ears per plot} \times 100}{\text{Field wt. per plot} \times \text{moisture correction}}$$

$$\text{Moisture correction for 15.5\% moisture} = \frac{100 - \text{per cent moisture in grain}}{84.5}$$

14. Root lodging. The extremely early lodging of many of the strains due to white grub injury was noted and data collected. It was assumed that the lodging was due entirely to the white grub injury because of its peculiar nature and the high soil infestation. The number of plants actually lodged in each plot was determined. No broken stalks were considered in the data, only a very few being present when the lodging notes were taken. Later root specimens for examination were obtained from the plots.

Methods of Prediction of Double Cross Characters

The methods of prediction of agronomic characters of double cross maize hybrids from known single cross data used in this investigation follow very closely the methods suggested by Jenkins (1934). Several new methods were used which provide an indication of various differences between methods and as such afford a good basis for comparison. The methods used are outlined in the following paragraphs.

Five methods were employed in making the character predictions and all are based upon single cross data. This basis was used because it represents a comparative parental condition as expressed in the succeeding progeny. It was used because information on single crosses is usually available and ordinarily no extra effort is needed to collect the data. Methods used in the investigation are designated as Method I, Method II, Method III, Method IV, and Method V.

Method I involves the component single crosses (AxB) and (CxD) of a double cross hybrid represented as (AxB) x (CxD). The data for a specific character were summarized for each single cross, and the mean between the two components was taken as a prediction measure of the double cross combination. A prediction measure for various characters can, therefore, be calculated easily from single cross data involving only the two parental single crosses. Such data is ordinarily available from the usual corn performance trials. There may be some doubt, however, whether component single crosses will give an accurate prediction value, because actually they do not represent the genic relationship which exists in the double cross combination. Method I can, therefore, be criticized legitimately. However, because it involves the testing of only two combinations, and because of the ease and the rapidity in calculating a prediction value it should be of some value if the method is proven to be statistically feasible.

The method of prediction designated as II involves the use of all possible single crosses of a double cross combination. They may be represented as follows: (AxB), (AxC), (AxD), (BxC), (BxD), and (CxD). In this method the mean values of a specific character of all of the six possible single crosses are summarized, and the mean of this entire group is used as the predicted performance value of the double cross combination (AxB) x (CxD). Every possible combination of the four parental inbred lines is thus involved in the calculation of the performance value for a particular character, thereby giving a mean prediction value which should, with some degree of accuracy, be a measure of the actual double cross performance.

Method III involves the mean value of a character in the crosses (AxC), (AxD), (BxC), and (BxD). This method differs from that of Method II in that the component single crosses (AxB) and (CxD) are not used. It is believed that these four single crosses represent more closely the heterozygosis or the allelomorphic combination of the dominant genic factors that exist in the double cross combination (AxB) x (CxD). The expression of a character, being dependent upon factorial expression, as well as being enhanced or suppressed by heterosis, could possibly be measured with considerable accuracy by this method. Environmental influences may also mask character expression.

Method IV represents the prepotency of the lines A, B, C, and D which in combination give the double cross (AxB) x (CxD). For example, the prepotency of inbred line A for a specific character is obtained by the summation of all of the values for that character in all of the single crosses in which A is one of the parental lines. The character value for each other line is obtained in a similar manner. The character values for the four parental lines of the double cross hybrid are then totaled, the mean of which is the predicted performance value for the double cross hybrid combination. The prepotency of the lines of Method IV is, therefore, a mean of their actual performance in numerous single cross combinations in which they are present to give the predicted value for a specific character.

Method V was formulated by using the mean of the four single crosses which were not the component parents of the double cross combination (Method III) and the value determined from the computation of the prepotency of the inbred lines in all possible single cross combinations (Method IV). In actuality it was a mean of Method III and Method IV. The method was used primarily to measure the actual allelomorphic combination of genes together with the prepotency of the lines. The mean obtained in such a manner should possibly provide a fair measure of the probable performance of the double cross combination.

Statistical Analysis

A great deal of thought, time and effort was spent in planning and laying out this experiment so that a proper statistical analysis of the various phases of the experiment might be obtained. Early analysis consisted almost entirely of assembling and summarizing the data in a form that could be used for later statistical treatment.

Analysis of variance was used to determine the significance of a character. This analysis of significance was necessary because the soil heterogeneity, and the environmental conditions masked the ultimate expression of the characters studied to a greater or a lesser degree. Therefore, before a character could be analyzed statistically it was first necessary to determine whether significant differences existed between inbred lines for that character. If the lines did differ significantly for a character, reasonable assurance was obtained, that succeeding progeny would also differ significantly for the character.

All characters were analyzed in this fashion in the preliminary analysis of the inbred lines, of the single crosses and of the double crosses. Such calculation of character significance made it possible to study the characters which might be measured as easily as possible, and also aided in the selection of the more important agronomic plant characters for more extensive analysis.

The objective of the experiment is to compare the predicted or expected performance of a double cross combination for a character with its actual performance for the same character. This involves the comparison of the actual performance value with the calculated predicted value. Statistical constants particularly suited for such an analysis include the use of correlation coefficients or the use of regression coefficients or possibly the use of both through covariance or by other methods.

The statistical method used in this study closely follows a method outlined by Snedecor (1938) in which an analysis of covariance is used as a measure of the relationship of paired values. In the analysis of experimental data in this study the method fits particularly well. It has the advantage that the influence of the error can be removed and the statistical accuracy of the various prediction methods can be obtained. A comparison of the significance among the methods can also be obtained by progressive steps of calculation. The method will be illustrated fully in the discussion of experimental data.

EXPERIMENTAL RESULTS

General Data Summarization

A study of agronomic characters in parent-progeny relations requires careful and detailed observations. Information obtained from such a study must be analyzed critically to discover parent-progeny relationships, and must be followed by a statistical analysis to evaluate the significance of their approximate existing similarities.

Inbred Lines. The inbred lines used in the study were handicapped under the conditions existing in the field even though they were protected from excessive competition by border rows. The lack of vigor, together with adverse environmental conditions, resulted in the modification of their normal plant characters. Height of plant was probably least affected.

No attempt was made to compare the plant characters of the inbred lines with the plant characters of their single and double cross progeny on a prediction basis except in a limited way.

Analysis of variance studies were made upon a number of measured characters. The inbred lines in general, as would be expected, had higher significant differences for the characters studied than was found in either the single crosses or the double crosses. This is shown in Table 11. The relative amount of the variation in the characters of the inbred lines, compared with that of the single crosses, and double crosses is shown by the F values in the table.

A summary of the inbred performance is given in Table 7. The differences among the inbred lines with respect to the various characters is fairly obvious in Table 7. Differences in yield, maturity, lodging, firing grade, smut susceptibility, plant height, ear height, and other characters as shown in Table 7 and Table 11 are significant. The variability among them should lend confidence to later differences in expression of the characters among their progeny. It may be assumed that characters which are stable with respect to environmental influences are more dependable for prediction than characters which are easily influenced by variations in environment. In other words the genetic characteristics will more certainly appear in following hybrid generations. The choice of lines having a wide diversity for a prediction study of agronomic characters, was a

Table 7. Data on six Pride of Saline inbred lines, Manhattan, Kansas, 1938. Means of six replications.

Rank in test	Pedigree	Acre yield bu.	Days to 1/4 Pollen	Days to 1/2 Silk	Number lodged plants	Firing grade	Smut %	Suckers %	Height Plant in.	Height Ear in.	Missing hills No.	Stand %	Broken shanks %	Length of shank in.	Corn ear worm class	Ears per cwt.	Nodes* Total	Nodes* Below ear	Leaves Total	Leaves Below ear
1	55	17.7	85	89	0.8	1.8	1.8	0.0	58.7	15.7	3	93.3	0.0	4.2	3.50	536	22.7	15.5	15.1	7.8
2	44	14.5	88	90	1.7	1.3	1.0	0.0	62.5	20.8	0	97.5	4.3	2.4	3.71	682	20.3	15.2	13.3	7.9
3	41	7.8	82	85	0.7	3.2	0,0	0.0	56.4	17.7	1	98.3	0.0	3.0	3.46	1249	18.1	13.3	11.6	6.6
4	54	6.6	85	89	0.5	3.2	6.1	0.0	65.4	24.8	2	95.8	5.2	2.1	3.88	1373	21.5	15.6	15.4	9.8
5	63	3.9	93	96	0.3	1.0	3.1	0.0	66.7	25.9	4	81.7	0.0	2.3	3.67	1132	20.8	16.5	12.3	8.0
6	26	0.4	89	96	0.3	1.8	44.2	0.0	73.8	25.5	12	64.2	0.0	1.8	3.50**	2231**	21.5	15.5	13.8	8.1
Mean of inbred lines		8.5	87	91	0.7	2.0	9.4	0.0	63.9	21.7	4	88.5	1.6	2.6	3.62	1200	20.8	15.3	13.6	8.0

* Node count mean of two replications
** Corn ear worm class and ears per cwt. Mean of two replications

fortunate one as the variability of so many characters among the inbred lines provides a sound basis for the investigation.

Single Crosses. All of the possible single crosses among six inbred lines included in this study, 15 in number, provide most of the fundamental data for the determination of prediction values. Physiological variations due to environment were apparent, but the effect was less than in either the inbreds or the double crosses. The character expression of the single crosses as a result should be a fairly accurate representation of their normal performance.

Significance of a number of the more important characters was determined by analysis of variance which is shown in Table 11. Less proportional variation for the characters studied was due to replication in the single crosses than in the inbreds or double crosses.

A summary of the data obtained from the single crosses is given in Table 8.

Differences in height among the single crosses were more significant than any other character measured. This was most conspicuous in the field and is evident in Table 11 as well. Single crosses were less variable in maturity and were earlier than the inbred lines as would be expected. The characters used in the prediction study were chosen pri-

Table 8. Data on fifteen possible Pride of Saline single crosses involving the Pride of Saline inbred lines listed in Table 7 and Pride of Saline variety. Manhattan, Kansas, 1938. Means of six replications.

Rank in test	Pedigree	Acre yield bu.	Days to 1/4 Pollen	Days to 1/2 Silk	Number lodged plants	Firing grade	Smut %	Suckers %	Height Plant in.	Height Ear in.	Missing hills No.	Stand %	Broken shanks %	Length of shank in.	Corn ear worm class	Ears per cwt.	Nodes* Total	Nodes* Below ear	Leaves Total	Leaves Below ear
	Variety																			
9	P. of S.	32.7	79	82	8.2	3.5	1.0	1.7	94.4	38.8	0	100.0	6.7	4.8	3.54	362	21.5	15.6	15.4	9.5
	Single Crosses																			
1	41 x 55	38.8	75	78	6.8	3.2	0.0	0.0	80.3	32.9	1	99.2	0.0	3.3	3.30	278	20.8	14.9	15.2	9.3
2	26 x 55	37.8	79	82	10.8	2.2	5.0	0.0	101.9	39.0	0	100.0	4.2	3.5	3.53	367	24.2	18.1	16.9	10.7
3	44 x 55	37.1	77	81	14.8	3.0	0.0	1.0	89.8	34.6	0	99.2	1.0	2.9	3.77	291	22.3	16.5	15.8	10.4
4	41 x 63	36.9	76	80	17.2	3.5	0.0	0.0	85.8	36.9	2	99.2	0.0	3.6	3.14	314	19.3	14.2	13.9	8.6
5	41 x 44	35.5	75	78	10.5	3.5	0.0	0.0	78.8	32.1	0	100.0	1.7	2.9	3.38	302	19.2	13.8	14.4	8.8
6	26 x 41	33.6	75	79	15.0	3.8	1.0	0.0	82.5	22.8	0	100.0	1.0	3.1	3.13	330	20.9	15.1	14.5	9.1
7	55 x 63	33.5	79	82	8.5	3.0	4.2	0.0	95.4	36.0	1	99.2	1.7	3.4	3.63	405	21.9	16.4	15.7	10.4
8	54 x 55	32.7	80	83	6.7	2.8	0.0	1.0	99.6	44.0	0	100.0	10.8	4.4	3.69	413	23.2	17.2	17.6	11.5
10	44 x 54	31.9	78	81	8.2	4.0	0.0	1.0	84.6	36.8	0	100.0	4.2	3.5	3.55	385	20.5	15.0	15.6	10.2
11	26 x 44	31.5	78	81	11.8	3.3	1.0	1.0	88.9	33.2	0	100.0	1.0	3.1	3.31	367	22.2	16.4	14.9	9.2
12	41 x 54	30.7	75	79	4.0	4.2	0.0	0.0	82.7	37.1	0	100.0	0.0	4.1	3.31	396	19.9	14.6	14.7	9.1
13	44 x 63	30.0	78	81	10.3	4.0	1.0	0.0	88.3	36.6	0	100.0	1.0	3.3	3.36	351	20.9	15.8	14.9	9.6
14	26 x 63	29.3	79	82	17.2	3.2	3.3	0.0	96.7	39.8	0	100.0	6.7	3.4	3.48	490	22.7	17.4	15.1	9.9
15	54 x 63	27.1	81	83	7.3	3.5	1.7	0.0	90.8	40.4	0	100.0	10.8	4.3	3.10	502	21.9	16.1	16.1	10.6
16	26 x 54	24.4	79	83	8.5	3.7	5.8	1.7	95.0	41.8	0	100.0	11.7	3.7	3.46	479	23.1	17.2	17.0	11.1
Mean of single crosses		32.7	78	81	10.5	3.4	1.5	0.4	89.4	36.3	0	99.8	3.7	3.5	3.41	378	21.5	15.9	15.5	9.9

* Node count mean of two replications

marily on the basis of statistical analysis as previously indicated as well as on their practical importance in a corn improvement program.

Double Crosses. Twenty-nine out of a possible 45 double crosses were studied and measured carefully for characters already mentioned. Each single cross was crossed with another at least two or three times, giving double cross combinations involving the single crosses in enough instances to make a prediction study feasible.

Double crosses appeared to be of an intermediate nature when compared to single crosses. Among the plant characters, height varied less within strains than any other character, which was also true in the inbreds and the single crosses, probably because it is an expression of vigor as well as being affected by environmental conditions to a lesser degree than other characters. Variation between replications increased over the single crosses, an undesirable feature, yet probably not enough to mask in their entirety, the normal character expression of the double crosses. This is shown in Table 11.

A summary of the double cross performance is given in Table 9.

Observational Studies. A summary of the eight related observational double crosses is given in Table 10. No com-

Table 9. Data on twenty-nine Pride of Saline double crosses involving the Pride of Saline single crosses listed in Table 8 and Pride of Saline variety. Manhattan, Kansas, 1938. Means of six replications.

Rank in test	Pedigree	Acre yield bu.	Days to 1/4 Pollen	Days to 1/2 Silk	Number lodged plants	Firing grade	Smut %	Suckers %	Height Plant in.	Height Ear in.	Missing hills No.	Stand %	Broken shanks %	Length of shank in.	Corn ear worm class	Ears per cwt.	Nodes* Total	Nodes* Below ear	Leaves Total	Leaves Below ear
	Variety																			
18	Pride of Saline	23.6	79	82	7.7	3.5	4.2	1.7	93.2	39.6	0	100.0	9.2	4.4	3.57	457	21.1	15.6	15.5	9.9
	Double Crosses																			
1	(41x55) x (44x54)	30.4	76	80	7.0	4.0	1.0	1.0	85.3	33.9	0	100.0	7.5	4.0	3.64	373	20.9	15.0	15.4	9.8
2	(26x44) x (41x55)	29.7	78	82	9.0	3.5	2.5	0.0	85.2	34.7	1	100.0	4.2	3.5	3.43	376	21.4	15.6	15.5	9.7
3	(41x55) x (44x63)	27.3	77	80	16.3	4.0	0.0	0.0	79.4	33.5	0	100.0	1.7	3.1	3.47	393	21.6	16.0	15.4	9.9
4	(26x41) x (44x63)	27.1	76	80	12.7	4.2	1.0	0.0	83.8	37.2	1	98.3	1.0	3.2	3.40	398	21.8	16.3	15.2	9.8
5	(41x54) x (44x63)	26.9	74	79	8.5	4.8	0.0	0.0	79.9	35.5	0	100.0	3.3	3.7	3.44	419	21.1	14.8	15.2	9.6
6	(26x41) x (44x54)	26.4	76	81	6.0	4.2	0.0	2.5	83.1	36.2	0	100.0	5.8	3.6	3.49	438	21.2	15.4	15.6	9.7
7	(26x63) x (41x54)	26.4	77	82	11.3	4.0	2.5	0.0	88.9	37.8	2	99.2	5.9	4.0	3.36	422	21.6	15.9	15.2	9.5
8	(41x44) x (54x55)	25.6	76	81	11.0	4.2	0.0	1.0	83.7	36.4	0	100.0	5.0	3.3	3.38	415	21.7	15.8	15.7	10.2
9	(26x54) x (44x55)	25.2	78	81	13.3	3.8	1.0	5.9	92.1	37.5	0	99.2	5.9	3.8	3.75	452	22.2	16.4	16.3	10.6
10	(26x55) x (41x54)	24.8	76	81	9.8	3.8	2.5	0.0	87.6	37.7	1	100.0	3.3	3.4	3.58	452	22.0	15.5	16.5	10.3
11	(41x54) x (44x55)	24.8	76	80	10.2	4.5	1.0	0.0	84.5	34.3	0	100.0	1.7	3.4	3.60	392	20.7	14.9	15.5	9.7
12	(26x54) x (41x44)	24.8	76	81	13.2	5.0	1.7	0.0	84.7	34.7	0	100.0	6.7	3.7	3.58	435	21.3	15.7	15.9	10.0
13	(26x55) x (41x44)	24.7	76	81	11.3	4.3	2.5	1.0	84.7	34.1	0	100.0	1.7	3.1	3.54	407	21.8	15.7	15.5	9.3
14	(26x41) x (55x63)	24.5	77	82	7.5	3.7	1.0	0.0	88.6	35.9	0	100.0	5.0	4.0	3.50	444	22.5	16.5	15.5	9.8
15	(26x44) x (41x54)	24.2	77	81	4.5	4.0	1.0	0.0	83.2	36.6	1	100.0	9.2	3.5	3.27	453	21.3	15.9	15.6	10.1
16	(41x54) x (55x63)	23.8	76	80	7.0	4.2	1.0	0.0	82.6	35.2	1	98.3	3.4	3.8	3.90	461	21.0	15.7	15.2	9.8
17	(26x54) x (41x55)	23.8	78	81	9.3	3.8	0.0	1.0	94.2	38.7	0	100.0	3.3	4.1	3.46	442	21.9	16.1	16.3	10.6
19	(26x41) x (54x63)	23.6	77	81	10.8	3.8	0.0	0.0	88.1	38.1	0	100.0	5.0	4.3	3.36	456	21.9	16.1	15.8	10.0
20	(26x44) x (54x63)	23.6	78	82	11.0	4.0	1.7	0.0	89.8	36.2	0	98.3	5.1	3.9	3.67	470	22.0	16.5	15.7	10.0
21	(26x63) x (44x54)	23.2	80	83	9.0	3.8	1.7	0.0	91.0	37.7	1	99.2	6.7	3.8	3.47	469	21.8	16.1	15.7	9.9
22	(41x44) x (55x63)	23.1	76	81	12.7	4.2	1.0	0.0	81.9	33.2	2	99.2	1.0	3.2	3.73	424	21.1	15.4	14.9	9.2
23	(44x55) x (54x63)	23.0	78	81	12.5	4.7	0.0	0.0	85.2	34.6	0	100.0	3.3	4.0	3.61	492	21.3	15.7	15.7	10.0

Table 9. (cont.)

Rank in test	Pedigree	Acre yield bu.	Days to 1/4 Pollen	Days to 1/2 Silk	Number lodged plants	Firing grade	Smut %	Suckers %	Height Plant in.	Height Ear in.	Missing hills No.	Stand %	Broken shanks %	Length of shank in.	Corn ear worm class	Ears per cwt.	Nodes* Total	Nodes* Below ear	Leaves Total	Leaves Below ear
24	(41x55) x (54x63)	22.9	77	81	11.2	4.5	1.7	1.0	87.8	39.2	0	100.0	5.0	4.1	3.57	503	21.6	15.8	15.7	10.2
25	(26x44) x (41x63)	22.8	77	81	15.8	4.3	1.0	0.0	84.5	35.1	0	100.0	0.0	3.2	3.48	470	21.2	15.7	14.8	9.4
26	(41x63) x (44x54)	22.7	76	81	11.5	5.0	1.0	0.0	83.3	36.3	0	100.0	1.7	3.6	3.57	454	20.7	15.4	15.5	10.0
27	(41x44) x (54x63)	22.7	78	81	11.8	4.8	0.0	0.0	83.5	34.1	0	100.0	3.3	3.8	3.33	430	20.8	15.0	15.0	9.4
28	(26x41) x (54x55)	22.6	77	81	8.5	3.8	1.7	0.0	89.9	37.2	0	99.2	10.1	4.0	3.42	478	22.1	16.3	16.6	10.6
29	(26x44) x (54x55)	21.7	78	82	9.7	3.8	3.3	3.3	93.1	39.7	0	100.0	7.5	4.0	3.37	502	23.0	17.3	17.2	11.2
30	(26x63) x (41x55)	21.6	78	82	11.2	4.0	2.5	1.0	90.5	36.2	0	100.0	3.3	3.9	3.39	486	21.9	16.1	15.5	9.8
	Mean of double crosses	24.6	77	81	10.5	4.2	1.2	0.6	86.2	36.1	0.3	99.7	4.4	3.7	3.51	442	21.6	15.8	15.6	9.9

* Node count mean of two replications

Table 10. Observational data on seven Pride of Saline double crosses involving the Pride of Saline single crosses listed in Table 8 and Pride of Saline variety. Manhattan, Kansas, 1938. Means of two replications.

Rank in test	Pedigree	Acre yield bu.	Days to 1/4 Pollen	Days to 1/2 Silk	Number lodged plants	Firing grade	Smut %	Suckers %	Height Plant in.	Height Ear in.	Missing hills No.	Stand %	Broken shanks %	Length of shank in.	Corn ear worm class	Ears per cwt.	Leaves Total	Leaves Below ear
	Variety																	
3	Pride of Saline	40.8	80	83	4.0	2.5	5.0	5.0	100.7	44.0	0	100.0	17.5	5.7	3.60	273	15.2	9.4
	Double Crosses																	
1	(41x63) x (44x55)	43.0	77	80	11.0	3.5	2.5	0.0	90.3	35.8	0	100.0	5.0	3.9	3.61	256	14.9	9.1
2	(26x55) x (41x63)	42.2	78	81	13.5	3.5	0.0	0.0	95.9	40.0	0	100.0	0.0	3.5	3.47	256	15.4	9.4
4	(41x63) x (54x55)	39.0	78	82	1.5	3.0	0.0	2.7	91.4	39.9	0	92.5	0.0	4.4	3.53	318	15.7	10.0
5	(26x55) x (44x63)	37.3	78	81	7.0	3.0	2.5	0.0	96.2	37.1	0	100.0	0.0	3.6	3.44	277	15.6	9.4
6	(26x55) x (54x63)	35.0	80	82	4.0	3.0	13.2	0.0	101.9	42.8	0	95.0	7.9	3.5	3.53	311	16.7	10.4
7	(26x54) x (41x63)	34.4	78	81	10.0	4.0	5.0	0.0	91.8	39.4	0	100.0	10.0	4.2	3.43	323	15.6	9.8
8	(26x63) x (44x55)	30.9	79	82	12.5	3.5	0.0	0.0	93.5	36.5	0	100.0	0.0	3.8	3.54	333	14.8	9.3
	Mean of double crosses	37.4	78	81	8.5	3.4	3.3	0.4	94.4	38.8	0	98.2	3.3	3.8	3.51	296	15.5	9.6

parisons can be made with the double crosses listed in Table 9. They were of interest from the agronomic viewpoint and so were included in a separate experiment conducted in conjunction with other studies. The supply of seed of the eight double crosses planted in this test was so low that two replications could only be planted. The failure of the crossing material in the Washington greenhouse during the winter of 1937-38 was the primary factor contributing to the lack of seed.

Determination of Character Significance

Thirteen of the more important characters were selected from the data and used as a basis for beginning a study of prediction methods. The characters chosen were: difference between days to one-half silk and one-fourth pollen shedding, height of plant, height of ear, length of shank, broken shanks, nodal count (both total nodes and nodes below the ear), leaf count (both above and below the ear), smut resistance or susceptibility, corn ear worm damage, ears per hundred pounds, yield of grain, firing grade, and lodging due to grub worm injury. The previously mentioned characters are of great importance and probably receive more attention than do other characters in the search for superior hybrid combinations.

Before attempting a prediction study it was necessary to calculate the significance of the characters, partially because of the existing variability of each of the groups, and because of the impossibility of determining predictions upon the entire number of plant characters upon which observations were made. The method of elimination consisted mainly of a determination of character significance by analysis of variance studies and furthermore by choosing the characters normally considered to be of greatest importance.

The determination of significance was made for the characters of the inbred lines, the single crosses and the double crosses. A summary is given in Table 11.

Many of the characters of the inbred lines as shown in Table 11 were highly significant. The inbred lines did not differ significantly with respect to broken shanks, corn ear worm injury, nodal count below ear and lodging due to grub worm, that is, in these cases the lines were more or less similar. Although there were also significant differences between replications, characters of the inbred lines, being highly significant, were real and distinct. The normal expectancy, therefore, between crosses of the inbred lines for most characters would be resultant single crosses with characters differing in a measurable degree.

Upon further examination of the tabulated data of Ta-

Table 11. Significance of characters studied in inbred lines, single crosses and double crosses.

Source of Variation	Inbred Lines F	Inbred Lines 5%	Single Crosses F	Single Crosses 5%	Double Crosses F	Double Crosses 5%
1. 1/2 silk minus 1/4 pollen						
Replications	2.56	2.60	1.15	2.41	12.22**	2.27
Crosses or inbreds	14.10**	2.60	7.27**	1.80	3.24*	1.54
2. Height of plant						
Replications	4.48*	2.60	6.75*	2.41	3.95*	2.27
Crosses or inbreds	35.82**	2.60	57.61**	1.80	8.59**	1.54
3. Height of ear						
Replications	20.33*	2.60	17.49*	2.41	11.56**	2.27
Crosses or inbreds	125.27**	2.60	35.20**	1.80	4.81*	1.54
4. The Length of shank						
Replications	3.56*	2.60	1.58	2.41	5.18*	2.27
Crosses or inbreds	51.44**	2.60	15.50**	1.80	6.91**	1.54
5. Broken shanks						
Replications	0.46	2.60	6.13*	2.41	2.35*	2.27
Crosses or inbreds	1.72	2.60	2.49*	1.80	1.37	1.54
6. Nodal count						
Total						
Replications	3.62	6.61	0.12	4.54	5.50*	4.18
Crosses or inbreds	13.27**	5.05	50.37**	2.41	5.25*	1.85
Below ear						
Replications	0.20	6.61	0.17	4.54	0.40	4.18
Crosses or inbreds	4.62	5.05	50.17**	2.41	5.90**	1.85
7. Leaf count						
Total						
Replications	4.87*	2.60	0.66	2.41	14.00**	2.27
Crosses or inbreds	46.33**	2.60	2.98*	1.80	6.36*	1.54

Table 11. (cont.)

Source of Variation	Inbred Lines F	Inbred Lines 5%	Single Crosses F	Single Crosses 5%	Double Crosses F	Double Crosses 5%
Below ear						
Replications	8.50*	2.60	3.65*	2.41	18.94**	2.27
Crosses or inbreds	45.64**	2.60	91.18**	1.80	5.74*	1.54
8. Smutted plants						
Replications	0.41	2.60	2.54*	2.41	1.70	2.27
Crosses or inbreds	32.23**	2.60	1.14	1.80	1.30	1.54
9. Corn ear worm damage						
Replications	1.06	2.71	0.48	2.41	3.07*	2.27
Crosses or inbreds	1.00	2.87	4.12*	1.80	1.72*	1.54
10. Ears per cwt.						
Replications	4.34*	2.71	53.98**	2.41	20.28**	2.27
Crosses or inbreds	21.71**	2.87	6.01*	1.80	1.29	1.54
11. Yield of grain						
Replications	7.62*	2.60	74.04**	2.41	24.21**	2.27
Crosses or inbreds	42.17**	2.60	2.50*	1.80	1.05	1.54
12. Firing grade						
Replications	0.69	2.60	48.44**	2.41	8.72*	2.27
Crosses or inbreds	31.50**	2.60	4.56*	1.80	4.04*	1.54
13. Lodging due to grub worms						
Replications	6.25*	2.60	4.07*	2.41	2.00	2.27
Crosses or inbreds	0.87	2.60	5.88*	1.80	3.68*	1.54

* Statistically significant differences
** Highly significant differences

ble 11 the difference between single crosses is statistically significant for most of the characters studied, though in most cases the significance is not as great as in the inbred lines. This can be expected for crossing apparently increases intermediacy in most cases. The intermediate nature results from the union of two distinct entities of germ plasm. No significant differences were found between the single crosses in resistance or susceptibility to smut although there was a variation between replications.

Smaller variations between strains becomes more and more evident, along with their more pronounced intermediate nature due to crossing. For example, the F values for ear height (Table 11), of the series of inbred lines and crosses decrease progressively from an F value and five per cent point of 125.27 and 2.60 respectively for inbred lines, of 35.20 and 1.80 respectively for single crosses, and of 4.81 and 1.54 respectively for double crosses. In general this is representative of most of the characters studied. The variability of a single character decreases as the complexity and range of inherent germ plasm increases through successive crossing. The intermediate effect of character expression and modification is fairly evident in the data. The variation of the characters is especially large under abnormal environmental conditions.

Plant characters for method of prediction studies were chosen from Table 11. The choice was based upon the statistical significance of their differences, the general importance of the characters and their use by other investigators in previous studies. The characters that were chosen for study were those which differed significantly among the strains of the inbred lines, the single crosses, and the double crosses.

An exception was made in the case of corn ear worm damage. The inbred lines did not differ significantly among themselves in injury but seemed to have a significant degree of resistance in single cross and double cross combinations. Another exception was made for yield in which there was not a significant difference among the double crosses. However, yield was used because of its importance as well as the fact that it has been used by other investigators, and that it is desirable for a comparison with other characters.

In view of these considerations the seven characters selected for prediction studies were height of plant, height of ear, length of shank, corn ear worm damage, yield of grain, firing grade, and lodging due to grub worms.

Prediction Studies

The comparative similarities between parents and progeny and the reliability of a prediction of the characteristics of the double crosses from measurements made on the single crosses are determined by computation from single cross data. Although correlation and regression have commonly been used in such studies, both are obtained by the method of statistical analysis termed covariance. The results of data determined in such a manner can be analyzed more fully than would otherwise be possible by the methods ordinarily used. Experimental error is removed from consideration and the significance of a predicted method is determined upon the actual expression of the character itself. As previously indicated the method of calculation used will be outlined as far as it is feasible in the study of the methods of prediction for height of plant. The analysis of the other characters studied has been calculated in the same way.

Height of Plant. Variations in height were very noticeable in the field. In order to secure a proper estimate of height of plant, 10 plants in each plot were measured, the average of these measurements being used as the mean plot height. After all plot means had been calculated they were arranged for each kind of corn and by each replication and then entered in a table and the analysis of variance calculated to determine whether there were significant differences for height among the inbreds, single crosses and double crosses. An example of the summarizations of plot means of height of plant, and calculation of analysis of variance for height in the single crosses is given in Table 12. The significance of other characters was determined in the same way, as is shown in Table 12.

After it was determined that height of plant differed significantly between the inbred lines, between the single crosses, and between the double crosses, it was selected as one of the characters to be included in a method of prediction study. The single crosses listed in Table 8 give the average data of six replications from which the expected or predicted height of plant of the double cross hybrid is calculated. The averages listed in this table give a fairly accurate index of the character.

The predicted performance of the double cross hybrid is made by the methods previously outlined (pages 40-43) and based on the single cross performance the average of which is listed in Table 8. Thus the predicted values of height for the double cross (26x41) x (44x54) are made in the manner illustrated in Table 13.

Each of the predicted values of height for the other double crosses were calculated in a similar manner. The predictions for other characters were also made in the same

Table 12. Determination of statistical significance for height of plant among 15 single crosses by analysis of variance.

Pedigree	Rep. I	Rep. II	Rep. III	Rep. IV	Rep. V	Rep. VI	Sum
26 x 41	85.5	81.2	84.5	79.2	81.6	83.0	495.0
26 x 44	91.1	88.8	90.4	88.9	86.4	87.7	533.3
26 x 54	99.7	92.2	92.7	94.9	95.6	94.9	570.0
26 x 55	103.7	98.9	103.2	101.7	101.1	102.6	611.2
26 x 63	92.9	95.8	99.6	94.7	97.8	99.2	580.0
41 x 44	78.8	75.2	80.9	78.0	79.6	80.6	473.1
41 x 54	86.2	80.3	81.1	82.6	83.2	83.0	496.4
41 x 55	80.2	78.9	82.1	78.3	80.7	81.8	482.0
41 x 63	90.9	86.6	86.0	81.6	84.1	85.6	514.8
44 x 54	86.7	82.3	83.7	81.3	89.6	83.8	507.4
44 x 55	85.1	90.6	90.8	89.9	93.5	88.8	538.7
44 x 63	90.1	83.8	88.4	88.8	88.4	90.3	529.8
54 x 55	99.6	95.8	97.5	96.9	101.4	106.4	597.6
54 x 63	92.3	87.9	91.8	84.4	93.5	94.9	544.8
55 x 63	94.9	94.0	95.4	95.1	96.4	96.6	572.4
P.of S.	99.7	92.3	92.5	92.1	92.9	97.1	566.6
Sum	1457.4	1404.6	1440.6	1408.4	1445.8	1456.3	8613.1

$\frac{S\ x^2r}{16}$ 772936.38 - 772765.54 = 170.84

$\frac{S\ x^2c}{6}$ 777138.26 - 772765.54 = 4372.72

$\frac{(Sx)^2}{96}$ 772765.54

Sx^2 777688,39 - 772765.54 = 4922.85

Error 4922.85 - 4543.56 = 379.29

Sum of Squares Mean Square

Variance due to:	d.f.	Sum of Sq.	Mean of Sq.	F	5%
Total	95	4922.85			
Replications	5	170.84	34.17	6.75*	2.41
Crosses	15	4372.72	291.51	57.61**	1.80
Error	75	379.29	5.06		

Table 13. Illustration of the method used in calculation of the predicted performance of the double cross hybrid (26x41) x (44x54) (Height of Plant).

Hybrid pedigree	Possible single crosses involved	Method I Component single crosses	Method II All single crosses	Method III Single crosses other than component	Method IV Effect of inbred line Line	 Perf	Method V Method III plus Method IV
(26 x 41)	26 x 41	82.5	82.5		26	93.0	
x	26 x 44		88.9	88.9	41	82.0	
(44 x 54)	26 x 54		95.0	95.0	44	86.1	
	41 x 44		78.8	78.8	54	90.5	
	41 x 54		82.7	82.7			86.3
	44 x 54	84.6	84.6				87.9
Sum		167.1	512.5	345.4		351.6	174.2
Mean predicted value for height		83.5	85.4	86.3		87.9	87.1

way. The predictions for height made in Table 13 for the double cross (26x41) x (44x54) along with other height predictions are carried to Table 14 where they are further analyzed for the relationship of the predicted height value and the actual performance of the double cross hybrid in the field.

Calculations in Table 14 include the determinations of the sum of squares (SX^2) for the predictions obtained by the various methods, the sum of squares (SY^2) for the actual performance, and the sum of the predicted performance of each of the methods multiplied by the actual performance of the double crosses (SXY).

Before further analysis can be made a set of corrections for the actual performance and the various methods must be calculated.

These corrections being:

For X:

Method I $(2544.9)^2 /29 = 223328.14$

II $(2557.3)^2 /29 = 225509.77$

III $(2562.9)^2 /29 = 226498.50$

IV $(2578.1)^2 /29 = 229193.09$

V $(2570.0)^2 /29 = 227755.17$

For Y:

$(2500.1)^2 /29 = 215534.48$

Table 14. The predicted double cross performance by five methods (X) and the actual double cross performance (Y) for the 29 double cross hybrids studied.

Double cross pedigree	Actual double cross performance	Predicted Values: Method I Component single crosses	Method II All single crosses	Method III Single crosses other than component	Method IV Effect of inbred line	Method V Method III plus Method IV
(26x41) x (44x54)	83.1	83.5	85.4	86.3	87.9	87.2
(26x41) x (44x63)	83.8	85.4	86.8	87.5	88.1	87.8
(26x41) x (54x55)	89.9	91.0	90.3	90.0	89.7	89.8
(26x41) x (54x63)	88.1	86.6	88.9	90.0	89.2	89.6
(26x41) x (55x63)	88.6	88.9	90.4	91.2	89.9	90.5
(26x44) x (41x54)	83.2	85.8	85.4	85.2	87.9	86.5
(26x44) x (41x55)	85.2	84.6	87.0	88.2	88.6	88.4
(26x44) x (41x63)	84.5	87,3	86.8	86.6	88.1	87.3
(26x44) x (54x55)	93.1	94.2	93.3	92.8	90.7	91.7
(26x44) x (54x63)	89.8	89.8	90.7	91.1	90.2	90.6
(26x54) x (41x44)	84.7	86.9	85.4	84.7	87.9	86.3
(26x54) x (41x55)	94.2	87.6	90.3	91.7	89.7	90.7
(26x54) x (44x55)	92.1	92.4	93.3	93.7	90.7	92.2
(26x55) x (41x44)	84.7	90.3	87.0	85.4	88.6	87.0
(26x55) x (41x54)	87.6	92.3	90.3	89.3	89.7	89.5
(26x63) x (41x54)	88.9	89.7	88.9	88.5	89.3	88.9
(26x63) x (41x55)	90.5	88.5	90.4	91.4	89.9	90.6
(26x63) x (44x54)	91.0	90.6	90.7	90.7	90.2	90.4
(41x44) x (54x55)	83.7	89.2	86.0	84.3	88.0	86.1
(41x44) x (54x63)	83.5	84.8	85.2	85.3	87.5	86.4
(41x44) x (55x63)	81.9	87.1	86.4	86.0	88.2	87.1
(41x54) x (44x55)	84.5	86.2	86.0	85.8	88.0	86.9
(41x54) x (44x63)	79.9	85.5	85.2	85.0	87.5	86.2
(41x54) x (55x63)	82.6	89.0	89.1	89.1	89.3	89.2
(41x55) x (44x54)	85.3	82.4	86.0	87,7	88.0	87.8

Table 14. (cont.)

Double cross pedigree	Actual double cross performance	Predicted Values: Method I: Component single crosses	Method II: All single crosses	Method III: Single crosses other than component	Method IV: Effect of inbred line	Method V: Method III plus Method IV
(41x55) x (44x63)	79.4	84.3	86.4	87.4	88.2	87.8
(41x55) x (54x63)	87.8	85.5	89.1	90.9	89.3	90.1
(41x63) x (44x54)	83.3	85.2	85.2	85.1	87.5	86.3
(44x55) x (54x63)	85.2	90.3	91.4	92.0	90.3	91.1
Sums	2500.1	2544.9	2557.3	2562.9	2578.1	2570.0
Means	86.21	87.76	88.18	88.38	88.90	88.62
SX^2		223565.57	225688.35	226716.19	229223.15	227854.34
SY^2	215947.05					
SXY		219590.96	220689.39	221188.64	222350.13	221725.46

For XY:

Method I	(2544.9)(2500.1)	/29	=	219396.71
II	(2557.3)(2500.1)	/29	=	220465.71
III	(2562.9)(2500.1)	/29	=	220948.49
IV	(2578.1)(2500.1)	/29	=	222258.89
V	(2570.0)(2500.1)	/29	=	221560.59

The sums of squares and products for all the methods of prediction are then obtained by subtracting these corrections from their respective totals in the last three lines of Table 14. The sums of squares and products of Method I being:

$$Sx^2 = 223565.57 - 223328.14 = 237.43$$

$$Sy^2 = 215947.05 - 215534.48 = 412.57$$

$$Sxy = 219590.96 - 219396.71 = 194.25$$

All sums of squares and sums of products are obtained in a similar manner and results are entered in Table 15.

The number of the degrees of freedom (d.f.) represented in the experiment and shown in Table 15 is 28. The degrees of freedom being (n-1) or the number of kinds of corn in the experiment (29) minus one or 28.

Since the objective of the experiment is to analyze the relationship of the actual double cross performance with that of the predicted performance, we are interested in obtaining the correlation and regression coefficients between them as well as the error of estimate.

Table 15. Regression and correlation data for five methods of prediction of height of plant.

Method	d.f.	Sum of squares and products: Sx^2	Sxy	Sy^2	Correlation coefficient	Regression coefficient	Errors of Estimate: Sum of squares	d.f.	Mean sq.	Standard error of estimate	Standard error of reg. coef.	t
I	28	237.43	194.25	412.57	0.6206	0.8181	253.65	27	9.39	3.06	0.1986	4.119
II	28	178.58	223.68	412.57	0.8264	1.2525	132.40	27	4.90	2.21	0.1654	7.573
III	28	217.69	240.15	412.57	0.8014	1.1032	147.64	27	5.46	2.33	0.1580	6.982
IV	28	30.06	91.24	412.57	0.8193	3.0353	135.63	27	5.02	2.24	0.4088	7.425
V	28	99.17	164.87	412.57	0.8151	1.6625	138.47	27	5.12	2.29	0.2311	7.194
Sum	140	762.93	914.19	2062.85	0.7287	1.1983	807.79	135	5.98	2.44		

	5 per cent level	1 per cent level
Significant t :	2.052	2.771
Significant r :	0.367	0.470

The correlation coefficient is calculated from the data given in Table 15 by the following equation:

$$Sxy/\sqrt{(Sx^2)\,(Sy^2)} \quad \text{or} \quad \frac{194.25}{\sqrt{(237.43)\,(412.57)}} = 0.6206$$

The correlation coefficient obtained is entered in the table.

Calculation of the regression coefficient from data given in Table 15 is made by the equation:

$$Sxy/Sx^2 \quad \text{or} \quad \frac{194.25}{237.43} = 0.8181$$

The result is entered in the table.

The several correlation and regression coefficients in Table 15 show existing differences in the methods of prediction, that is the correlation coefficients 0.6206 and 0.8264 indicate a difference between Method I and II. Are these differences significant or are they due to variation in sampling among the hybrids measured? To answer the question regression equations for each of the methods of prediction are calculated to see if the slopes of the lines differ significantly.

The regression equation used in the determination of the regression lines was:

$$E = \bar{y} + \frac{Sxy}{Sx^2}\,(X-\bar{x})$$

The regression equations for each of the five methods used in prediction are given in Table 16. The means used for the calculation of the regression equations are obtained from Table 14.

The regressions of each method and their standard errors of estimate are plotted in Figures 2, 3, 4, 5, 6, and 7. In order that the regressions may be more easily compared, each of them and the average are plotted so as to intersect the common mean. An examination of these figures indicates that the slopes of the lines of the various methods differ from each other. If the prediction values are plotted with the actual values on the graph a significant relationship appears. The height predictions follow the regression line quite closely in most instances. The predicted values, therefore, have a significant relationship to the actual performance of the double cross hybrids for height.

If the prediction values of a particular method are statistically significant the next question is whether the several methods differ in accuracy, that is whether the predictions of a double cross character calculated by one method is likely to be nearer the actual outcome than by another method. How do the methods of prediction vary in significance among themselves? An analysis of such significance is determined through the use of errors of estimate and succeeding calculations. First of all, the sum of squares of errors of estimate is calculated from data given in Table 15, the equation being:

$$Sy^2 - (Sxy)^2 / Sx^2 \text{ or } 412.57 - \frac{(194.25)^2}{237.43} = 253.65$$

The results are then recorded in Table 15.

The sum of squares of errors of estimate for each of the methods is divided by the degrees of freedom (d.f.) of errors of estimate (n-2) in order to obtain the mean square. The succeeding calculation involves the determination of the standard error of estimate by taking the square root of the mean square. The equation may be represented in the following way:

$$Sy.x = \sqrt{Vy.x} \text{ or } \sqrt{9.3944} = 3.06$$

Results are recorded in Table 15.

This calculation determines the amount of quantitative variation in height of the double crosses measured in inches, not associated with or explained by the differences in the predicted height values. It indicates the deviation that should be expected in the actual performance of double crosses from the predicted values.

Table 16. Regression equations for five methods of prediction and their average.

Method I

$$E = 86.21 + 0.8181\ (X - 87.76)$$
$$= 0.8181X + 14.41$$

Method II

$$E = 86.21 + 1.2525\ (X - 88.18)$$
$$= 1.2525X - 24.24$$

Method III

$$E = 86.21 + 1.1032\ (X - 88.38)$$
$$= 1.1032X - 11.29$$

Method IV

$$E = 86.21 + 3.0353\ (X - 88.90)$$
$$= 3.0353X - 183.63$$

Method V

$$E = 86.21 + 1.6625\ (X - 88.62)$$
$$= 1.6625X - 61.12$$

Average Regression

$$E = 86.21 + 1.1983\ (X - 88.37)$$
$$= 1.1983X - 19.68$$

The calculation that now presents itself is the determination of the standard error of the regression coefficients of the various methods of prediction. In this way the significance of the regression of each of the methods of

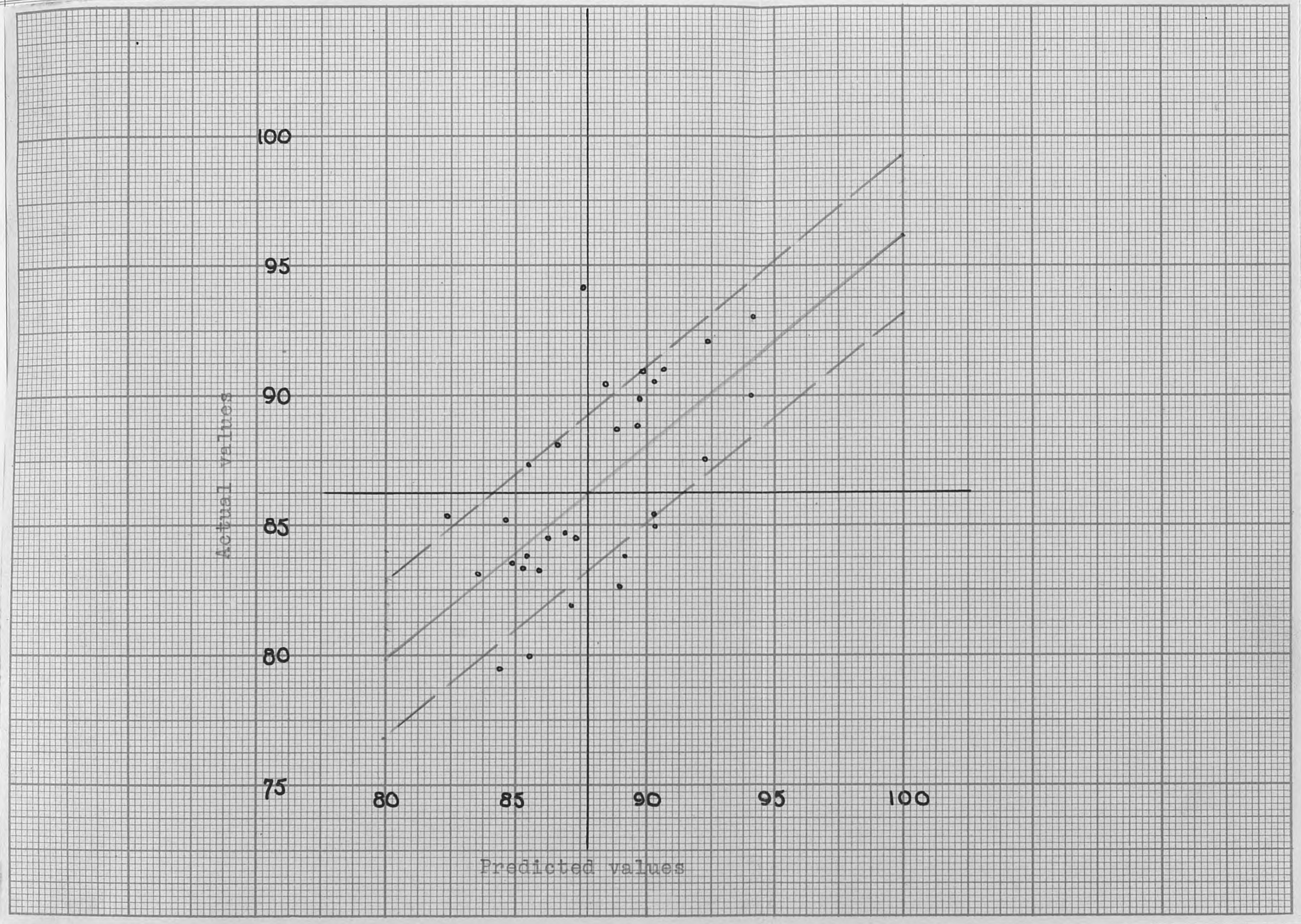


Figure 2. Scatter diagram, regression line and the standard error of estimate obtained by prediction Method I for the character height of plant.

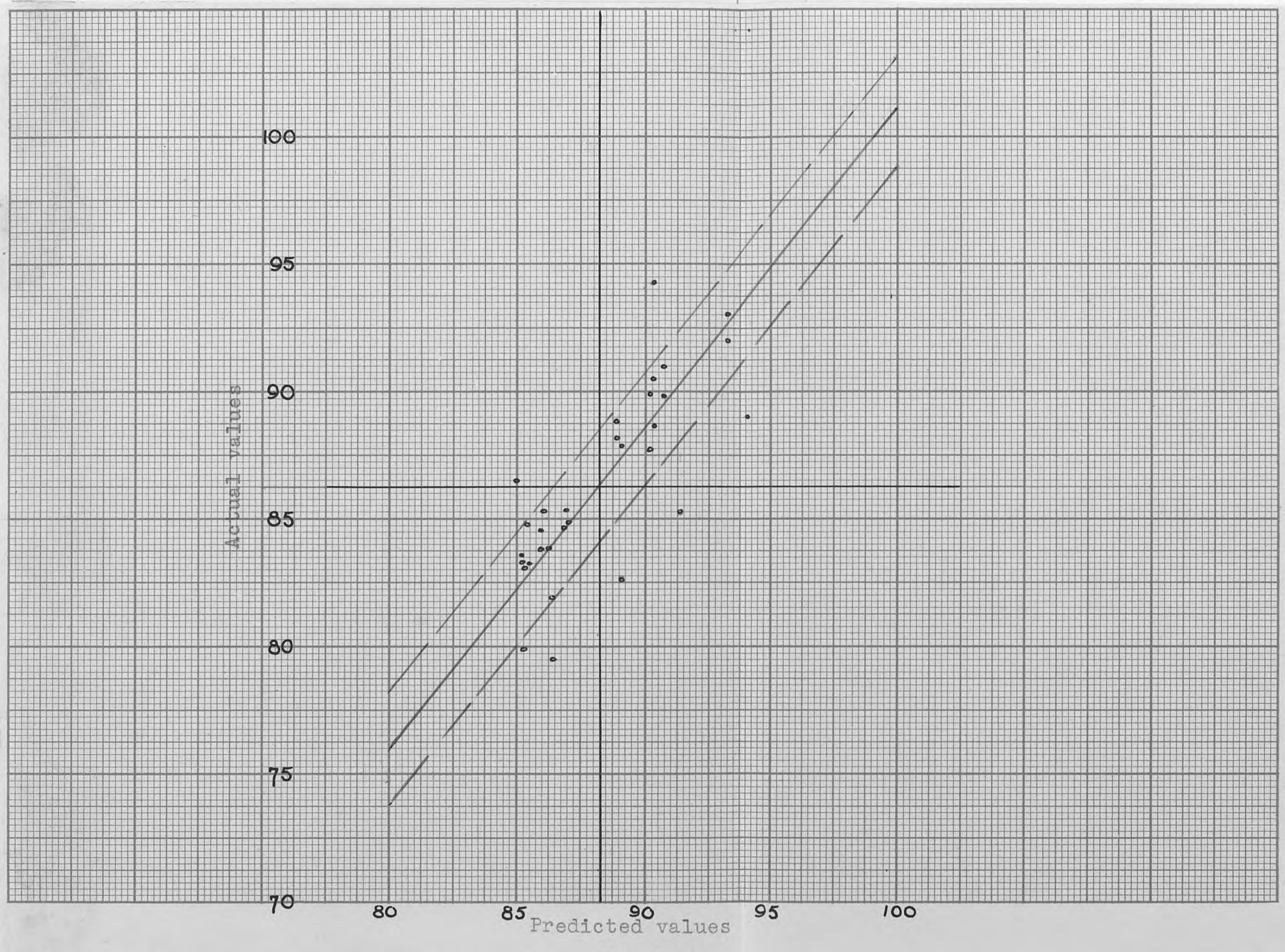


Figure 3. Scatter diagram, regression line and the standard error of estimate obtained by prediction Method II for the character height of plant.

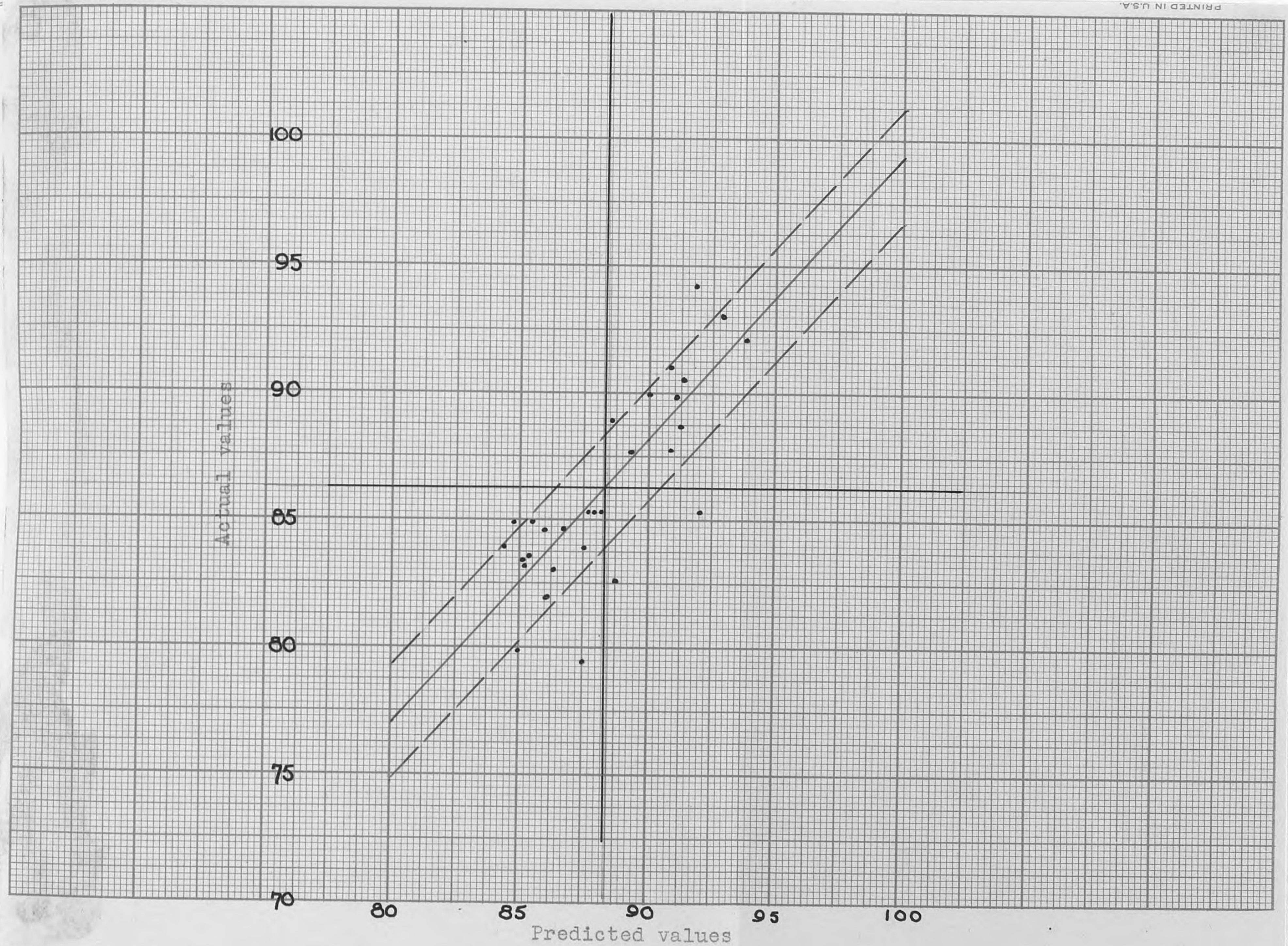


Figure 4. Scatter diagram, regression line and the standard error of estimate obtained by prediction Method III for the character height of plant.

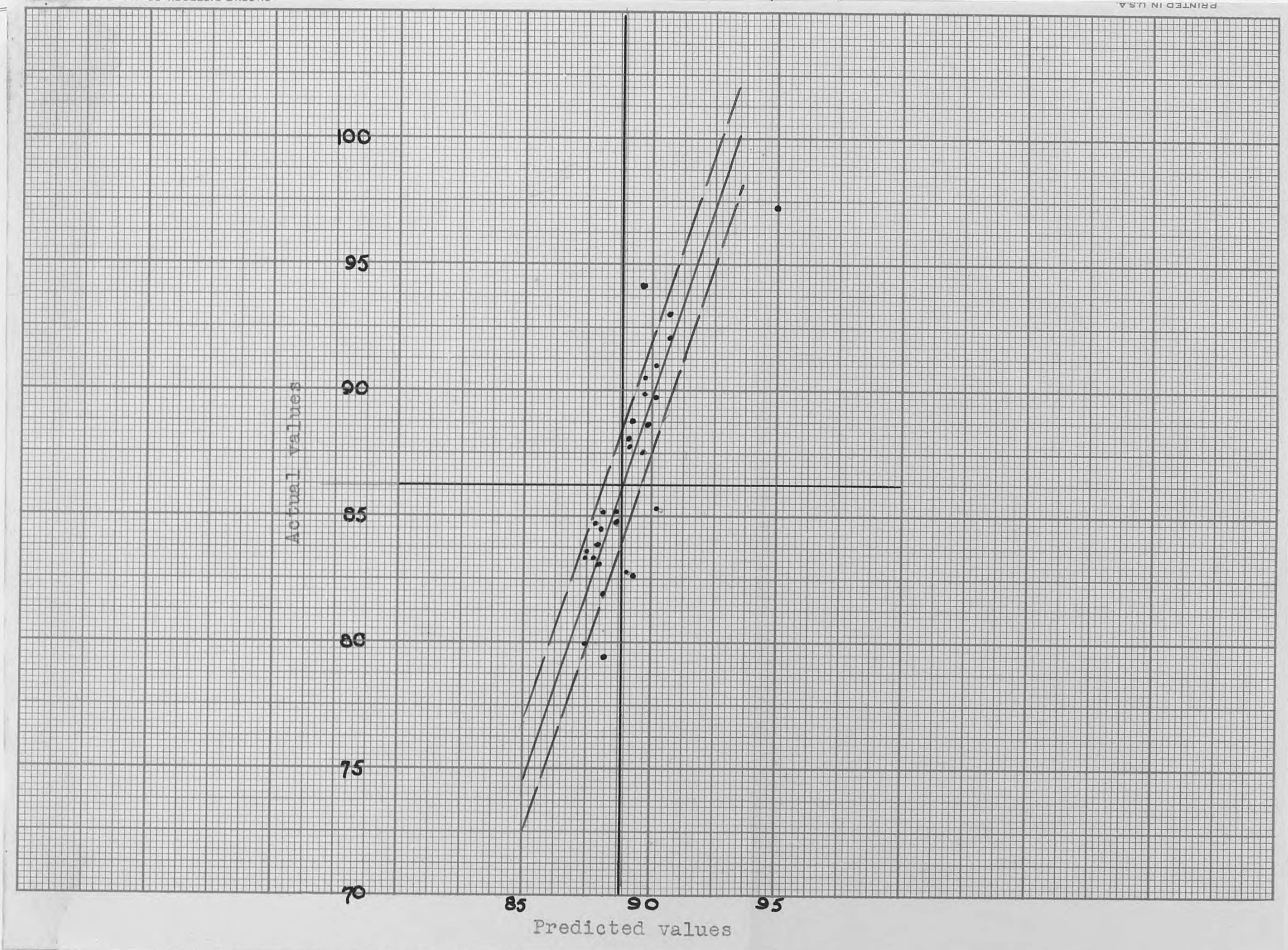


Figure 5. Scatter diagram, regression line and the standard error of estimate obtained by prediction Method IV for the character height of plant.

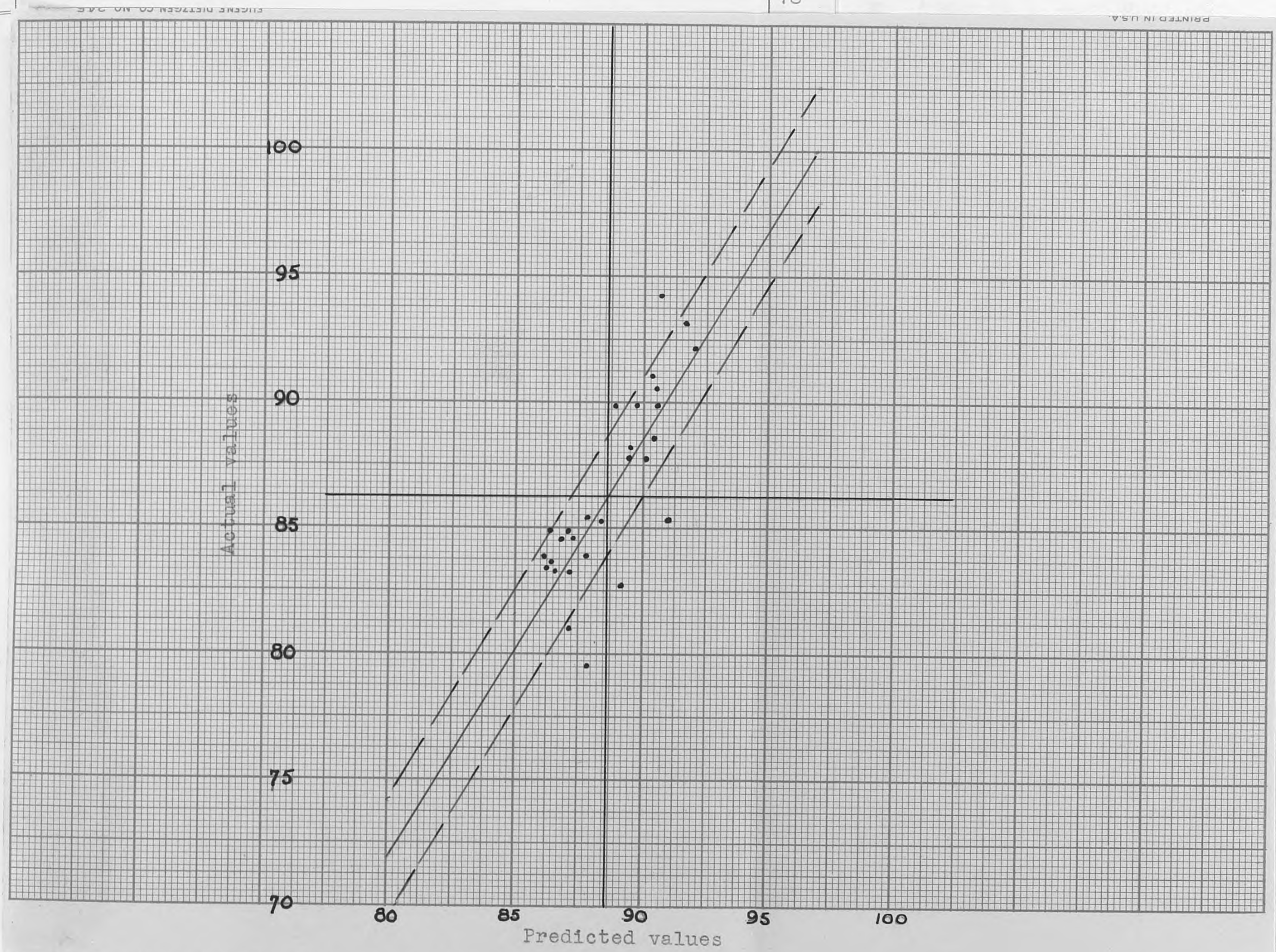


Figure 6. Scatter diagram, regression line and the standard error of estimate obtained by prediction Method V for the character height of plant.

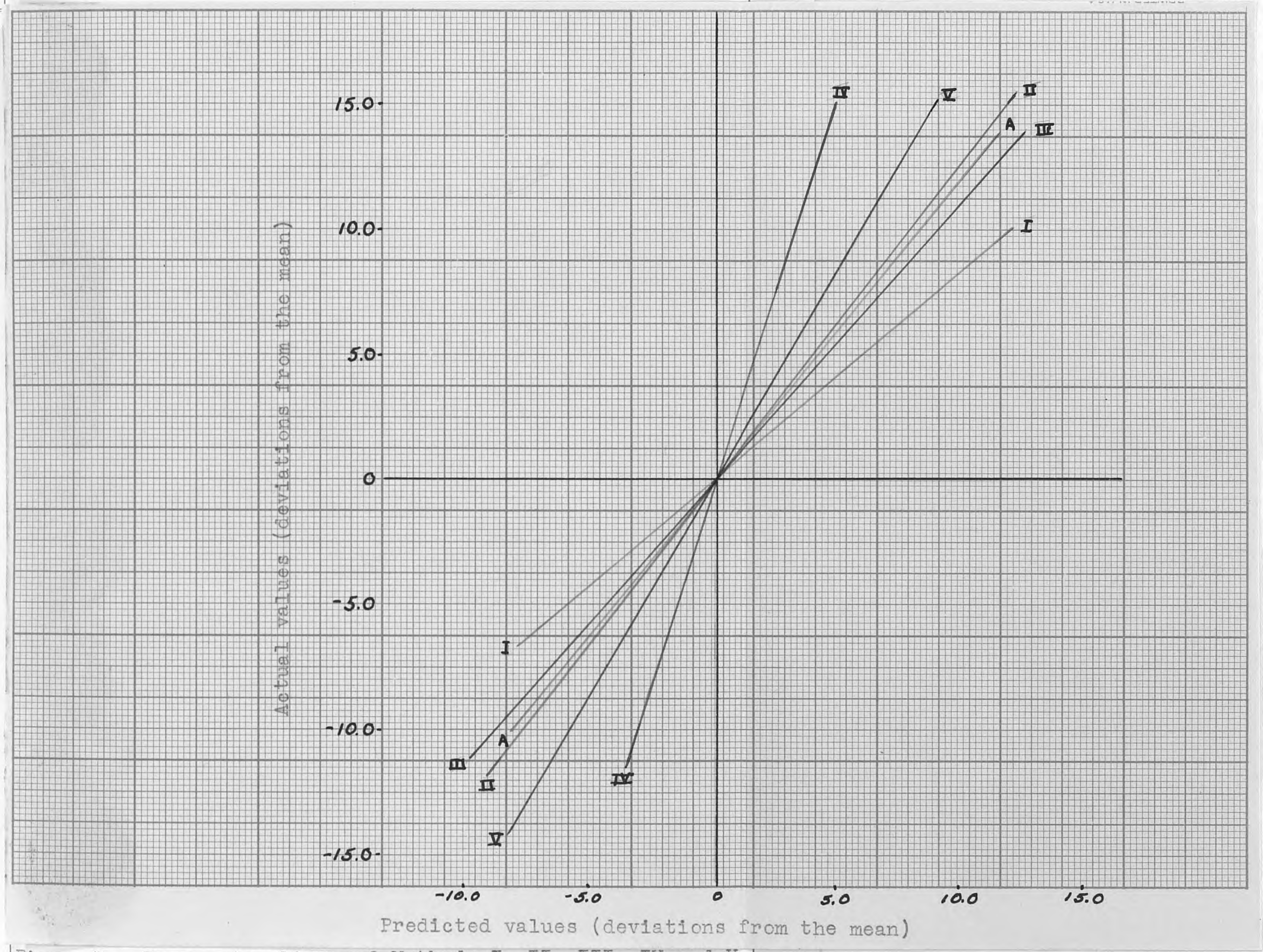


Figure 7. Regression lines of Methods I, II, III, IV and V drawn through the common mean for the character height of plant.

prediction is determined, the sampling variation of the regression itself being estimated. The equation used for the calculation is represented as follows:

$$Sy.x \, / \sqrt{Sx^2} \quad \text{or} \quad 3.06 \, / \sqrt{237.43} = 0.1986$$

The results are again recorded in Table 15 for each of the methods of prediction studied.

Finally the determination of the objective of the entire experiment is obtained, that of a determination of the actual significance of each method of prediction as compared with the other methods. The significance or the regression coefficients can be obtained in a simple way and is accomplished through the calculation of the t value. It is determined simply through the division of the regression coefficient by the standard error.

$$t = 0.8181 \, / \, 0.1986 = 4.119$$

Significance of the t value is obtained by consulting a t table (Snedecor 1938). For 27 degrees of freedom (n-2) the level of significance at the 5 per cent point is 2.052 and at the 1 per cent point is 2.771. The calculated t value for Method I, when compared with the 1 percent level of significance, shows a highly significant relationship between the predicted and the actual double cross measurements for height of plant. Other methods have even greater significance.

In addition it is possible by direct comparison between the methods of prediction (Table 15) to say that Method II is the prediction method which can be used most successfully in the population studied. Method II as a prediction method has a t value of 7.573 compared with 2.771 at the 1 per cent level of significance. The high significance of the t value of the Method II used for height justifies such a conclusion.

A direct relationship between size of the correlation and the size of the t value seems to occur. For Method II the correlation coefficient is 0.8264 and the t value is 7.573. Other methods have progressively lower correlation coefficients and t values.

Height of Ear. The inbred lines of corn used in the study differed significantly among themselves for height of ear. This is clearly shown in Table 11. The single crosses between them were also significantly different for the character as were the double crosses. The F value in each case decreased progressively with an increasing genic complexity due to successive crossing from the inbred lines to the double crosses.

Prediction studies made in a similar way as those for height of plant with corresponding measurements and calculations, gave evidence of varying significance for the methods of prediction of ear height in the double cross hybrids. Some indications of a significant relationship between the predicted and actual values for height of ear was obtained though significance was low as shown by the t values in Table 17.

Method II again has the highest significance with a t value of 2.4727 which is significant at the 5 per cent level but not at the 1 per cent level. Some reliability can probably be given to this value on that basis. The mean of measurements of all of the possible single crosses (Method II) is probably the best indication of what the plant breeder may obtain for the character of ear height.

Some of the lack of significance might possibly be explained by the highly significant differences between replications among the double crosses. Evidently it was not possible to measure the character of ear height with great enough accuracy under existing environmental conditions. Abnormal conditions may have affected normal expression of the character in the double crosses. Lack of data over a number of years on the problem of prediction of ear height makes it impossible to say whether the character can or cannot be predicted by the most significant method brought out in Table 17.

Methods III, IV, and V also had t values which were

Table 17. Regression and correlation data for five methods of prediction for height of ear.

Method	d.f.	Sum of squares and products: Sx^2	Sxy	Sy^2	Correlation coefficient	Regression coefficient	Errors of Estimate: Sum of squares	d.f.	Mean sq.	Standard error of estimate	Standard error of reg. coef.	t
I	28	196.62	24.47	85.75	0.1884	0.1245	82.70	27	3.06	1.75	0.1248	0.9976
II	28	87.67	37.29	85.75	0.4299	0.4253	69.89	27	2.59	1.61	0.1720	2.4727
III	28	132.62	43.01	85.75	0.4033	0.3243	71.80	27	2.66	1.63	0.1416	2.2903
IV	28	11.91	12.57	85.75	0.3932	1.0554	72.48	27	2.68	1.64	0.4754	2.2200
V	28	54.65	28.34	85.75	0.4141	0.5186	71.05	27	2.63	1.62	0.2192	2.3659
Sum	140	483.47	145.68	428.85	0.3199	0.3013	367.92	135	2.73	1.65		

	5 per cent level	1 per cent level
Significant t:	2.052	2.771
Significant r:	0.367	0.470

significant at the 5 per cent level. A direct relation between the size of correlation coefficient and the size of the t value is present. Each of these methods have a lower t value than Method II. Method II, therefore, has a theoretical significance for a more reliable prediction value in this study, but other methods might also be used if practicability is questioned. In the event of the use of a method for prediction of height of ear, the low significance of each method of prediction in these studies limits its reliability to a marked degree, and care and caution must be exercised if its use is contemplated.

The relationship between the methods is shown in Figure 8. All regression lines are moved to the common mean to bring out clearly the statistical variation between the various methods. Method II represents the best probable prediction method for height of ear, though it is hardly adequate because its significance is based on the odds of 19-1. It may or may not give an accurate estimation of progeny performance in a similar population.

Length of Shank. The significant differences for length of shank appearing in the inbred lines, single crosses and double crosses seemed to indicate that a prediction study for the character might be interesting. Significance for the character of length of shank is given in Table 11. In all cases, that is within inbred lines, within single crosses and within double crosses, highly significant differences were found for length of shank.

Length of shank is a character which is quite important in corn improvement work, for a desirable position of the ear on the stalk varies, depending upon methods of harvesting commonly used in production areas.

As a general rule abnormally short shanked plants drop ears more easily than plants which have shanks of normal length. Where corn is harvested by mechanical means hybrids are desired which are relatively short shanked and which drop few ears. It should be possible to obtain a high yielding hybrid of this type through recombination. Hybrids having long shanks are also undesirable, whether husked manually or mechanically. Prediction for the character of length of shanks has some economic importance when considered in this light.

Calculation of the methods of prediction of length of shank followed that outlined earlier for plant height. Results indicate that a method of prediction other than the one previously found to be the most accurate in predictions for plant height and ear height, has the highest correlation, the highest t value and the lowest standard error of estimate. This is indicated in Table 18.

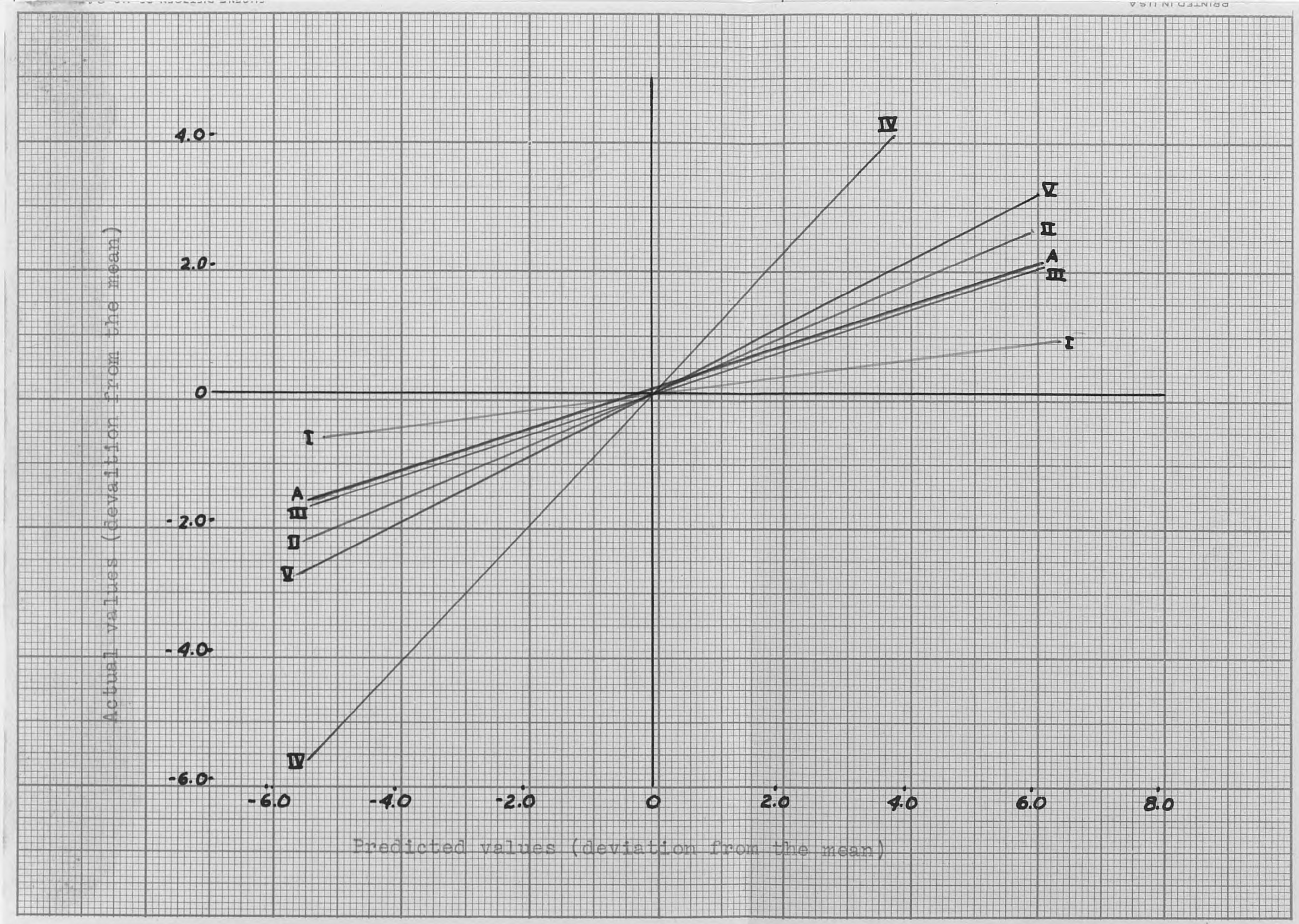


Figure 8. Regression lines of Methods I, II, III, IV, and V drawn through the common mean for the character height of ear.

Table 18. Regression and correlation data for five methods of prediction for length of shank.

Method	d.f.	Sum of squares and products: Sx^2	Sxy	Sy^2	Correlation coefficient	Regression coefficient	Errors of Estimate: Sum of squares	d.f.	Mean sq.	Standard error of estimate	Standard error of reg. coef.	t
I	28	1.27	1.00	3.25	0.4926	0.7874	2.46	27	0.0911	0.302	0.2696	2.9206
II	28	1.14	1.36	3.25	0.7083	1.1930	1.63	27	0.0604	0.245	0.2311	5.1623
III	28	1.31	1.49	3.25	0.7233	1.1374	1.56	27	0.0578	0.240	0.2105	5.4033
IV	28	0.19	0.55	3.25	0.7051	2.8947	1.66	27	0.0615	0.248	0.5675	5.1008
V	28	0.53	0.91	3.25	0.6947	1.7170	1.69	27	0.0626	0.250	0.3434	5.0000
Sum	140	4.44	5.31	16.25	0.6254	1.1959	9.00	135	0.0667	0.258		

	5 per cent level	1 per cent level
Significant t:	2.052	2.771
Significant r:	0.367	0.470

A highly significant t value of 5.4033 was obtained for the prediction value calculated by Method III, being considerably higher than the t value of 2.771 at the 1 per cent level of significance. The high significance of Methods II, IV, and V should not be over-looked and possibly these methods are approximately equal to Method II in their suitability for determining a prediction of this type. Method II has a t value of 5.1623 as compared to a t value of 5.4033 for Method III and because of its value in determination of progeny performance as to height of plant and height of ear has much in its favor for a general prediction method.

Method I as a means of predicting length of shank is also valuable. It is, however, far below the significance of the other four methods and, therefore, seems to have little place in the prediction of the length of shank in the double crosses from single cross data. It becomes more and more apparent that actual component single crosses (Method I) cannot be used in estimating double cross performance in the population studied in this investigation, since this method was the least satisfactory for height of plant, height of ear and length of shank.

Regression lines for the methods of prediction used for length of shank are shown in Figure 9. All regressions are centered on a common mean giving a comparable relationship

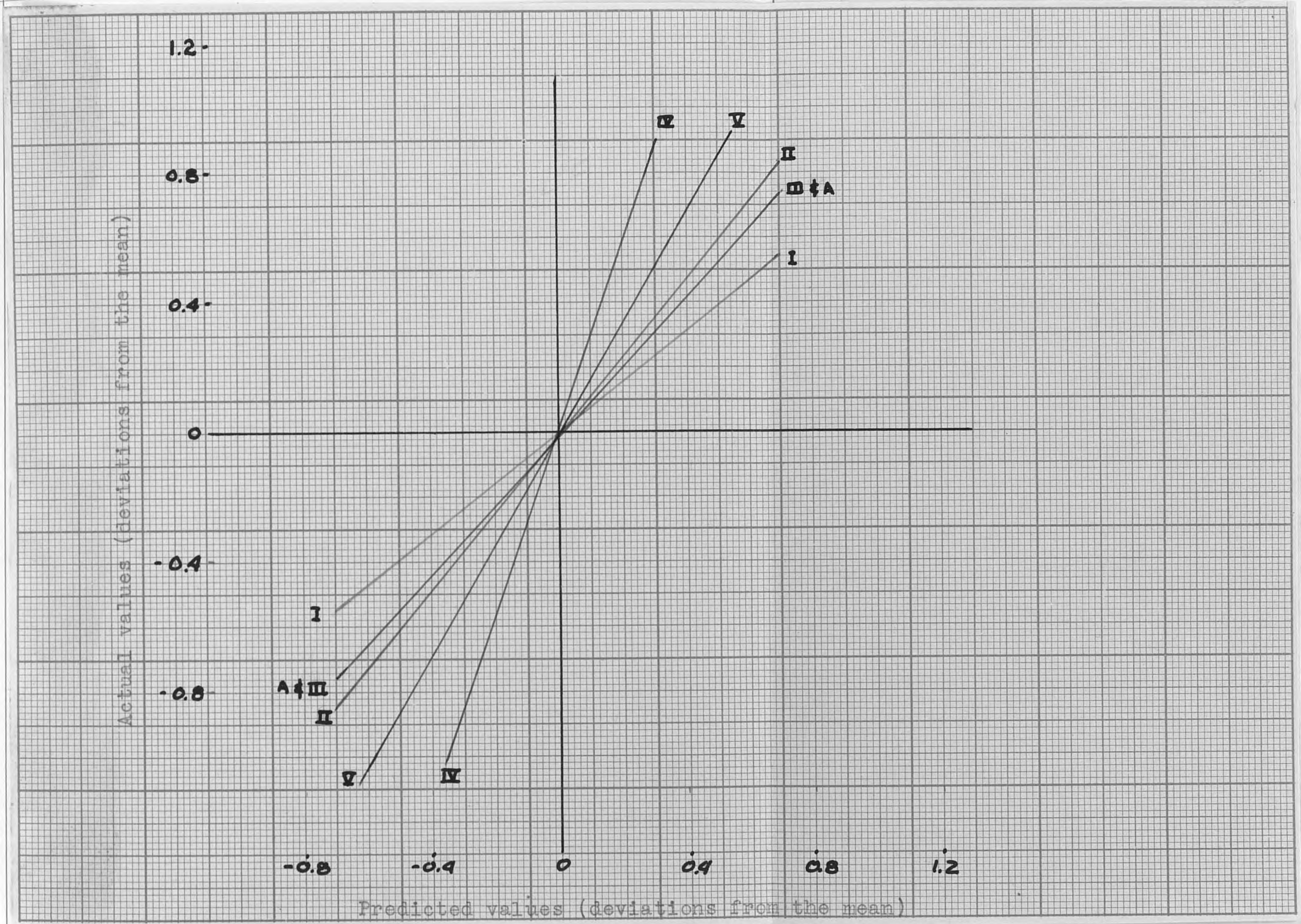


Figure 9. Regression lines of Methods I, II, III, IV and V drawn through the common mean for the character length of shank.

between the methods considered in prediction of the character.

Corn Ear Worm Damage. In the preliminary analysis of corn ear worm damage, (Table 11) no significant differences in resistance were found between the inbred lines. Each of the inbred lines, in general, tended to be quite susceptible as shown by their mean class injury of 3.62 in Table 7.

The single crosses, however, as shown in Table 11, differed significantly among themselves for resistance. The range of class injury in this group was 3.10 for the most resistant to 3.77 for the most susceptible single cross, a range of more than one-half class. Ordinarily differences between crosses of one-half class have been found to be significant. The mean corn ear worm damage for the single crosses was 3.41.

The possibility exists that the apparent resistance to corn ear worm damage of the single crosses can be ascribed to factors which are combined from their parental inbred lines. Quantitative factors might, therefore, explain the differential significant resistance of the single crosses produced from inbred lines which were not significantly different for the character. Another explanation can be given for the variation in resistance between the groups. It seems logical to assume that the effects of heterosis could be involved in producing single crosses which differ significantly for corn ear worm damage. Variations in resistance might also be due to both the recombination of factors together with the effects of heterosis. It was not possible to obtain data to verify these assumptions in this investigation.

The mean class injury for corn ear worm damage of the double crosses was intermediate between the mean of the single crosses and the mean of the inbred lines, as might be expected. A range of 0.63 of a class existed between the highest and lowest class injury, the class of 3.27 being the most resistant and a class of 3.90 being the most susceptible. The range was large enough to give significant differences between the 29 double crosses studied, significance for which is shown in Table 11.

The analysis of corn ear worm damage produced peculiarities which were uncommon to other characters studied. Probably most important of all is the large amount of error involved in the corn ear worm study resulting in a low t value even though the coefficient was barely significant. Experimental error then apparently is not revealed in the correlation of 0.3729 and a prediction based upon its significance would likely be erroneous. A summary of the results of prediction is given in Table 19.

Table 19. Regression and correlation data for five methods of prediction for corn ear worm damage.

Method	d.f.	Sum of squares and products: Sx^2	Sum of squares and products: Sxy	Sum of squares and products: Sy^2	Correlation coefficient	Regression coefficient	Errors of Estimate: Sum of squares	Errors of Estimate: d.f.	Errors of Estimate: Mean sq.	Errors of Estimate: Standard error of estimate	Errors of Estimate: Standard error of reg. coef.	t
I	28	0.6749	0.2109	0.5611	0.3427	0.3125	0.4952	27	0.183	0.427	0.5201	0.6008
II	28	0.1777	0.1023	0.5611	0.3240	0.5757	0.5022	27	0.186	0.431	1.0262	0.5610
III	28	0.2220	0.0664	0.5611	0.1882	0.2991	0.5412	27	0.200	0.447	0.9933	0.3011
IV	28	0.0260	0.0452	0.5611	0.3729	1.7385	0.4825	27	0.179	0.423	2.6273	0.6617
V	28	0.0933	0.0542	0.5611	0.2369	0.5809	0.5296	27	0.196	0.443	1.4525	0.3999
Sum	140	1.1939	0.4790	2.8055	0.2617	0.4012	2.5507	135	0.189	0.434		

	5 per cent level	1 per cent level
Significant t:	2.052	2.771
Significant r:	0.367	0.470

The t value for each of the methods of predictions is so low compared to the values needed for significance, that as methods for predicting double cross performance of corn ear worm damage in this investigation, are of little utility.

Regression lines when grouped or centered on the common mean show the relationships between the various methods. The relationship is diagrammatically shown in Figure 10.

Yield of Grain. A study of the prediction of probable yield of grain of double cross hybrids by methods outlined previously was made for two reasons. It was studied primarily, first, because much of the earlier extensive work of prediction involving methods similar to those used in this investigation, (Jenkins (1934) and Doxtator and Johnson (1936)) was largely on the yield of grain; and second, because in earlier analysis of variance studies of yield (Table 11) no significant differences between the double crosses were found for yield of grain. In addition there was a highly significant difference between the yields of the inbred lines used and a low but significant difference between the yields of the single crosses studied, the significance decreasing as the progeny of the inbred lines became more diverse by crossing, as might be expected. A predicted performance for yield formulated from single cross data as

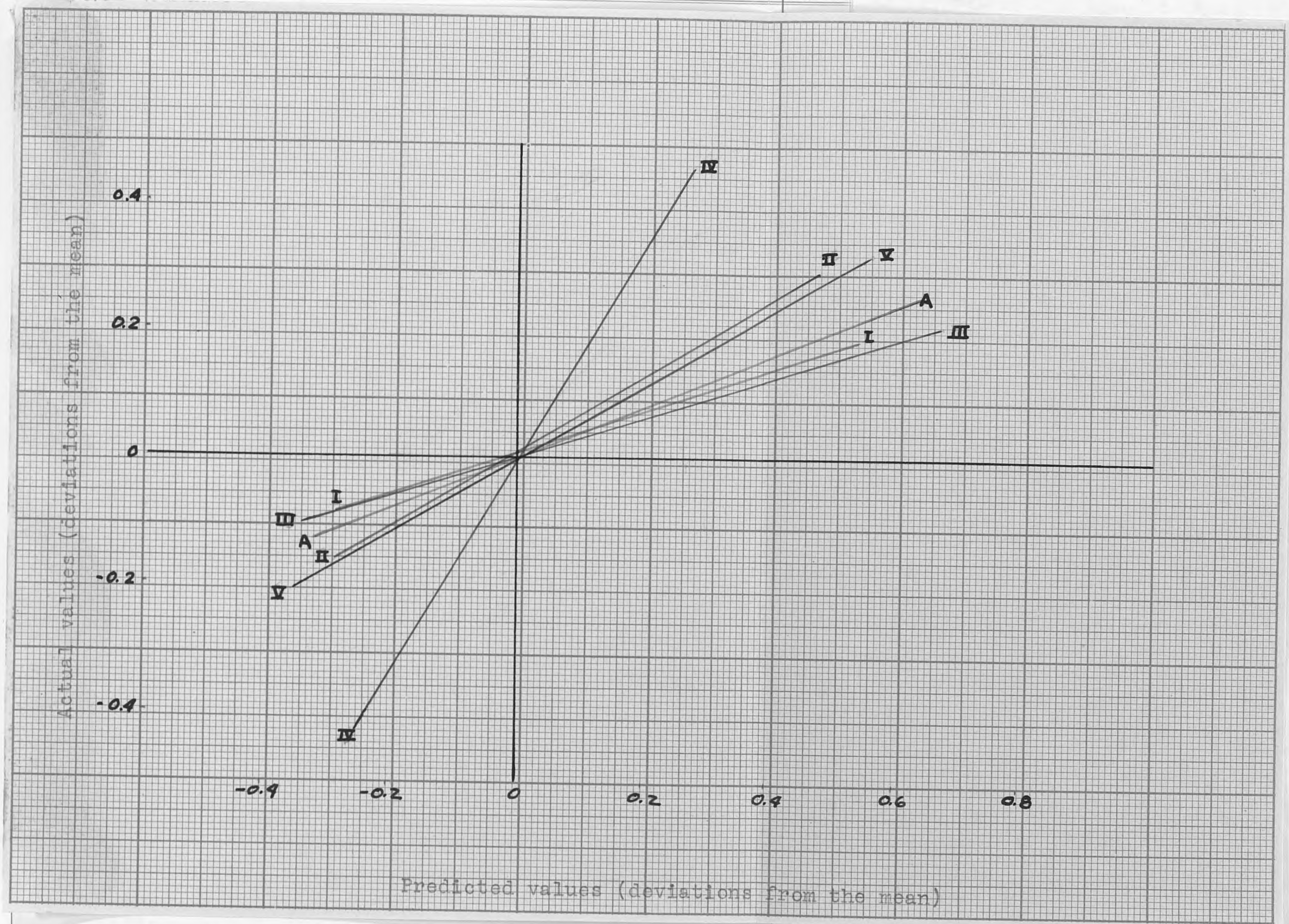


Figure 10. Regression lines of Methods I, II, III, IV, and V drawn through the common mean for the character corn ear worm damage.

compared with actual performance of the double crosses for yield under these conditions might be interesting when analyzed statistically. However, the high and very significant differences occurring between replications of the single crosses and also the high and very significant differences between replications of the double crosses indicated that a significant variation among the prediction methods would probably not be apparent. A summary of the significance of the five prediction methods for yield of grain is given in Table 20.

When analyzed statistically all t values for the methods of prediction were approximately similar. No significant method for prediction was found. Prediction methods in this study have no apparent value in the yield of grain predictions from single cross performance. All values of t are low in comparison to the values necessary for significance.

The highest value for t of any method of prediction used was 1.4750 for Method IV. The lowest t value was 1.0185 for Method I. Correlations too were approximately similar numerically, the highest being 0.2730 for Method IV and the lowest being 0.1928 for Method I, neither approaching significance.

Presumably environmental effects due to various abnormal climatic conditions as well as soil heterogeneity have

Table 20. Regression and correlation data for five methods of prediction for yield of grain.

Method	d.f.	Sum of squares and products: Sx^2	Sxy	Sy^2	Correlation coefficient	Regression coefficient	Errors of Estimate: Sum of squares	d.f.	Mean sq.	Standard error of estimate	Standard error of reg. coef.	t
I	28	101.25	22.24	131.42	0.1928	0.2197	126.53	27	4.69	2.17	0.2157	1.0185
II	28	98.04	28.33	131.42	0.2496	0.2890	123.23	27	4.56	2.14	0.2173	1.3300
III	28	120.72	31.88	131.42	0.2531	0.2641	123.00	27	4.56	2.14	0.1948	1.3557
IV	28	15.00	12.12	131.42	0.2730	0.8080	121.63	27	4.50	2.12	0.5478	1.4750
V	28	54.48	22.01	131.42	0.2601	0.4040	122.53	27	4.54	2.13	0.2890	1.3979
Sum	140	389.49	116.58	657.10	0.2304	0.2993	616.92	135	4.57	2.14		

	5 per cent level	1 per cent level
Significant t:	2.052	2.771
Significant r:	0.367	0.470

greatly influenced the expression of yield of grain. No method of prediction can be used to determine the yield of grain when the character is masked or suppressed in expression by adverse environment.

An index of the variations among the methods of prediction can be obtained by studying the regression lines shown in Figure 11 each of which is drawn through the common mean. No reliable prediction can be made from them, or normal expectancy of progeny determined because the methods used are not significant. The yield of grain obviously was masked by adverse environmental conditions.

Firing Grade. A study was made of the firing damage that occurred in the field during the late summer season of 1938. Conditions seemed to be ideal for such a study. Just enough firing damage occurred in the plots of susceptible strains, which, therefore, could be easily graded for firing damage. The more resistant plants apparently were not injured by the drought.

In the analysis of variance shown in Table 11, highly significant differences between the inbred lines were found with respect to firing. Such a variation between inbred lines for drought or firing resistance should give some basis for expecting differences for the same character in the single crosses made in all possible combinations from the

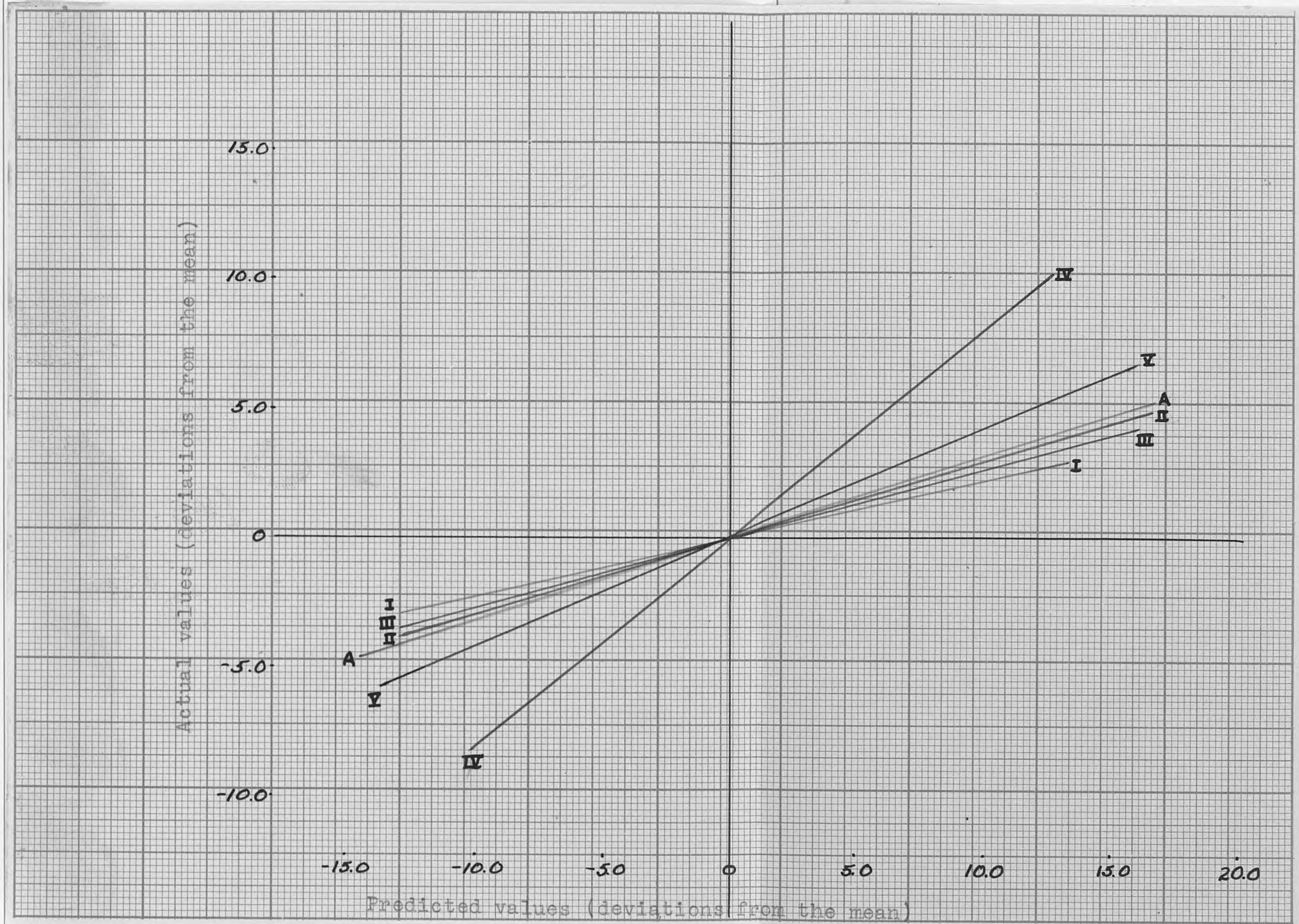


Figure 11. Regression lines of Methods I, II, III, IV and V drawn through the common mean for the character yield of grain.

six lines.

A significant difference in firing grade between the single crosses was found. There was also a highly significant difference in firing between replications of the single crosses, giving weight to the ununiformity of firing damage which occurred. Within the double crosses significant differences for firing were also found, as well as a significant difference, though not as high as in the single crosses, between replications of them. The general relationship of firing damage between the inbred lines, the single crosses, and the double crosses should give some foundation for a method of prediction study for the character.

Statistical analysis of predictions for the character by five methods are given in Table 21.

Highly significant t values were obtained for each of the methods except I. The methods ranked in order of their significance are as follows: Method III, Method II, Method IV, Method V, and Method I. All the methods of prediction except that of Method I were significant at odds of 99 to 1. Methods II to V inclusive do not vary a great deal in their significance and it is suggested that they might be used interchangeably depending upon their practicability.

Correlation coefficients of the methods were also nearly identical, except in the case of Method I. As in pre-

Table 21. Regression and correlation data for five methods of prediction for firing grade.

Method	d.f.	Sum of squares and products: Sx^2	Sxy	Sy^2	Correlation coefficient	Regression coefficient	Errors of Estimate: Sum of squares	d.f.	Mean sq.	Standard error of estimate	Standard error of reg. coef.	t
I	28	2.31	0.95	4.51	0.2941	0.4113	4.12	27	0.153	0.391	0.2572	1.5991
II	28	1.29	1.41	4.51	0.5851	1.0930	2.97	27	0.110	0.332	0.2938	3.7202
III	28	1.65	1.62	4.51	0.5934	0.9818	2.92	27	0.108	0.328	0.2563	3.8307
IV	28	0.23	0.56	4.51	0.5490	2.4348	3.15	27	0.117	0.342	0.7140	3.4101
V	28	0.79	1.01	4.51	0.5344	1.2785	3.22	27	0.119	0.344	0.3874	3.3002
Sum	140	6.27	5.55	22.55	0.4668	0.8852	16.38	135	0.121	0.348		

	5 per cent level	1 per cent level
Significant t:	2.052	2.771
Significant r:	0.367	0.470

vious character studies Method I gave the smallest correlations and t values and the highest standard error of estimate for the prediction of progeny performance, again indicating that component single crosses can hardly be used as a basis for estimating double cross performance.

The relation between the various methods of prediction is given in Figure 12. Regressions are drawn through the common mean and their variation is shown by differences in the slope of the line.

Lodging Due to White Grubs. Severe lodging in many of the plots occurred early in the fall, particularly following a steady south wind which blew for several days from October 21 to October 23. Investigation revealed that lodging was entirely of the root type, no stalk breaking occurring at this early date. Most of the lodged plants were lying on the surface of the soil and very few were leaning at all. Examination of the lodged plants showed severe root injury, the lodged plants having but few brace roots and very few fibrous roots remaining intact.

A determination of the casual organism was made by probing the soil beneath a number of lodged hills in several plots. In the soil directly adjacent to the roots of the lodged plants many white grub worms were found. The number of grubs, were carefully counted under each hill to deter-

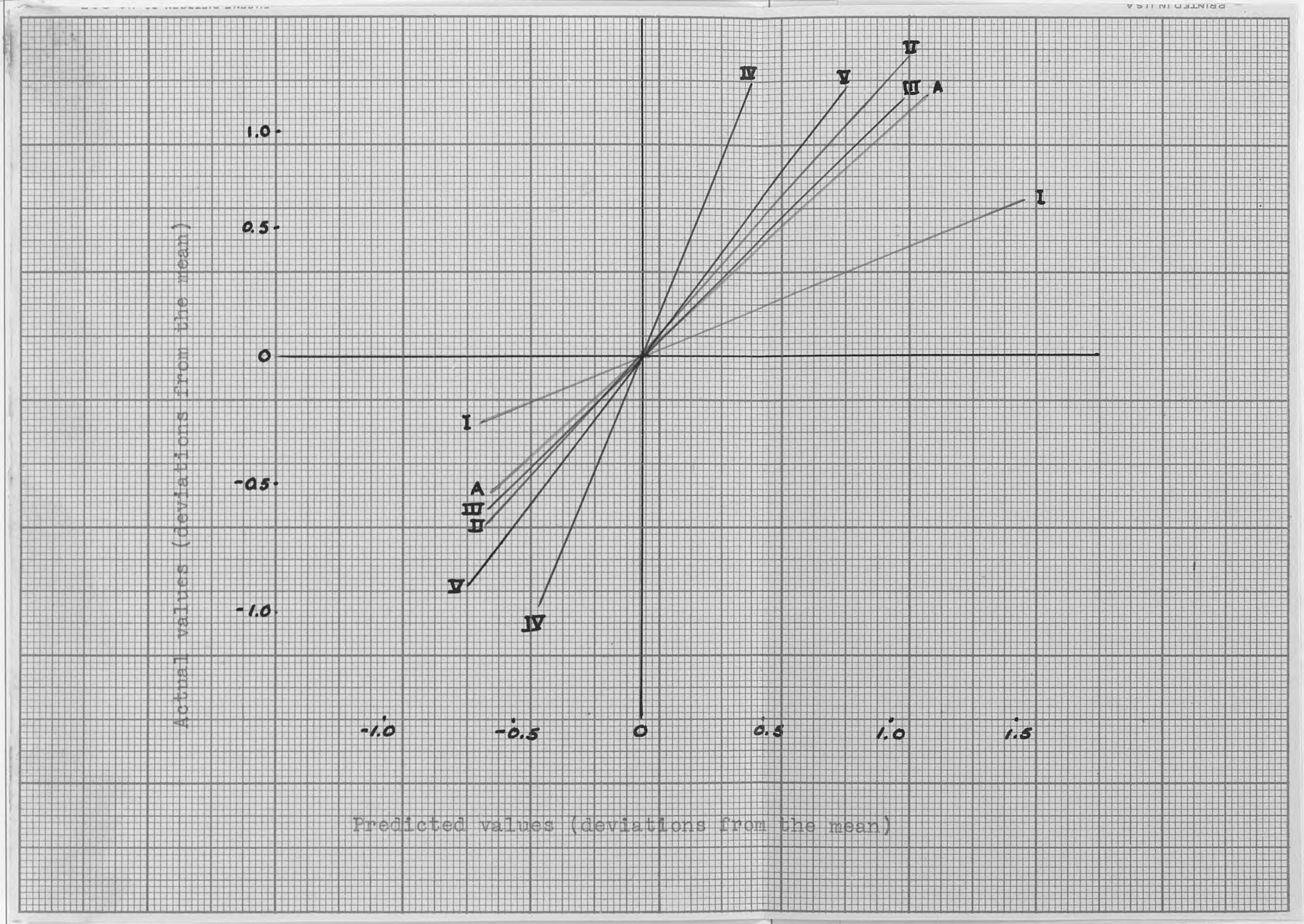


Figure 12. Regression lines of Methods I, II, III, IV and V drawn through the common mean for the character firing grade.

mine the relative infestation. Three to ten grub worms were found under each hill, with six to eight appearing most frequently. Consultation with various members of the Department of Entomology verified the cause of the damage and concluded that the amount of infestation present was great enough to cause the lodging.

The worm was classified by Mr. Bryson of the Department of Entomology as <u>Phyllophaga</u> <u>spp</u>. The injury was attributed primarily to second year grubs of a three year cycle species. The grubs ordinarily do little damage during the hot dry months of the summer season, but begin to do considerable damage during moist weather in the late summer and early fall after corn has nearly matured. No injury by either Western or Southern corn root worm was detected during the growing season, the root injury being almost entirely ascribed to damage by the white grub.

The lodging notes were analyzed statistically to determine whether or not significant differences in lodging occurred in the inbred plots, the single cross plots and the double cross plots. A summary of the apparent significance is given in Table 11.

Among the inbred lines studied no apparent significance was obtained. No differences were noticeable in the field, all inbred lines appearing to be more or less resistant to the grubs as exemplified by little if any apparent lodging.

The character of resistance is not known although several suppositions have been made by various entomologists and agronomists. The resistance might possibly be attributed to secondary factors, that is, because of abnormal environmental conditions the inbred lines did not develop grain normally, many of them being nearly barren. It has been observed in the case of disease resistance to Diplodia zeae and other dry rots, that corn plants which are barren are generally more resistant to the disease than those which are allowed to produce grain normally. Barrenness could possibly contribute apparent resistance to grub worms in the same way, although this is merely a supposition made from general field observations. Barrenness of the plants could contribute apparent resistance in another way. Anchorage is little needed by barren plants. Plants normally require good root systems to support the heavy ears which they produce, and any attack on the roots is demonstrated by lodging. This type of anchorage is little needed by barren plants and they may thus appear resistant to attack by the grub worms.

The resistance was further studied by examining the roots of all of the six inbred lines used in the investigation. A comparison of the roots for each inbred line was made and is illustrated in Plate I.

EXPLANATION OF PLATE I

The differential resistance to injury of the roots of six inbred lines of corn to the white grub worm, *Phyllophaga spp.* is shown in Plate I. The inbred lines PS26, PS54, PS41, PS44, and PS63, illustrated in figures 1, 2, 3, 5 and 6 respectively, show little if any root damage, the lines apparently being resistant to injury in a greater or lesser degree. Inbred PS55 illustrated in figure 4 has a distinct variation in resistance and susceptibility to white grub damage. The roots shown in each figure were taken from their respective plots in replication six of the experiment.

Plate I

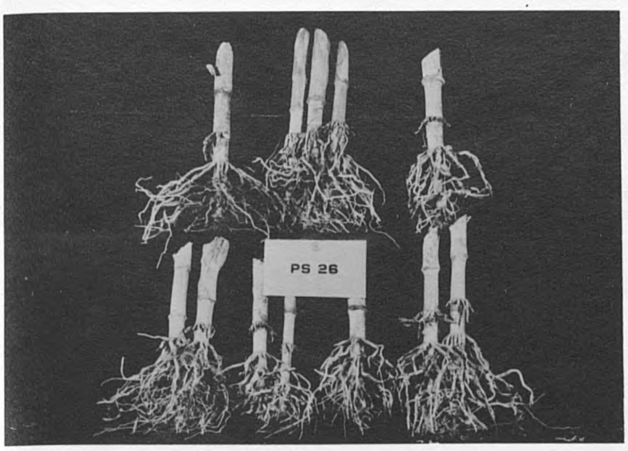


fig. 1

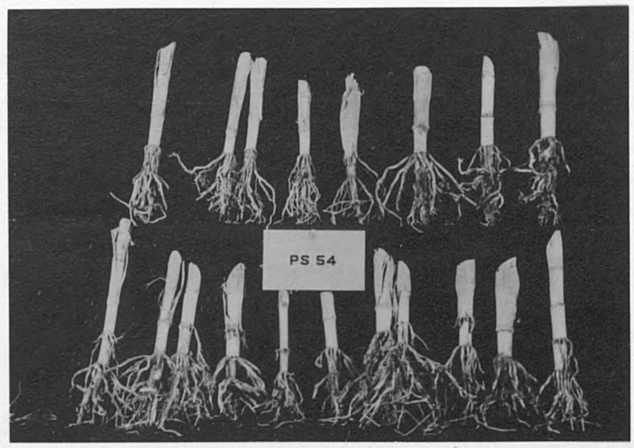


fig. 2

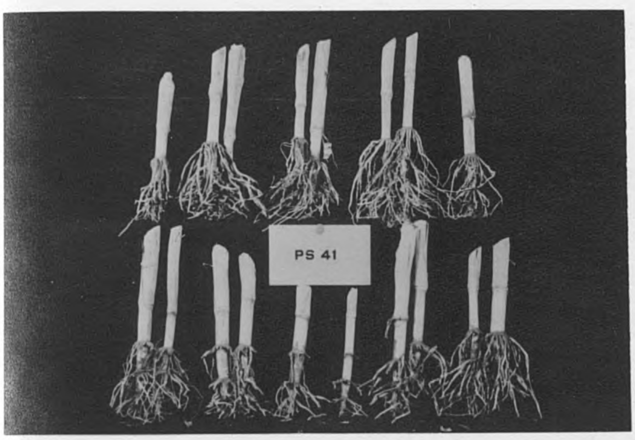


fig. 3

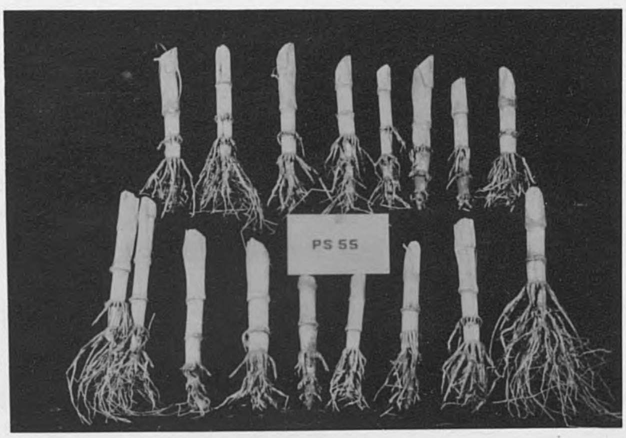


fig. 4

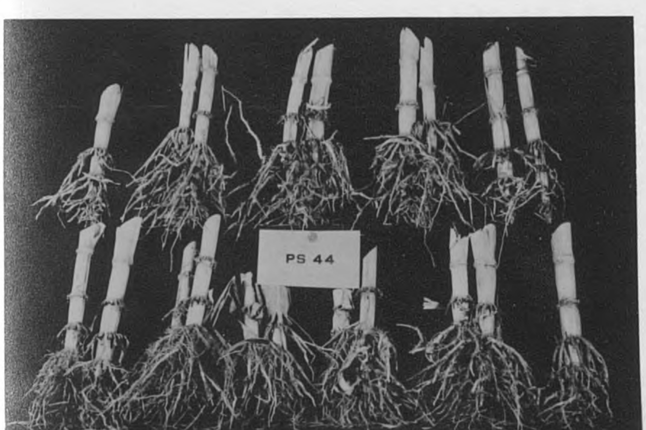


fig. 5

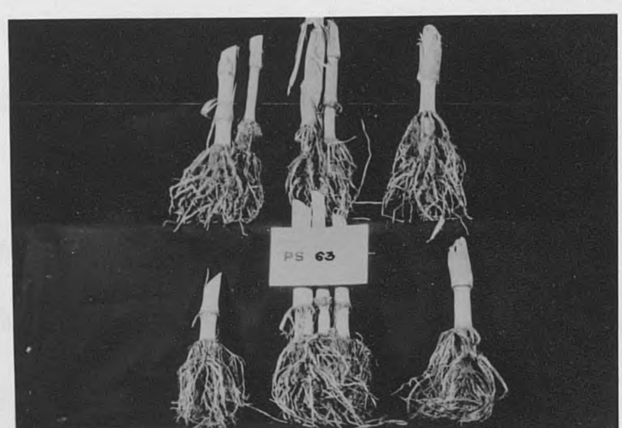


fig. 6

The root systems of the several inbred lines differed from each other in some respects. Because of the differences among the inbred lines it is possible that resistance or susceptibility to grubs might be found in crosses between them. However, no noticeable susceptibility was evident except perhaps in inbred PS55. Several plants had stalks nearly devoid of roots while other plants had many roots. Assuming that no selection has been made within the PS55 inbred line for resistance to grub worms it might be expected to show some segregation for resistance and susceptibility. The other inbred lines showed little evidence of susceptibility, but in reality the roots of the various lines appeared to be more or less intact.

Single crosses involving the six lines exhibited varying degrees of susceptibility and resistance in the field. This variation between single crosses is particularly well portrayed in Plate II.

The single cross 41 x 63 was the most susceptible to lodging due to grub worms. Most of the stalks were uprooted, a few leaning or had fallen against the small number of plants that remained standing in the plot. The most resistant single cross found in the field was 41 x 54. It remained upright in a remarkable manner, and was conspicuous for that character in the field.

EXPLANATION OF PLATE II

The roots of the single crosses (PS26 x 44) and (PS41 x 54) illustrated in figures 1 and 2 respectively, show a characteristic variation in resistance or susceptibility to damage by white grub worms, Phyllophaga spp. In combination the two single crosses gave the most resistant double cross. The roots of the single cross (PS41 x 55), illustrated in figure 3, show a high susceptibility to damage by white grubs. This single cross in combination with the single cross illustrated in figure 4 which was moderately susceptible, gave the double cross hybrid which was the most susceptible to white grub injury. The roots shown in each figure were taken from their respective plots in replication six of the experiment.

Plate II

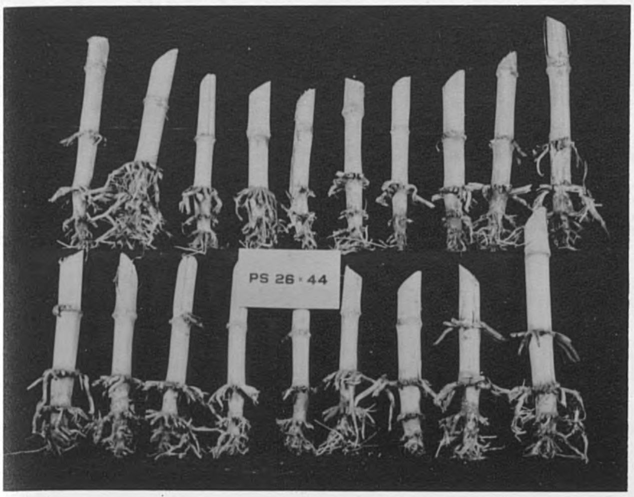


fig. 1

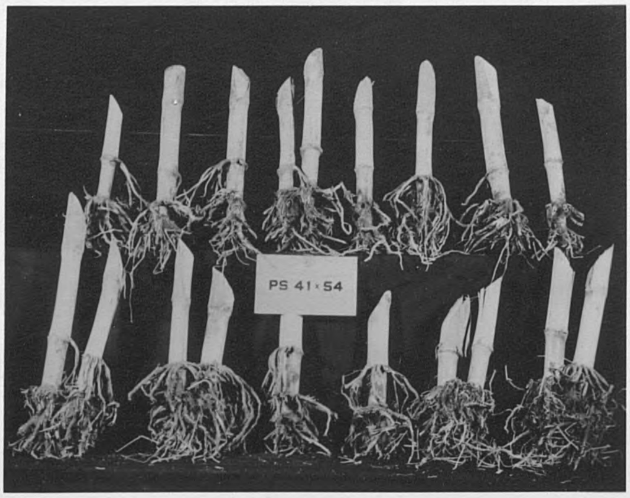


fig. 2

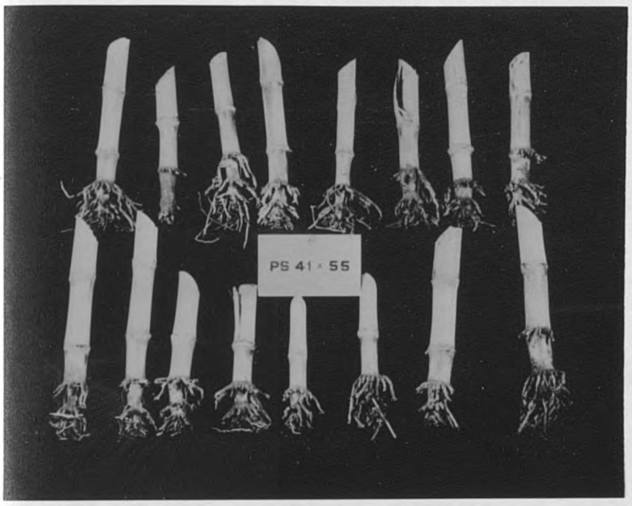


fig. 3

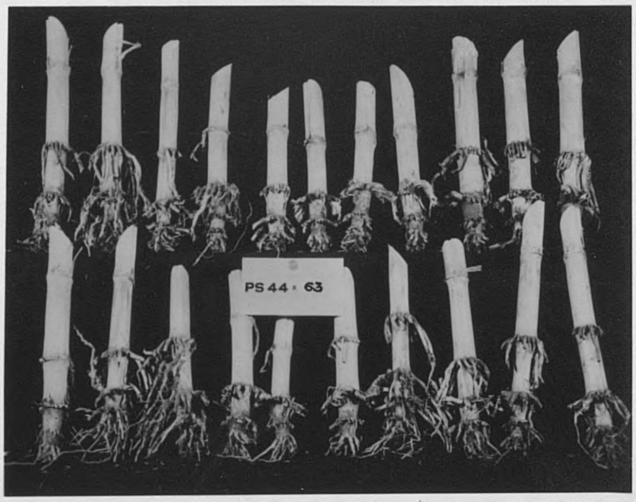


fig. 4

The root resistance of this cross is shown in Plate III. In comparison with the other single crosses shown it is outstanding in its resistance to attack, which is so clearly portrayed in the field. The single cross 41 x 54 had fewer roots cut off by grubs, and most of the roots were still intact while the roots of the single crosses (26x44), (41x55) and (44x63) had been lost in varying amounts, and which corresponded to actual lodging due to grub worm damage.

A statistical study of lodging due to grub worms by analysis of variance brought out a highly significant difference between single crosses for the character. A significant difference between replications for this type of lodging was also found. A summary of the significance of lodging due to grub worm damage is given in Table 11.

Differences such as have been shown to exist in the single crosses provide exceptional material for use in prediction of parent progeny performance. The character is so conspicuous and obvious that existing differences in the progeny should be found easily.

When the single crosses, whose roots are shown on the top of Plate III are crossed the double cross (26x44) x (41x54) is obtained. This double cross was the most resistant to lodging due to grub injury, the plants and roots of which are shown on Plate IV.

EXPLANATION OF PLATE III

The plants of the most susceptible single cross (41x63) to white grub worm damage, as shown by the severity of lodging, is illustrated in figure 1. The plants of the most resistant single cross (41x55) to white grub worm damage is illustrated in figure 2. The plants shown in each of the figures were those found in their respective plots in replication six of the experiment.

Plate III

fig. 1

fig. 2

EXPLANATION OF PLATE IV

The plants and the roots of the most resistant double cross hybrid (26x44) x (41x54) to white grub worm damage are illustrated in figures 1 and 2, respectively. The plants and the roots of the most susceptible double cross hybrid (41x55) x (44x63) to white grub worm damage are illustrated in figures 3 and 4, respectively. The roots of the parent variety Pride of Saline, from which all of the inbred lines used in this study were obtained, is shown in figure 5. The roots and plants were those found in their respective plots in replication six of the experiment.

fig. 1

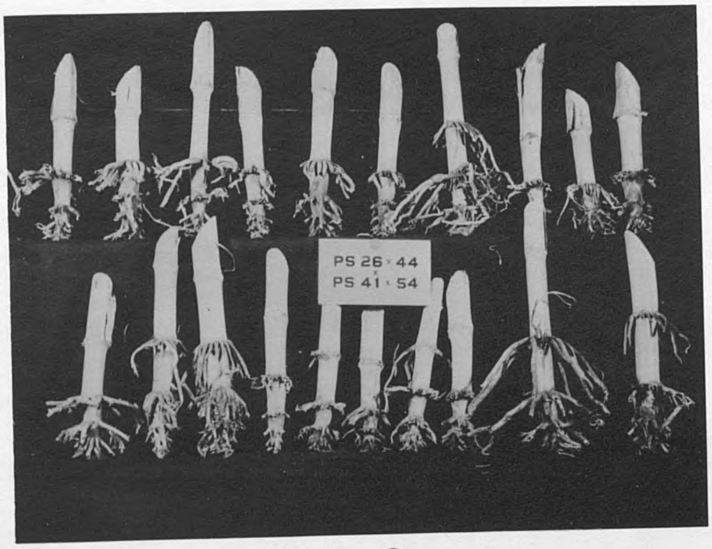


fig. 2

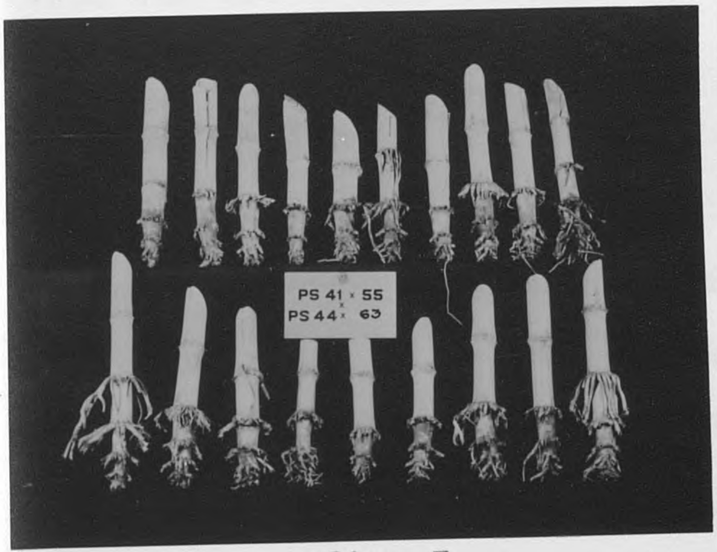


fig. 3

fig. 4

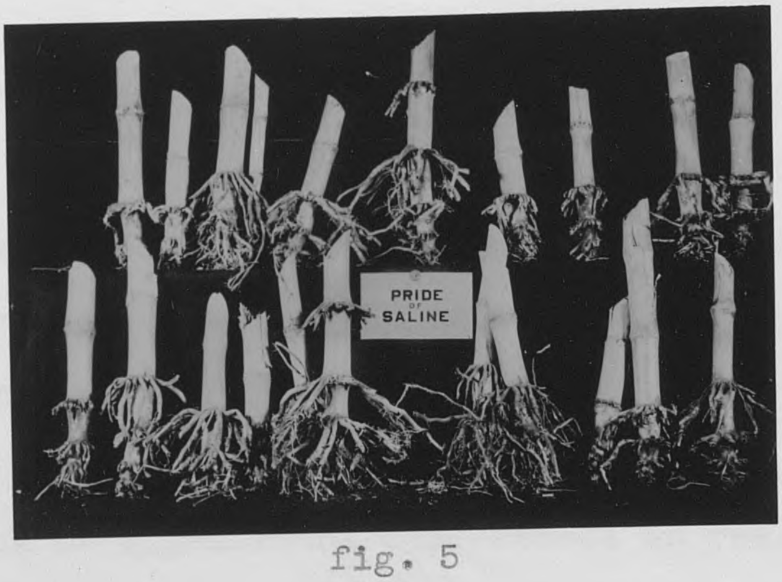


fig. 5

It was far more resistant to lodging than the double cross originating from the single crosses (41x55) and (44x63) whose roots are also shown on Plate III. The resulting double cross (41x55) x (44x63) is illustrated on Plate IV, both plants and roots showing markedly greater effects of grub worm damage than the double cross (26x44) x (41x54). A differential field lodging and root injury between the two double crosses can easily be detected from the illustrations on Plate IV.

When the roots of both of these double cross hybrids are compared to the roots of Pride of Saline the variety from which the parental lines originated as shown on Plate IV , they appear to be more susceptible. Pride of Saline apparently may have some inherent natural resistance acquired by natural selection, which perhaps has been partially lost through inbreeding to obtain the parent inbred lines.

The differential resistance of double cross hybrids to lodging due to grub worms is assumed from data of double crosses grown in this investigation. Table 11 gives significant differences between the double crosses for lodging due to grub worms, no significant difference apparently occurring between replications.

The lack of significant differences in resistance between the inbreds, and the significance for resistance found in the single crosses and in the double crosses, suggest the possibility that the phenomenon of heterosis might be involved. No evidence or proof of this was obtained.

The study of the possibility of predicting probable lodging damage of the double cross hybrids from single cross data by the five methods outlined and used in this investigation is summarized in Table 22.

A significant correlation at the 5 percent level of 0.4055 was obtained for Method II. No other methods were found to be correlated significantly. A t value of 2.3082 significant at the 5 per cent level was obtained for Method II. This was the only method studied for which a significant t value was obtained. Method II is probably more significant than the other methods used because less error is associated with it. This is shown in the error of estimate in Table 22. A standard error of estimate of 2.49 being ascribed to Method II as compared to a higher error value for each of the other methods studied. Method I has a very low correlation coefficient and a very low t value, both of which are not significant, again showing the impossibility of using the component single crosses as a basis for parent-progeny relations.

Relationships of the various methods are shown in Figure 13. Regression lines of the methods used were plot-

Table 22. Regression and correlation data for five methods of prediction for lodging damage by white grubs.

Method	d.f.	Sum of squares and products: Sx^2	Sxy	Sy^2	Correlation coefficient	Regression coefficient	Errors of Estimate: Sum of squares	d.f.	Mean sq.	Standard error of estimate	Standard error of reg. coef.	t
I	28	123.67	1.46	200.96	0.0093	0.0118	200.94	27	7.442	2.73	0.2455	0.0481
II	28	69.77	48.02	200.96	0.4055	0.6883	167.91	27	6.219	2.49	0.2982	2.3082
III	28	98.53	45.21	200.96	0.3213	0.4588	180.22	27	6.675	2.58	0.2588	1.7728
IV	28	9.57	13.76	200.96	0.3138	1.4378	181.18	27	6.710	2.59	0.8382	1.7153
V	28	42.43	27.77	200.96	0.3007	0.6545	182.78	27	6.770	2.62	0.4025	1.6261
Sum	140	343.97	136.22	1004.80	0.2317	0.3960	913.03	135	6.763	2.60		

	5 per cent level	1 per cent level
Significant t:	2.052	2.771
Significant r:	0.367	0.470

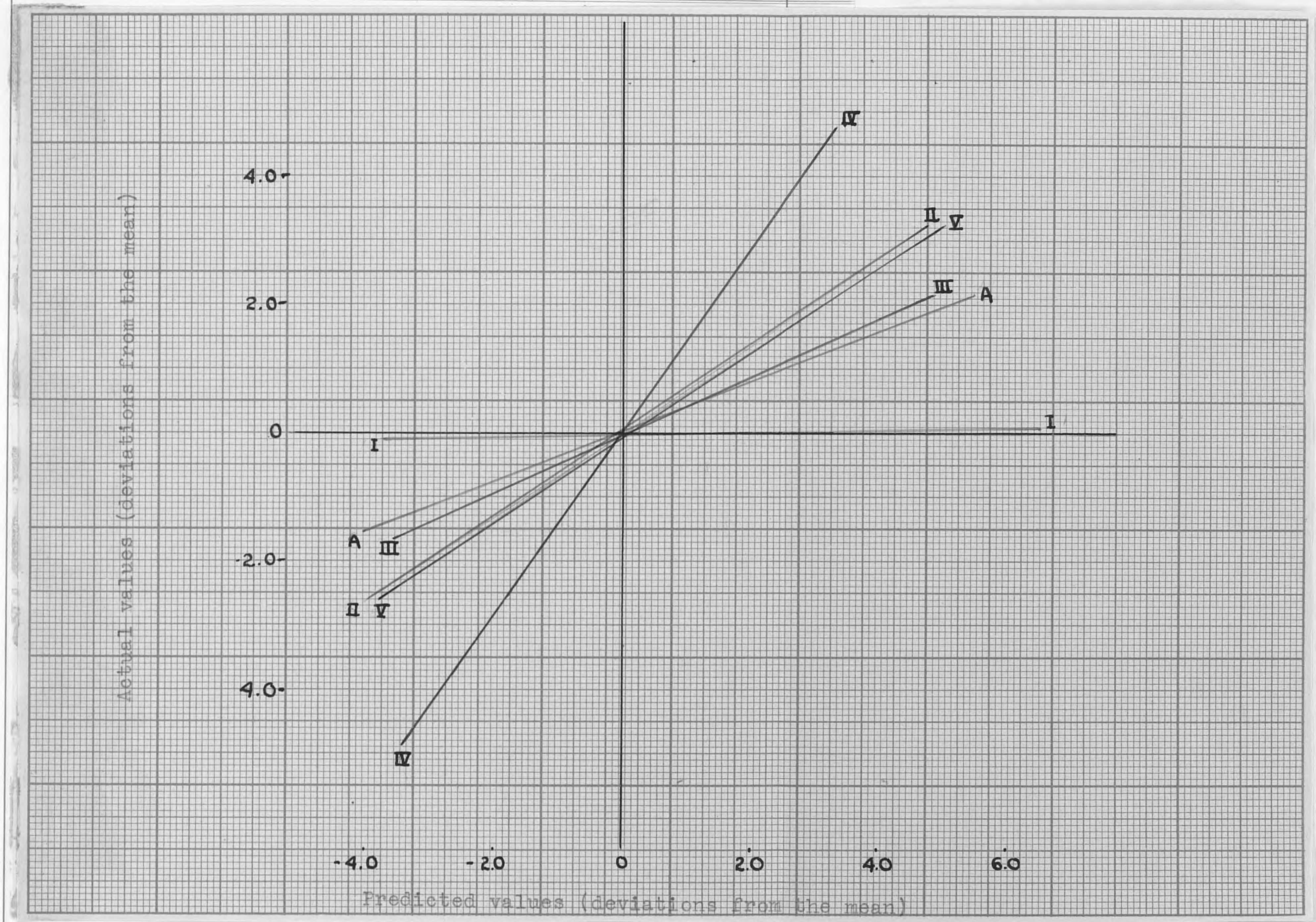


Figure 13. Regression lines of Methods I, II, III, IV and V drawn through the grand mean for the character lodging due to grub worms.

ted through the grand mean, showing the variation in slopes of the various lines, Method II being the only significant prediction method found and significant at the 5 per cent level only.

DISCUSSION

In determining the possibility of predicting agronomic characters of double cross maize hybrids, close scrutiny as well as careful detailed measurements of parental material is required. However, before predictions for characters of succeeding progeny can be made, the parental material must be different with respect to characters, that is, the characters to be measured and studied must be real and distinct before significant differences in related progeny are found. It is essential, therefore, that the inbred lines and the single crosses involved in the prediction equation of double cross performance have diverse hereditary complexes, and in addition have fairly obvious agronomic characters which can be easily measured and characters whose expression is not entirely dependent upon environmental influence.

The significance determined by analysis of variance for the various characters studied in the inbred lines, in the single crosses and in the double crosses is shown in Table 11. In general greater significant differences for characters studied were found among the inbred lines than among either the single crosses or the double crosses. This would be expected for each inbred line, being unrelated to the others, represents a germinal entity and possesses distinctive characteristics. The six inbred lines when crossed give 15 possible single crosses. These single crosses, as shown by statistical analysis, did not possess quite as highly significant differences for the measured characters as was found in the inbred lines. The analysis indicated a trend toward an intermediate nature of the single crosses, a trend which can be considered logical. The double crossed hybrids produced from the possible single cross combinations appeared to be more intermediate for the plant characters than was true of the single cross hybrids. Evidently, additional crossing tends to increase the intermediate nature, masking a character in a greater degree each time the cross is made and as a result the significance for the character becomes less and less. This trend is clearly shown in Table 11.

A prediction study of the performance of characters in the double crosses involving the use of single cross data, was made to determine whether or not the breeding behavior of a character could be detected in one way or another from parental plants. The methods of prediction used in the study were largely formulated by Jenkins (1934).

In the calculation of the significance of the predicted character values compared with the actual double cross characters, the statistical method termed correlation has been used exclusively in previous work by other investigators. There are several apparent disadvantages of using a correlation coefficient as a basis for determining the significance of this parent-progeny relationship. Perhaps the most important disadvantage is the inability of obtaining an accurate estimate of the amount of error involved in the experiment. The method used in determining the statistical significance of the methods of prediction used in this investigation was covariance, together with other statistical constants that were helpful in obtaining comparisons between the prediction methods. The method has been previously outlined in the discussion of the prediction of plant height.

A summary of the correlation coefficients and the t values obtained for five prediction methods for seven plant characters is given in Table 23.

For the most part the low non-significant correlation coefficients and the low non-significant t values obtained for the prediction of probable progeny performance by Method I eliminates it from receiving general consideration as a prediction method. On the basis of the data given in Ta-

Table 23. Summary of correlation coefficients and t values calculated from experimental data.

Method of prediction	Height of plant: Corr. coef.	Height of plant: t value of reg. coef.	Height of ear: Corr. coef.	Height of ear: t value of reg. coef.	Length of shank: Corr. coef.	Length of shank: t value of reg. coef.	Corn ear worm: Corr. coef.	Corn ear worm: t value of reg. coef.	Yield of grain: Corr. coef.	Yield of grain: t value of reg. coef.	Firing grade: Corr. coef.	Firing grade: t value of reg. coef.	Lodging due to grubs: Corr. coef.	Lodging due to grubs: t value of reg. coef.
I	0.6206	4.119	0.1884	0.9976	0.4926	2.9206	0.3427	0.6008	0.1928	1.0185	0.2941	1.5991	0.0093	0.0481
II	0.8264	7.573	0.4299	2.4727	0.7083	5.1623	0.3240	0.5610	0.2496	1.3300	0.5851	3.7202	0.4055	2.3082
III	0.8014	6.982	0.4033	2.2903	0.7233	5.4033	0.1882	0.3011	0.2531	1.3557	0.5934	3.8307	0.3213	1.7728
IV	0.8193	7.425	0.3934	2.2200	0.7051	5.1008	0.3729	0.6617	0.2730	1.4750	0.5490	3.4101	0.3138	1.7153
V	0.8151	7.194	0.4141	2.3659	0.6947	5.0000	0.2369	0.3999	0.2601	1.3979	0.5344	3.3002	0.3007	1.6261

	5 per cent level	1 per cent level
Significant t:	2.052	2.771
Significant r:	0.367	0.470

ble 23 no reliable estimate of the double cross performance can be made from its component single crosses. It seems imperative, therefore, that the most logical method of prediction of agronomic characters in double crosses involves a method other than one based on component single crosses.

In general, Method II as shown in Table 23 appears to be the most accurate prediction method used. Higher correlation coefficients together with higher t values, both of which measure significance of the predicted character with the actual performance, were obtained by this method than by any other method. It is probable that this method would give comparable results in a similar population. The method involves means of all possible single cross combinations which can be made from four inbred lines, and therefore, from a practical point of view is not entirely suitable because of the necessity of growing all of the possible single crosses.

The highest correlation coefficient and t value for firing grade and for length of shank was obtained by using the prediction Method III. By this method the four single crosses not present in the actual double cross provide data for the computation of the estimated performance. The genic disparity which occurs in the double cross hybrid is represented by this method. Method III has proven to be especially desirable in yield predictions, Doxtator and Johnson (1936). It is probably a more desirable method than II, for fewer crosses need to be grown in order to obtain measurements for use in calculation of the predicted performance value.

From a practical point of view Method IV seems to have excellent possibilities in prediction of probable double cross performances of agronomic characters. Many single cross combinations can be grown and observations of a general agronomic nature and measurements of the characters can be taken. Calculation of the prepotency of the inbred line is made by summation of the character values of each single cross in which it appears. This prepotency value for the inbred line, together with the value for each of the three remaining lines obtained in a similar way, is averaged, giving the character prediction value for that double cross combination. The disadvantage of the method is fairly evident, in that all hybrid combinations having the same inbred lines would have equal prediction values.

Little value as a method of prediction can be assigned to Method V. Originally the method attempted to combine into a prediction value both the prepotency of the lines involved in a double cross as well as the theoretical genic disparity of the hybrid complex. The prediction value obtained, however, was generally intermediate between Method III and Method IV, resulting from the clarification of the mean values of the two methods.

SUMMARY AND CONCLUSIONS

The value of five proposed methods for the prediction of agronomic characters has been analyzed statistically. The statistical method termed covariance has been used exclusively in this study, together with necessary ramifications for the determination of method significance.

The regression lines for each method of prediction for each character have been drawn. All have been drawn through the grand mean of the particular character studied, giving a diagrammatic representation of the parent-progeny relationship. Significance of the regression is determined largely by the slope of the line and by the standard error of estimate.

The possibility of predicting the probable performance of seven characters, namely; height of plant, height of ear, length of shank, corn ear worm damage, yield of grain, firing grade and lodging due to grub worm damage in 29 double cross hybrids from known single cross data has been studied.

Five methods were used in determining prediction values for each character in the double cross progeny calculated from the performance of 15 possible single crosses between six inbred lines.

Method I, involving a prediction based upon component single crosses, gave a lower statistical relationship between parent and progeny than any other method used. The method gives but little indication of the actual expected character performance in the double crosses in the population sampled.

A prediction value based upon the mean performance of a character of all possible single cross combinations between six inbred lines, has been shown to have the highest statistical significance among the five prediction methods studied. It appears that this method, designated as II through-out this study, in general, should give the most accurate indication of the probable character performance in the double cross progeny of a similar plant population.

The apparent statistical significance of Method III closely resembles that of Method II with respect to the relation between the actual performance of the characters studied and the predicted performance for the same characters. The variation between the two methods is so small that they can probably be used interchangeably, except possibly for the character of lodging due to grub worms, for which Method II is superior. In this study, from a practical point of view, because of the fewer combinations necessary in obtaining the prediction, Method III has the advantage.

The mean performance of the lines involved in all of the single cross combinations provides a prediction value for Method IV which is comparable to those of Methods II and III. It is of no value where double crosses involving the same four lines are studied in various combinations, primarily, because the prediction value in every combination involving these lines remains the same.

Method V was not found to be of value in a prediction study. It merely involves an average of the mean values of Methods III and IV and is, therefore, intermediate between them.

Heretofore in prediction studies measured by correlation coefficients little consideration has been given to experimental error. Significance of a correlation without due regard for experimental error may easily lead into difficulty in a prediction study. This is clearly shown by the prediction Method IV in which a significant correlation of 0.3729 for corn ear worm damage, a character in which the experimental error is extremely high, was obtained whereas if calculated through the covariance method proposed in this study, the prediction method was far from significant.

The significance of prediction methods obtained by the covariance method used in this investigation, is a more reliable index of progeny performance, than correlation coefficients.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Mr. R. W. Jugenheimer and Dr. H. H. Laude for the assistance, the advice and the many suggestions they have given in directing this study; and to Dr. A. M. Brunson of Purdue University, Lafayette, Indiana, under whose guidance this research was outlined.

The author is also indebted to Dr. R. H. Painter and his assistants who have given both time and effort in obtaining the corn ear worm data; to Mr. H. R. Bryson for his suggestions and aid in the study of lodging due to grub worms; and to Mr. L. N. Skold for his valuable assistance in securing experimental data.

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