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NEARESTNEIGHBOR PROCEDURE AND DENSITY-DEPENDENT YIELD PREDICTION IN BARLEY (HORDEUM VULGARE L.)

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NEAREST NEIGHBOR PROCEDURE
AND DENSITY-DEPENDENT YIELD PREDICTION
IN BARLEY (*HORDEUM VULGARE* L.)

by

Sahr Sama Monde

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In the Graduate College

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THE UNIVERSITY OF ARIZONA
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As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Sahr Sama Monde

entitled NEAREST NEIGHBOR PROCEDURE AND DENSITY-DEPENDENT YIELD PREDICTION IN BARLEY (HORDEUM VULGARE L)

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

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Date

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

R D Ramage
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SIGNED: ____________________

DEDICATION

This dissertation is dedicated to humanity's "zero" column.

To those who are born into and live their lives in perpetual bondage; bondage to disease, hunger, and ignorance.

To those who are always discriminated against, humiliated, and oppressed simply for being different; belonging to one race, culture, or creed and not to the other.

To those who cannot make any claims on freedom, justice, and the standards of life that are considered averagely decent in their communities.

Yes, it is dedicated to "the wretched of the earth."

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ABSTRACT

Agronomists are constantly experimenting with improved plot techniques that can enable them to make more precise inferences from field data. This dissertation reports two investigations: (a) evaluation of the yield potentials of some barley genotypes using two non-traditional methods, and (b) comparative assessment of the two methods.

Two separate but related experiments were conducted. The nearest neighbor procedure was the first. The use of spaced-plant parameters to predict yield at normal commercial density was the second experiment.

Four variations of the nearest neighbor procedure were examined. For each version the plant to be evaluated always occupied the center of the rectangle of nearest neighbors. Evaluation consisted of yield adjustments where the yield of the individual plot was compared with the mean of its nearest-neighbor genotypes. Individuals were ranked according to those deviations. Unadjusted yield data were also ranked.

The error mean squares derived from ranks of various configurations were compared *inter se* and with that from unadjusted yield. Nearest neighbors always showed a smaller error variance than the unadjusted data. Of these, the first nearest neighbors produced the smallest mean square for error and, hence, the highest efficiency of

genotype ranking. This procedure substantially controlled for the effects of soil heterogeneity.

Averages of individual ranks were computed and related to respective genotypes (entries). For each procedure the top 25% which fell in the upper bracket of the yield curve were considered to possess high yield potentials. This method of adjustment, ranking, averaging, and selection was applied to the unadjusted data as well as to each of the nearest neighbor procedures.

Unadjusted mean yield and nearest neighbor techniques were contrasted. The rankings generated by the two procedures were similar but not identical. The significantly lower error variance of the nearest neighbor adjustments indicated that those should be used instead of unadjusted mean yield when precision is needed. However, unadjusted mean yield ranking provides broad identification of high yielding genotypes, and is a simpler statistical procedure.

The second experiment examined the effectiveness of yield and yield components of spaced plants in predicting yield at normal cultural density. It was conducted for two years using primarily trend analysis.

Results for individual years showed that none of the metric components of spaced plants was a satisfactory predictor of crop yield. However, when data were pooled over the whole experimental period, most of the yield components of spaced plants showed highly significant correlations with crop yield.

Regression models were developed from the components which demonstrated good prediction of crop yield. Under the conditions of this study, productivity (biological yield or total weight) was revealed by all the analyses as the most important spaced-plant component for predicting yield at higher densities.

INTRODUCTION

The variety in plant breeding is a taxonomic unit which by its phenotypic performance may be distinguished from other groups of the same species. Factors contributing to such variation in metric characters are the genotype, environment, and the interaction between them.

An important property of metric characters such as yield is their heritable entity. It is the fraction of the phenotypic variability which is expected to be transmitted to the progeny. Success in crop improvement relies heavily on this parameter. When the breeder conducts yield tests to evaluate lines, he is actually trying to attach numerical description to this concept. Early generation testing postulates that relative performance in the "nth" generation can be predicted from the second or third generations based on the heredity of the yield components.

A thorough understanding of the mechanisms involved in genotype development and yield expression is indispensable to plant improvement goals. Assuming that researchers have full grasp of this facet of their work, the only limiting factor to their progress could be the methods of handling the materials. In order to characterize the cultivar and predict its yield potential accurately, refined statistical techniques have been incorporated into field experimentation. Yield trials often produce high experimental errors. The magnitude of this statistic affects the degree of confidence attached to field data. Any procedure which reduces this term significantly, is considered efficient.

Uniformity trials, contiguous control plots, and moving average adjustments are some of the methods commonly used towards that goal. Uniformity trials attempt to identify not only the range of soil heterogeneity and fertility, but also the best plot type that would produce the most accurate data. However, the effects of soil heterogeneity and competition always interfere with the efficiency of selection in such plots.

The methods of sampling for yield which also vary in their relative efficiencies, are equally vital to the procurement of accurate field data. Check plots are examples of those techniques which are known to reduce error variance considerably. A check plot generally provides a good measure of the fertility of adjacent plots. It is, however, possible that such standard genotypes may interact uniquely with the environment different from other genotypes under test.

For the purposes of minimizing experimental error, the moving average adjustments are superior to control plots as shown by numerous experiments which attempted to compare them. However, the number and patterns of the plots which could participate in that procedure to offer the most precise evaluation of the experimental line, have yet to be identified.

Complex field designs are not always the most productive in terms of the quality of information gained from them. They may exhibit no clear-cut advantages to compensate researchers for the massive resource inputs. That is why many breeders still rely on simpler methods such as visual selection. The main problem with that method is that it relies heavily on the breeder's subjective judgement.

Despite various criticisms of the method, yield testing still remains the only reliable procedure for evaluating lines. The evaluation criterion is mean yield. In the analyses of variance, the F-statistic tries to test the null hypothesis on the homogeneity of means. The rejection of this hypothesis, however, neither shows which means have real differences, nor does it rank them in order according to some well-defined criterion like yield. In ranking cultivars according to their yield potentials, the chances of committing the Type II class of error are always present.

Various multiple comparison methods are used to examine the nature of differences between means. Collectively, they are very effective statistical tools when employed properly, but indiscriminate use could result in the loss of information.

Many workers have given considerable attention to the search for better field plot techniques and statistical designs. All of these efforts have been directed at reducing the experimental error and thus deriving more precise inferences. In those activities, emphasis is put on field treatment, the collection and analyses of data. Seeding rate for the crop is held constant relative to the cultural practices of the particular area.

Programs which operate on scarce resources often require stringent economies for crop production. Under such circumstances, agronomists need to examine density/yield relationships in order to predict maximum yield from minimum data. Research attempts to predict crop yield at solidly seeded commercial density from single plant yields have been futile. Most of the results showed that single plants are ineffective for that purpose. Many workers have therefore proposed the use of yield and yield components measured on single plants as estimates of yield potential of the genotype under normal planting densities. Measurements of components have also been ineffective in predicting yield potential at higher commercial densities.

Much of the work in relating characters of spaced plants to yield at higher densities have been conducted on wheat. Part of the present study examined yield components of spaced plants as selection criteria in estimating yield potential in barley.

The objectives of this study were to: (1) compare the performances of the genotypes (entries) under test; (2) rank entries by yield according to various nearest neighbor patterns of yield adjustments; (3) compare the efficiency of those adjustments with unadjusted yield data; (4) examine the predictive value of those adjustments; and (5) investigate the effectiveness of spaced plants in predicting yield at conventional high-density stands.

REVIEW OF LITERATURE

Nearest Neighbor Procedure

The yield potential of any crop depends on the effects of the gene action and the genotype-environment interaction involved. Plant breeders need thorough understanding of these effects to evaluate and characterize their crops accurately. Hamilton (1959) proposed that the methods used in plant breeding programs be examined with the view of determining whether it was the genetic material or the methods by which cultivars were being handled that was limiting progress.

To make precise inferences from experimental data, researchers have made tremendous progress in integrating refined experimental techniques in field trials. These statistical procedures make it possible not only to evaluate genetic and environmental effects, but also to establish variety and strain differences (Lessman and Atkins 1963). The nature and importance of soil heterogeneity, and the identification of precise sampling methods for determining yield and quality of crops, are among the main considerations.

There is no value as the true mean of a particular plot. Experiments conducted on such plots would always give different means. What contributes to these differences is experimental error (Love 1923). It arises from variation in random sampling. The degree of confidence attached to field data depends on this parameter. Hence any technique which creates a significant reduction in this fraction of the total variability is considered efficient. Breeders are always investigating soil types, slopes, sizes and orientation of plots, the effects of competition, and the various sampling methods for yield, which can reduce the experimental error.

Uniform conditions, even over a very small portion of the field, rarely exist. In most cases the texture, depth, drainage, and treatment aspects of the soil differ from plot to plot. Even where those differences are so slight as to escape the notice of the most observant eye, they may have very big effects on the plants growing in them (Parker 1931).

Harris (1915) proposed the use of intraclass correlations of yield from adjacent plots as coefficients of soil heterogeneity. However, most researchers who determined those coefficients found that they only served to show the amount of correlation in the fertilities of the adjacent plots.

The individual plot is the basic unit of most analyses and the statistical procedures applied reflect the importance of identifying the almost ideal plot type in these experiments. Crop species usually vary in their responses to environmental components when grown in different planting arrangements. Thus the type of plot satisfactory with one experiment may not be adequate for another. Hence the justification for uniformity trials.

Differences in the yielding ability among genotypes are sometimes small, but important. Plots which can give accurate estimates of yield are required to detect these differences. Smith (1938) developed an index of soil heterogeneity that could enable the calculation of the optimum plot size for any crop. This index "b" is the regression of the logarithm of the variances of plots of different sizes on the logarithm of their areas. Generally "b" varies from 0 to 1 where 1.00 indicates no correlation between contiguous plots and a value of 0 means a high correlation between yields of adjacent plots. But a careful examination of that parameter would show that it measures only the type, not the amount, of soil heterogeneity. Hence a coefficient of 1.0 would indicate no more a tendency for two adjacent plots to yield alike than for two plots taken at random.

The shape and orientation of plots are also important for the ease in mechanical practice. They also influence the probable error. Many researchers have shown the advantages of long narrow plots over square plots in controlling variability due to soil heterogeneity (Holle and Pierce 1960). Christidis (1931) reviewed most of the published results on the effects of soil heterogeneity on error variability. He concluded that the size of the coefficient of variability (C.V.) is directly related to the ratio of the plot width to the plot length and the main factor influencing the C.V. is the orientation of the plot to the fertility gradient. In spite of the considerable volume of data on the subject of plot type, none of the findings have universal applicability. The responses of crops to their immediate environments vary rapidly with time.

Fisher (1931) demonstrated that precise experimental inferences are possible if the principles of randomization, replication, and local control are practiced. Parker (1931) noted that large single plots are not adequate indicators of variability. The differences between soils of one half of the field and the other half are naturally reflected in the differences in yield. The only solution is the scattering of repetition plots of any of the varieties being tested against each other. They could then sample the different conditions of the trial area and have equal chances of being grown partially on favorable and partly on unfavorable portions. Stadler (1921) gave a general rule that the variability of a given field as measured by the probable error will in general be reduced by replication in proportion to the square root of the number of replications.

These Fisherian principles are used universally today in crop improvement. They have some disadvantages, however. They demand a large amount of land area and seed to obtain the specified degree of precision. Thus the numbers of evaluated varieties and replications must be kept small if the experiment is to become manageable. No experiment can evaluate large numbers of varieties under these conditions. Additionally, these principles require that varieties be evaluated in the presence of competition (Fasoulas 1976).

When a large number of varieties are to be compared in variety trials, breeders have to solve the problem of arranging them first. In such situations the Latin Square design would require a large number of replications, thus making it unwieldy. Even the Randomized Complete Block design would become unsuitable because they are likely to contain too many plots to eliminate fertility differences accurately. Yates

(1936) introduced the incomplete block designs to avoid these disadvantages in the standard designs. Lattice squares are examples of incomplete block designs. Kramer and King (1959) compared the analyses of yield from 39 triple rectangular lattice designs with those of the randomized complete block design. They found that the lattice was 34.4% more efficient than randomized complete blocks. In fact, they noted a range of 0-197% gain in efficiency for experiments based on the lattice design.

Plot layout and soil conditions alone are not the only objects for refinement. Even in sampling for yield, researchers have given considerable attention to improving research efficiency so as to evaluate large populations accurately at reduced research costs. Precise information on the effects of plot type, competition, the use of border rows, and check plots is required to achieve these goals.

Since 1900, many workers have studied the relationships between rod-rows and field plots, using simple correlation coefficients. Klages (1933) found that the mean correlation for yield from the two types of plots ranged from 0.72, 0.56, 0.56, 0.54, and 0.42 for spring wheat, durum wheat, oats, barley, and flax, respectively. Ross and Miller (1955) found that correlations between rod-rows and drill strips ranged between 0.76 and 0.95 for barley and oat yields. There is a general agreement that rod-row and field plots are equally satisfactory for small grains. In barley, Rasmusson and Lambert (1961) tested five varieties in rod-row and field plots at four locations for four years. They found that none of the interaction variance components involving variety and method of testing were significant. They concluded that rod-row tests were adequate for yield determination.

But the rod-row method introduces the problem of competition among adjacent plots in the relative productivities of varieties. According to Fasoulas (1976), competition interferes with the efficiency of selection in two ways. It affects genotype evaluation by not allowing maximal genotypic expression and differentiation. It also introduces ranking errors due to the masking effects of intra- and inter-varietal interactions. To remove the effects of competition, Stadler (1921) proposed changing the order of the varieties in each range to bring together different varieties. Arny and Hayes (1918) showed that border rows could reduce the effects of competition. Now it is generally accepted that rod-row plots should include border rows in order to avoid competition between varieties and reduce seed mixing between adjacent plots. Border rows also have disadvantages. They increase the area required to test the same number of varieties, and thus contribute to the error from soil heterogeneity.

The use of hill plots and check varieties was introduced as a possible solution to problems connected with rod-row plots. Hill plots have the advantage of using a smaller land area and small amounts of seed. Frey (1965), from experiments on yield components in oats, showed that for many attributes such as panicles per plant and spikelets per panicle, the precision of measurements in hills and rod-rows were equal. But yield itself was measured more accurately in rod-rows. Burrows and Shands (1964), in a study of snap-back and lodging of barley, found that hill plots were effective only in the initial stages of testing. In evaluating hill plots, the question that must be answered is whether the number of seeds per hill is adequately representative of the lines tested. Also, it would be worthwhile to know the role competition plays between adjacent hills in evaluating the agronomic characters of small grains.

The intraclass correlation coefficients developed by Harris (1915) described the relationship between contiguous plots. This idea must have established the basis for the check or control plots. The assumption is that the yield of check plots provides a good measure of the relative fertilities of adjacent plots on which the experimental line is grown. Wiebe (1935) tested 1500 Federation wheat lines in plots each 4.6 meters long and 0.3 meters apart. He showed that the correlation between nearby rows in the nursery decreased almost linearly as the distance between rows increased. To confirm that assumption, Briggs and Shebeski (1968) estimated the correlation between yields of adjacent plots. The correlations between the yields of control plots located 2.7 meters apart was between 0.68 and 0.88. The coefficients decreased rapidly as the distance between plots increased.

The adjustment of yields by means of check plots was a popular practice in the 1920s. Check plots of the same variety used to be distributed among test plots as frequently as possible and handled similarly. The method produced a significant reduction in experimental error (Stadler 1921). Pritchard (1916) was the first to use check plots for yield correction in sugar beets. He wanted first to determine the optimum number of checks and then to ascertain which frequency was most efficient. The coefficient of variation he obtained showed that his experimental lines were as variable as the check plots. He concluded that the use of every alternate row as a check plot was not satisfactory in compensating for variability arising from soil heterogeneity. When the efficiency of frequently repeated control plots was compared with moving average adjustments, the latter was found to be superior to check plots (Knott 1972). In some cases, adjustments with checks increased rather than reduced the experimental error (Stadler 1921). The use of replication instead should produce the same efficiency. Yates (1936) also noted that control plots are merely indicators of the fertilities of the neighborhood plots. Hence a proper randomization, when applied to all varieties, can enable valid comparisons to be made without resorting to check plots.

A standard check has a variable but short life span. It also exhibits a unique 1:1 genotype-environment interaction which may enable the checks to give responses at variance with other genotypes under test. The individual genotype can also perform well or poorly under different conditions and that performance could be out of phase with other genotypes under test. These facts make the standard controls inadequate for evaluation purposes. For these reasons, Jensen (1976) introduced the method of floating checks which uses derived statistics generated by nursery entries. A floating check is a hypothetical nursery entry, a statistic not tied to a genetic entity like the standard check. Instead it floats on the interactions within the genotype-environment complex.

Since floating checks have relative rather than absolute values, they have a perpetual nature.

The moving mean procedure was introduced as a modification of the check plot method. This is a yield adjustment technique in which the yield of a trial plot is rated against the mean of either check or other trial plots in its vicinity. Any number or pattern could be used for this comparison. The adjustment starts from a definite point in the field and moves systematically to another. In the process, a number of plots in the pattern are dropped and a new set added. Hence the trial plots and the standard are always changing in a definite direction. Knott (1972) tested the value of control plots in every fifth row, by comparing error variances and F-values when yields were expressed in the following ways: (1) plot weight expressed as a percentage of two nearest plots; (2) plot weight expressed as a percentage of two nearest controls; and (3) plot weight adjusted by expressing yield as a percentage of the moving average of the nearest seven hybrid plots, excluding the check plot but including the plot in question. Methods 2 and 3 gave smaller errors and large F-values. But there was no indication which was better. Townley-Smith and Hurd (1973) also compared the accuracy of using repeated controls and those employing moving means which included varying numbers of experimental plots. Repeated controls reduced experimental error by 1.2 to 34% in three out of five trials, while in the other two no reductions were found. But where moving averages were used, the error mean square was reduced in all trials. In each case, the reduction was greater than that obtained with control plots. These results clearly show that the moving mean of adjacent hybrid plots gives a superior control of experimental error.

The number or pattern of adjacent plots which would give the most precise results in the moving average adjustments is still not clear. Scheuring (1979) conducted two experiments in this regard. First, he tried to determine the patterns and sizes of adjacent plot combinations that would give maximum homogeneity in fields planted to single varieties. Using results from his own field trials in sorghum, and data from standard experiments in the literature, he ran simple correlation coefficients for the moving averages of each of nine configurations in each of the five experiments. He concluded, from the mean squares and coefficients of variation, that the cross-configuration comparisons with central plots were more efficient than any of the other configurations. For the second experiment, he used data from sorghum yield trials conducted in widely separate areas of Texas. He applied three methods of mean separation and also conducted moving average deviation procedures using three adjacent plot configurations. None of the adjustments resulted in an improvement over the analysis of variance of the unadjusted data. These experiments could neither identify the superior genotypes nor give the true rankings of the hybrid population. However, the cross-configuration moving average was again more effective than any of the other procedures.

Fasoulas (1976) recognized the effects of competition and soil heterogeneity in preventing maximal genotypic expression and confounding differentiation of yield potential. Under such conditions, individual performance cannot be evaluated accurately. He proposed the "honeycomb design" for that purpose. The design is based on the principle that when single plants are compared at small distances, differences in yield reflect mostly genetic effects. Also within small areas the yields of single plants should be correlated because they screen comparable environmental conditions.

The honeycomb is made of hexagonal cells, each cell representing a unit of soil homogeneity and containing seven equidistant plants. One plant is in the center and the others are in the corners forming a ring of six. Since the central plant shares a common environment with the surrounding six plants, any superiority in yield will be ascribed to the superiority of the genotype itself. A certain genotype is selected provided it yields more than each of its six neighbors. Every plant participates in six different ring configurations which offer the chance of selecting superior yielding genotypes at all levels of soil fertility. However, the honeycomb method is unsuitable for modern cultural practices. Genotypes whose evaluation is based on the removal of the effects of competition and soil heterogeneity will do poorly in conventional programs. Also, it requires far more land to grow the same amount of crop.

Some of the methods of yield sampling mentioned above are labor-intensive and often require complex calculations; they are also expensive. However, the results obtained from them show that they are not always superior to the simpler conventional methods like visual selection. Briggs and Shebeski (1970) found that visual selection for yield in wheat was superior to random sampling though the ability to identify the highest yielder was limited. They suggested that the intensity of selection should be reduced to retain the highest yielders. Knott (1972) reported that visual discrimination in F_2 was effectively reflected in the F_3 yields of wheat.

This method is only reliable in sampling highly heritable characters. For characters such as grain yield which exhibit low heritability, it is not very effective. Lupton and Whitehouse (1955) studied wheat strains which were previously identified visually as being superior. They concluded that if visual selection was the only way for ranking those varieties, then many valuable strains would have been discarded before the stage of yield trials. McKenzie and Lambert (1961) found poor correlation between visual ratings of lines and the actual yields of both F_3 and F_6 lines of two barley crosses. Therefore they considered it unsatisfactory for yield evaluation. In pedigree selection, however, the rejection of lines in the early generations depends mostly on visual evaluation for seed yield and other agronomic characters.

Yield testing still remains the main procedure for assessing populations, the main criterion for genotype performance being the mean yield. In the analysis of variance, Fisher's F-test is used to test the homogeneity between means under the assumption or normal distribution with common variance. An indication of non-significance means that an apparent difference would arise more frequently than 1 in 20 (5% level) or 1 in 100 (1% level) times by chance if no real differences existed.

It does not imply that true differences do not exist. The rejection of the null hypothesis of homogeneity does not show which means differ significantly. At this stage investigators could be interested in one of two things: (1) to find out which varieties rank in the same top percentage of the population; or (2) to see which varieties differ from each other.

There are a number of ways for ranking and selecting a number of desirable types from samples of populations. First, an appropriate function (A) has to be established. This function (A) could be statistics such as sample means or variances. The value of (A) is then computed for each of the samples in the population. In the ranking procedure Aj would denote the value of (A) for the sample from the jth population for j=1, 2, 3...k. Any format could be used for ordering. In the case of sample means, the values can be ranked from the largest to the smallest which is the reverse where minimal variances are desired (Gibbons, Ingram, and Sobel 1977).

Multiple comparisons are the methods used to discriminate between means. Their most common use is comparing one mean with every other mean. The types of experiments in which they are appropriate are those whose objective is to pick the "winner" among a set of qualitative treatments (Peterson 1977). The two most popular tests used for evaluating these differences among means are the Least Significant Difference (LSD) and Duncan's Multiple Range Test (DMRT).

The LSD utilizes the standard error of a difference between means. When this statistic is multiplied by the tabulated value of "t" at the desired significance level, the product serves as the Least Significant Difference. This test should be applied only when the F-test for the homogeneity of the variance is significant. Also it should not be applied indiscriminately to test all possible pairs. For instance, the difference between the highest and lowest means in an array will on average be higher than differences between means taken at random. There is, therefore, the likelihood of over-estimating the significance of certain differences (LeClerg 1957).

The DMRT considers the probability of detecting real differences when they exist and also assures the highest probability of rejecting the significance of mean differences when the real differences do not exist. This offers protection against Type II error. The DMRT is also very simple to calculate, but it gives overlapping groups of means.

A new method for mean separation, called the cluster analysis, was proposed by Scott and Knott (1974). Compared with the DMRT it has advantages in partitioning means into discrete non-overlapping groups. But as the variance of the treatment means decreases, the distinction between the two methods decreases also. Both tend to separate means into non-overlapping groups under this condition (Gates and Bilbro 1978). Multiple comparisons are important statistical tools when applied properly. The consequences of indiscriminate use are loss of information and reduced efficiency.

Density-dependent Yield Prediction

Two types of density/yield relationships are known. One is when yield increases with seeding rate and stays constant at higher levels.

The other is where yield rises to a maximum but declines at higher densities. These relationships are described as asymptotic and parabolic, respectively.

Agronomists are often interested in the quantitative relationships between plant population and crop yield for two reasons. First, they would like to predict maximum yield from optimum density. From reviews of related experiments, Smith (1937) concluded that variability of seed densities does not by itself diminish potential yield. But if the plant density per area exceeds the optimum range, then there will be some loss in yield compared with even-spacing at optimum density. Experiments conducted in southern Saskatchewan over a 15-year period confirmed that view. The results showed no significant differences in wheat yields between 67, 101, and 131 kg/ha seeding rates (Pelton 1969). However when Kirby (1967) conducted similar experiments in barley, he found that yields for intermediate planting densities exceeded those at higher levels. In general, results from research on small grains have shown that although grain yields are affected by planting rates, the net yield is not influenced significantly. It is the planting pattern to which yield is most sensitive (Holiday 1963).

The second reason why a precise definition of the density/yield relationship becomes useful is in programs which operate on limited resources. Such information could enable agronomists to predict yield/density curves accurately from minimum data. In this regard, the combination of plant density with various yield components has been studied widely, especially in wheat. Shebeski (1967) investigated the reliability of predicting yields at commercial seeding rates from those of single plants. He tested 440 F_2 single plant selections for yield in F_3 against controls of unselected plants. The results indicated that single plant selection for yield in F_2 was not an effective predictor of yield in subsequent generations. Briggs and Shebeski (1970) and Knott (1972) obtained the same results from similar experiments in wheat.

Many plant breeders and physiologists have proposed the use of other traits, both morphological and physiological, measured on single plants in early generations as yield potential estimates. Harvest index has often been suggested as the most valuable yield component for this purpose. Fischer and Kertesz (1976) studied the roles of harvest index in spaced plants and grain weight in microplots as predictors of yield in commercial plots of spring wheat. The experiment included spaced plants seeded at 60-cm intervals in single rows, microplots which were heavily planted at 120 kg/ha, and large commercial plots ranging from 60 to 100 kg/ha. They obtained moderate correlations between numerical components of single plants and large plots, but the associations of grain weight between the two densities were generally poor. Harvest index derived from spaced plants was more important than yield as a predictor of yielding ability in commercial plots.

Multiple correlation and regression methods are often used to predict the relationships among yield components on the one hand, and between those parameters and yield on the other. However, the methods used to collect and treat data for such purposes vary widely. Hsu and Walton (1971) measured single plant characters, but their dependent variable was yield per plant which bore little relationship to crop yields in regular stands. In other experiments the characters used as independent variables were taken from a competitive situation, not applicable to single plants. Syme (1972) used mean yields of field plots of wheat as the dependent variables which were regressed on characters of single plants grown in the greenhouse. Harvest index, days from sowing to emergence of the seventh leaf, and 1000-grain weight accounted for 78.5% of the variation in cultivar mean yields for field-grown trials. He suggested that a multiple regression analysis of these variables in other cultivars could be used to predict their relative yields. Similar methods were used by Nass (1973), but to make his results more objective, he used the same treatments on the plants under study. He correlated 22 variables and found a high positive association between grain yield and harvest index. From the stepwise-multiple regression analysis, he identified spikes per plant and yield per spike as the most reliable predictors of yield. Those variables gave the smallest residual mean square than any of the other variables. Nass (1973) noted that those three characters, when considered together in a selection program, should be an effective means of selecting for yield in spring wheat.

McVetty and Evans (1980) attempted to use morpho-physiological characters on F_2 spaced plants to identify high yielding F_4 bulks in spring wheat. Simple correlation coefficients between F_2 parameters and F_4 bulk yields were first calculated. The characters which demonstrated the strongest associations were used as yield potential estimates.

Next, they derived appropriate regression equations relating F_2 yield components to F_4 bulk yields. That procedure enabled them to identify the top 15% of the cultivars. When all the data were combined, productivity or biological yield showed the highest correlation with F_4 bulk yields. An equation for "productivity" regressed on F_4 means gave values of 905 grams or more per plot. Retention of all the F_2 cultivars that yielded 905 grams or more resulted in identifying 17 out of 53 high-yielding bulks. Finally, they conducted a stepwise multiple regression on the two sets of variables, and selected the top 15% of the F_2 population.

In theory, the prediction of yield potentials across differing densities is possible and generally correct. However, the problems associated with such methods in practice, make them questionable. Whatever results ensue from the functional analyses mentioned above would depend on which components served as dependent and independent variables in equations. Most breeders know that yield and seed size decrease when a line selected from spaced planting is cultivated at higher density. For that reason, they make all predictions and selections from densities at which they normally plant their crops.

MATERIALS AND METHODS

This study was conducted for three years and involved two separate but related experiments. The first experiment was intended to examine the effectiveness of nearest neighbor yield adjustment procedures in identifying and selecting superior genotypes from a population. Yield trials were conducted and data collected annually for three years. The second investigation was based on the hypothesis that components of spaced plants could be used to predict yield at regular commercial seeding densities. This experiment was conducted for the first two years only.

Experiment One: Nearest Neighbor Yield Adjustment Procedures

First Year

Thirty-four lines were selected from Composite Cross XXXII (CCXXXII) to provide a range of variability for yield components. CCXXXII is a male sterile facilitated recurrent selection population which has been the source of new varieties for a number of years. Six standard varieties were included to make a total of 40 entries for this experiment. Those were tested for yield in a 20-replicate randomized complete block design. The lines and varieties are listed in Table 1. The plots were grown on the University of Arizona Experiment Station Farm at Marana. Wheat plots were grown on all sides of the block to serve as border rows.

Table 1. Entry number, seed source, and names of the lines investigated in the two experiments.

1977 Entry Number	1978 and 1979 Entry Number	Seed Source	Variety Name
1	1	76-B-5812-139-144	
2	2	76-MA-771-135	
3	3	76-MA-771-536	
4	4	76-MA-771-70	
5	5	76-MA-771-46	
6	6	76-MA-771-287	
7		76-MA-771-217	
8	8	76-MA-771-528	
9		76-MA-771-891	
10	10	76-MA-771-834	
11		76-MA-771-726	
12	12	76-MA-771-549	
13	13	76-MA-771-919	
14		76-MA-62219	
15		76-MA-62219-4-4	
16		76-MA-62219-8-1	
17	17	76-MA-62219-11-3	
18	18	76-MA-62219-6-9	
19		76-MA-62219-11-1	
20		76-MA-62219-20-12	
21		76-MA-62219-16-15	
22		76-MA-62219-11-12	
23		76-MA-62219-16-7	
24	24	76-MA-4-22 - 5 to 8	
25		76-MA-4-21 - 13 to 16	
26	26	76-MA-4-21 - 9 to 12	
27	27	76-MA-4-121 - 5 to 8	
28	28	76-MA-4-20 - 9 to 12	
29	29	76-MA-4-20 - 1 to 4	
30	30	76-MA-4-20 - 5 to 8	
31	31	76-MA-4-20 - 13 to 16	
32	32	WPB-4-3Y	Reliance
33	33	76-C-6225	
34	34	WPB-6-3D	Gus
35	35	76-C-66215	
36		76-B-751-1-3	399
37		76-B-751-16-18	Kombar
38	38	76-B-751-22-24	CM67
39		76-B-751-10-12	Valbar
40	40	76-B-751-7-9	Arivat

Each plot consisted of a bed containing two rows, 3.048 meters long and 30 centimeters apart. A distance of 101.6 cm separated the centers of the beds and a 35.56 cm alley separated plants on a bed. Fertilizer treatment at 84.02 kg of actual N per hectare and a seeding rate of 84.02 kg per hectare were in accordance with normal cultural practice in Arizona.

Genotype evaluation through systematic comparisons necessitated harvesting all the plots. A sickle was used to harvest individual plots whose produce was bundled separately, and threshed. Yield data were taken as grain weight per plot and expressed in grams.

Statistical Analyses. The mean yields and the analysis of variance were calculated for the unadjusted yield data. On the basis of the F-tests the means were subjected to multiple comparison procedures to examine the nature of the differences among them.

For the nearest neighbor procedure, the experimental area of 800 plots was considered as a matrix containing that number of single distinct and unreplicated entries. Every entry in the matrix was ranked from the highest (1) to the lowest (800) first without any adjustments. Then it was adjusted by comparing it with the means of its nearest neighbors which assumed any one of the following patterns (Figure 1):

1. Nearest 8 neighbors - NN1.
2. Nearest 16 neighbors - NN2.
3. Nearest 8 and 16 neighbors - NN3.
4. Nearest 8 and 16 neighbors unequally weighted - AVN1,2.

12	37	12	25	1	9	5	21	6	34	16	28	3	29
21	3	22	39	11	17	22	11	1	21	15	25	38	24
14	24	9	19	31	1	34	33	14	3	29	30	9	35
29	22	31	6	26	35	37	3	25	22	38	38	25	21
38	25	39	10	2	15	14	31	11	6	9	18	11	6
4	30	28	15	24	8	29	14	35	19	25	12	35	11
15	35	28	39	40	13	33	25	4	20	11	33	4	3
16	18	4	38	34	39	4	38	30	25	35	10	30	14
11	33	8	9	36	25	15	X	32	17	4	29	32	31
39	10	11	25	28	37	14	10	37	15	30	37	20	38
12	29	10	35	5	36	X	29	15	31	32	1	15	33
19	37	14	11	21	26	12	15	20	29	37	13	37	30
30	1	18	4	33	29	19	16	26	24	20	15	26	10
25	13	7	30	15	4	25	39	40	1	26	22	40	25
13	15	16	32	19	3	13	22	24	14	40	20	21	15
27	20	17	37	4	40	27	21	19	25	24	14	24	16
7	14	30	20	3	33	32	9	28	7	21	27	19	13
32	21	27	26	20	7	10	28	2	28	19	23	28	5
34	23	33	40	30	21	18	23	3	34	2	6	2	6
10	17	34	24	25	27	31	1	36	9	13	11	22	36

Figure 1. Field layout of the entries in the nearest neighbor yield adjustment procedure.--The plants were distributed at random and evaluation was based on individual performance. Starting from the entry (X), the eight plants immediately surrounding (X) formed its nearest neighbors. The plots surrounding those eight were the second neighbors, and so on. Each plant occupied the center of a rectangle and shared a common environment with other plants forming the rectangle. This method should minimize variation due to soil heterogeneity. But with second and third nearest neighbors, fertility gradients were expected to increase such variability in proportion to distances from (X). See relevant sections in this chapter for additional details.

For instance, entry number 16 in the center of the experimental block is immediately surrounded by eight neighbors which must be contiguous such that the yields of both sets should be highly correlated. In each case the deviation of the mean yield of the neighbors from the yield of the individual entry, which was always in the center of any of the four configurations, was determined. Each entry was then ranked on a scale of 1 (highest) to 800 (lowest), according to the values of the deviations from their respective neighbors. A Programming Language (APL) was developed to facilitate the systematic yield adjustments. Programs in the Statistical Package for the Social Sciences (SPSS) were used for all other analyses.

The experiment was conducted on a uniformly prepared soil. Hence the assumption that yield of contiguous plots were positively correlated. Any differences between an entry and the mean of the neighboring plants should therefore be attributed more to genotypic than environmental factors. A cultivar with superior yielding potential was always expected to exhibit that ability despite the spot in the field in which it was located. It should then yield more than, or comparatively with, the mean of the plots in its neighborhood for the particular pattern of adjustments. Failure to do so readily changed its ranking to a lower level on the 1 to 800 scale.

This procedure ensured the equal participation of every unit in the matrix, either as the item to be tested or as a member of the nearest neighbor configuration. The basic assumption was that genotype identity had no value. Bias which could arise from the distribution of individual plots in the field or from the computation of deviation values, was removed by the complete randomization of the whole experiment.

The data for the border plots which were planted in wheat, showed smaller than average yields of commercial plots in Arizona. The wheat was heavily ravaged by birds during the days between harvest and threshing. That data was therefore discarded. Instead, the grand mean of the whole experiment was used each time an outside plot was required to adjust yields of entries on the periphery of the matrix.

In yield trials the performance of individual plots is not the main object of interest. It is the average performance of the cultivars under consideration that serves as the primary criterion for ranking lines. But the entries in the matrix were treated as individual units, different from all others. To interpret the 800 ranks in terms of the 40 cultivars, the average of the ranks for each cultivar was calculated. For instance, a certain entry in the center of the matrix might rank 16 out of 800; another entry might rank 106 out of 800. These entries had no identity during the systematic comparisons, but if on checking the records these plots so ranked were found to be replicates of the same line, the ranks of the remaining 18 replicates would be identified and their sum averaged over the number of replicates--in this case, 20. With 40 varieties, there were 40 such averages which were ordered from the highest to the lowest as the ranks of the averages of the ranks (RAR).

This experiment was conducted on the premise that nearest neighbor adjustments were alternatives, and perhaps more efficient ways of treating yield data for the purpose of selection than ordinary mean yields. Mean squares were calculated for the unadjusted data and the individual patterns to see which one gave the least variance. How the ranks of the averages of the ranks compared with the ranks of the mean yields (RMY) was determined through functional analyses--scattergrams, correlation and regression models.

Second Year

The problems encountered in handling the experiment in the previous year necessitated the reduction in size of this one. Twenty-five cultivars were selected for this study. Selection of those entries out of the original 40 was based on preliminary calculations of rank mean yield and ranks of average ranks of the nearest eight neighbors. The selections included a range of yields from the highest to the lowest. Table 1 also lists the lines studied in the second and third years of this investigation.

The plants in this experiment were planted in a balanced randomized lattice square design in which the lines in each replicate were arranged in a 5 x 5 square, and surrounded completely by border rows of CM72, a standard barley variety. All other treatments were the same as for experiment one in the first year.

Statistical Analyses. Analysis of variation was conducted on cultivar yields excluding those for border rows. Multiple range tests (LSD) were also used to compare mean yields of the 25 lines.

The patterns and APL programs for the nearest neighbor adjustments were the same as in the first year. To facilitate the full participation of peripheral plots, the yields of the border rows flanking them served as their nearest neighbors. The second and third neighboring patterns consisted of adding a second and third circle of the same border yields around the experimental plots. Subsequent analyses were the same as for this experiment in the first year.

Third Year

Extension of this study into the third year was intended to examine the nature of the rankings over years. All the trial cultivars, field treatments, and analyses were the same as those of the previous year.

Experiment Two: Density-dependent Yield Prediction

First Year

Two ranges of wheat separated this experiment from experiment one. Four replicates of the 40 cultivars (Table 1) were planted in a randomized complete block design for this study. Other field treatments were similar to those for the first experiment except the seeding rate. For this investigation the planting density was 8.40 kg per hectare (as compared with 84.02 kg per hectare for the previous study).

A single plant was harvested from each plot using a sickle. All tillers of the plant were cut at ground level and tied into a bundle. Data was collected on four variables:

1. Tiller number.
2. Productivity = total weight = biological yield.

3. Seed weight.

4. Seed number.

The data collected from these variables were manipulated to generate four additional parameters:

5. Straw weight = productivity - seed weight.

6. Harvest index = proportion of seed weight to total weight.

7. Number of seed per tiller.

8. Average seed weight.

Statistical Analyses. Analyses of variance was conducted on all the variables listed above. The mean yields were subjected to multiple range tests to determine whether real differences existed between the cultivars. Correlations, regressions and all other analyses were directed at evaluating the hypothesis about the effectiveness of using single plant characters in predicting yield of similar genotypes planted at commercial densities.

Second Year

Twenty-five lines were also used for this experiment. All other aspects were the same as those for the second experiment in the first year. In order to develop a single regression equation which could handle the two experiments in both years, the means of all the variables were pooled and a single stepwise multiple regression performed on the combined data.

This experiment was terminated at the end of the second year. The correlation studies in the two previous years were hardly supportive of the underlying hypothesis.

EXPERIMENTAL RESULTS

The complete study involved two experiments designated in this report as Experiments One and Two. The first experiment, concerned with field trials, was conducted for three years. The second experiment, concerned with spaced plants, was carried out for two years.

Experiment One: Nearest Neighbor Procedure

First Year

The mean squares for the analysis of variance of the randomized complete block design are given in Table 2. Variability due to lines was highly significant. Mean grain yields of the 40 entries were investigated for differences using the LSD procedure. The ordered mean yields listed in Table 3 were highly uniform.

The next series of results under this section are related to the nearest neighbor procedure. Error variances pertaining to the ranks of the unadjusted data and the data from the four adjustment procedures are presented as error mean squares in Table 4. The ranks of the unadjusted yields gave the highest error variance while the nearest eight neighbors indicated the least variation.

Ranks of the average ranks (RAR) were calculated for all the configurations in order to relate the 800 items in the matrix back to the 40 entries. Table 5 contains the results of those analyses in detail. Columns 2, 4, 6, 8, 10 contain averages of the ranks, while

Table 2. Experiment one, first year. Mean squares for grain yields of the 40 entries.

Source	D.F.	Mean Squares
Total	799	115034.65
Entries	39	886136.92***
Replicates	19	469096.80
Error	741	65371.80

***P $\leq$ 0.001

Table 3. Experiment one, first year. Mean grain yields (grams/plot) of the lines separated by the LSD procedure.

1977 Entry Number	Mean Yield
29	915.90
9	1076.05
31	1089.05
30	1229.50
24	1235.90
14	1328.60
22	1347.70
19	1369.35
36	1373.60
20	1391.15
23	1407.90
15	1418.05
37	1420.55
11	1422.20
21	1456.75
39	1470.05
26	1498.00
1	1501.85
35	1507.65
7	1514.50
33	1529.15
17	1557.95
32	1564.30
18	1577.35
34	1587.55
25	1595.60
4	1596.35
16	1619.45
3	1634.55
28	1641.85
13	1646.20
8	1684.95
12	1684.34
38	1716.50
40	1723.95
5	1733.60
10	1757.05
27	1798.95
6	1859.80
2	1893.40

LSD 0.05 = 164.08
C.V. = 16.93

Table 4. Experiment one, first year. Error mean squares for ranks derived from the various yield adjustment procedures.

Method of Adjustment	Error Mean Squares
Unadjusted Yield Ranks	279987.04
Nearest 8 Neighbors	145532.94
Nearest 16 Neighbors	215430.55
Nearest 8 and 16 Neighbors	188045.51
Nearest 8 and 16 Neighbors Unequally Weighted	176714.75

Table 5. Experiment one, first year. Mean yields (2), average ranks (4, 6, 8, 10) and ranks of average ranks (3, 5, 7, 9, 11) obtained from yield adjustments using the nearest neighbor procedures in the first year.--Values were rounded up to the nearest whole number.

			Nearest 8 Neighbors		Nearest 16 Neighbors		Nearest 24 Neighbors		Average Nearest 8 & 16 Neighbors	
Cultivar Number 1	Yield g/Plot 2	Rank Mean Yield 3	Average Rank 4	Rank Average Rank 5	Average Rank 6	Rank Average Rank 7	Average Rank 8	Rank Average Rank 9	Average Rank 10	Rank Average Rank 11
1	1502	23	396	22	378	18	382	18	384	18
2	1893	1	127	1	135	1	127	1	136	1
3	1635	12	293	11	253	8	264	9	269	10
4	1596	14	253	8	273	9	262	8	256	8
5	1734	5	237	7	234	6	226	6	231	7
6	1860	2	163	3	139	2	138	2	138	2
7	1515	21	477	29	439	27	455	28	461	28
8	1684	9	255	9	275	10	266	10	261	9
9	1076	39	714	39	698	39	710	39	712	39
10	1757	4	145	2	156	3	144	3	141	3
11	1442	27	364	17	374	17	362	17	354	17
12	1685	8	298	13	288	13	292	13	294	13
13	1647	10	295	12	282	11	284	12	286	12
14	1329	35	482	30	548	31	538	30	531	30
15	1418	29	382	19	393	20	390	19	388	19
16	1619	13	340	15	292	15	298	15	306	15
17	1558	19	377	18	412	24	403	24	406	22
18	1577	17	393	20	389	19	392	20	389	20
19	1369	33	538	32	549	32	551	31	540	31
20	1390	31	500	31	560	33	560	33	558	32
21	1457	26	471	28	481	29	480	29	480	29
22	1348	34	541	33	569	34	569	34	569	34
23	1408	30	583	34	544	30	559	32	566	33
24	1236	36	645	37	643	37	649	37	650	37
25	1596	15	212	5	247	7	232	7	226	6
26	1498	24	456	27	427	25	438	26	442	26
27	1799	3	213	6	207	5	218	5	219	5
28	1642	11	312	14	289	14	294	14	297	14
29	916	40	759	40	758	40	761	40	762	40
30	1230	37	643	36	639	36	646	36	649	36
31	1089	38	676	38	688	38	682	38	683	28
32	1564	18	395	21	405	23	406	23	413	23
33	1529	20	414	24	395	21	400	22	424	24
34	1588	16	347	16	312	16	315	16	317	16
35	1508	22	398	23	396	22	396	21	401	21
36	1374	32	605	35	571	35	584	35	594	35
37	1421	28	430	26	465	28	452	27	445	27
38	1717	7	185	4	186	4	180	4	181	4
39	1470	25	428	25	432	26	430	25	431	25
40	1724	6	270	10	284	12	278	11	278	11

columns 3, 5, 7, 9, 11 show the ranks of those averages. Hence, for the purposes of brevity in interpretations, the latter set of columns should adequately describe the conduct of those data-points in the cause of the adjustments. From Table 5 it was also possible to identify the top 25% of the lines which demonstrated the highest yield potential. These are listed in Table 6.

This experiment was intended to examine the effectiveness of the nearest neighbor procedure in predicting the performance of the entries under study. Whether these procedures were equivalent to each other, on one hand, and to the rank mean yield, on the other, in achieving that goal, was investigated through trend analysis. The values in columns 3, 5, 7, 9, 11 of Table 5 were used to generate the relevant statistics which are presented as simple linear regressions in Figure 2, and correlating coefficients in Table 7. Rank mean yield (RMY) was as good a predictive tool as any of the nearest neighbor comparisons. This is what the graphs and correlation table indicate.

Second Year

In spite of the differences both in the number of entries and in the experimental design, the second year data was treated in the same manner as data of the first year.

Mean squares for the grain yields of the 25 entries given in Table 8 reveal a high variability among lines. Table 9 contains the ordered mean yields of the 25 entries. Only line 31 was significantly distinct from the others. The remaining 24 were highly overlapping.

Table 6. Experiment one, first year. The top 25% of entry means as identified by the unadjusted mean yields and the nearest neighbor adjustments.--These lines have been ordered from the highest (1) to the lowest (10) according to the ranks of average ranks.

Method of Adjustment	Entry Number of Entries in the Top 25% of Entry Means									
	1	2	3	4	5	6	7	8	9	10
Unadjusted Mean Yields	2	6	27	10	5	40	38	12	8	13
Nearest 8 Neighbors	2	10	6	38	25	27	5	4	8	40
Nearest 16 Neighbors	2	6	10	38	27	5	25	3	4	8
Nearest 24 Neighbors	2	4	10	38	27	5	25	4	3	8
Nearest 8 and 16 Neighbors Unequally Weighted	2	6	10	38	27	25	5	4	8	3

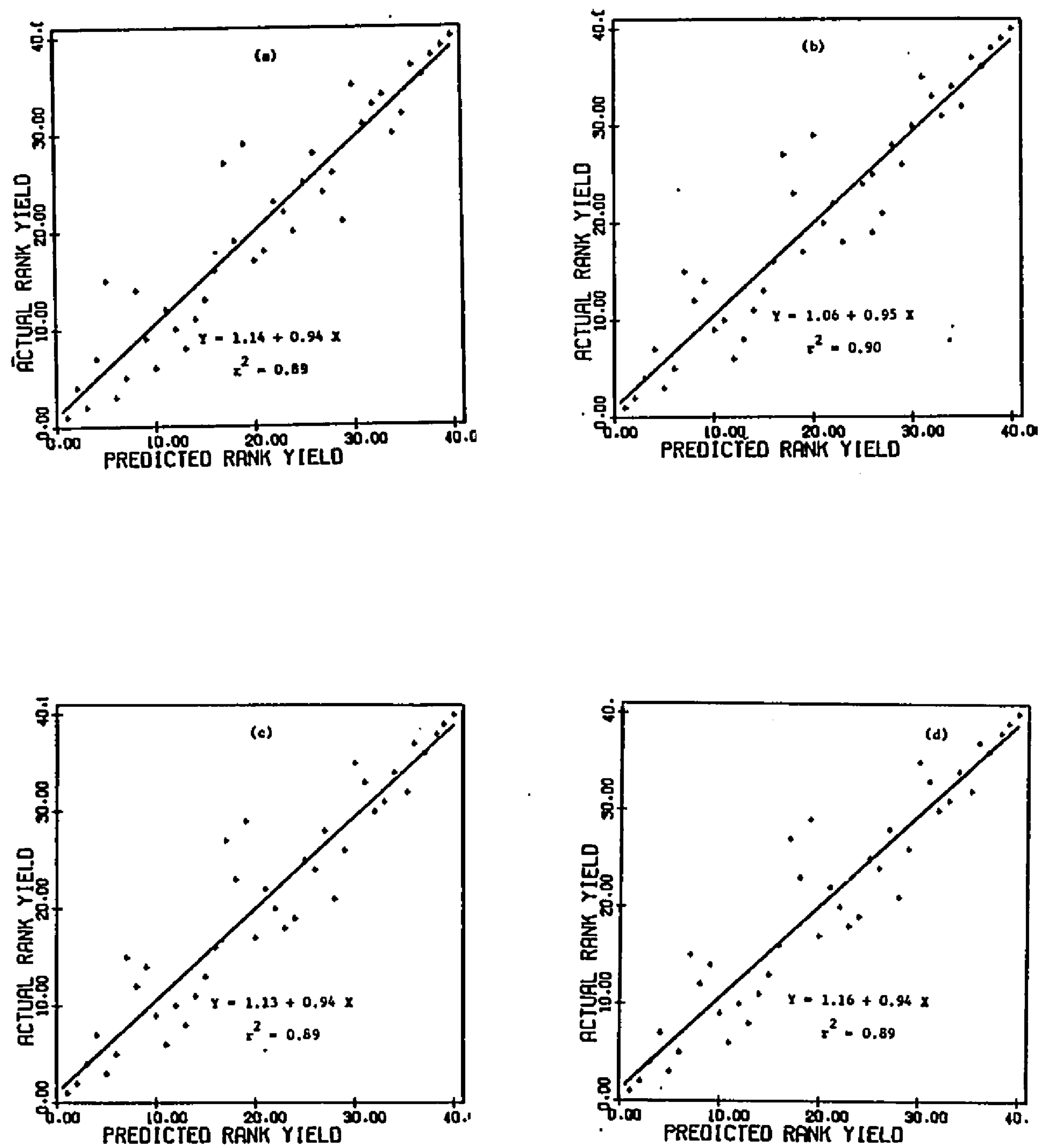

Figure 2. Experiment one, first year. Linear regression models showing relationships between rank mean yield and the rank yields predicted by the nearest neighbor procedures.--(a) nearest neighbor 1; (b) nearest neighbor 2; (c) nearest neighbor 3; (d) average nearest neighbor 1 and 2.

Table 7. Experiment one, first year. Correlation coefficients showing relationships between rank mean yield and ranks of average ranks obtained from the nearest neighbor procedures.--These coefficients are significantly greater than zero at the 0.001 level of probability.

NN1	0.94			
NN2	0.95	0.99		
NN3	0.94	0.99	1.00	
AVN12	0.94	0.99	0.99	1.00
	RY	NN1	NN2	NN3

Table 8. Experiment one, second year. Mean squares for grain yields of the 25 entries.

Source	D.F.	Mean Squares
Total	149	97215.27
Entries	24	435951.12***
Replicates	5	4153.64
Error	120	33345.67

***$P \leq 0.001$

Table 9. Experiment one, second year. Mean grain yields (grams/plot) of the lines separated by the LSD procedure.

1977 Entry Number	Mean Yield
31	338.00
24	543.17
30	590.17
4	895.50
28	919.83
26	939.33
29	994.67
32	1022.33
35	1077.17
18	1090.33
12	1090.33
27	1109.83
40	1121.67
13	1126.00
1	1128.83
34	1128.83
33	1133.67
3	1168.67
5	1170.67
17	1309.00
8	1321.50
6	1330.67
2	1403.83
10	1437.33
38	1455.67

LSD 0.05 = 206.64
C.V. = 16.95

Results of the ANOVA treatment of the 150 items in the matrix are given in Table 10. The error mean squares showed the same trends as in the previous year. Variation due to non-adjustment was the highest while comparisons based on the nearest eight neighbors produced the smallest error term.

For the second and third years, only the ranks of average ranks are presented. Those for the second year are tabulated in Table 11. The top 25% of the lines identified on the basis of RAR in Table 11 are listed in Table 12, in descending order. Figure 3 and Table 13 show the comparisons between rank mean yields and rank of average ranks, and correlation coefficients, respectively.

Third Year

This was a repetition of experiment one in the second year. The purpose of that replication was to examine the stability of the RARs for the entries over time. That, in turn, would demonstrate the stability of the yield potential of the lines.

The mean squares for entry yields in Table 14 showed marginal variation. The lines were not significantly different from each other in mean performance, as indicated by the LSD treatment of the means given in Table 15.

Whether the yield data were adjusted by any of the nearest neighbor patterns or not, there was always a total of 150 ranks for each matrix. Those ranks were used as data-points which were subjected to ANOVA treatment and the results are included in Table 16 as error mean squares.

Table 10. Experiment one, second year. Error mean squares for ranks derived from the various yield adjustment procedures.

Method of Adjustment	Error Mean Squares
Unadjusted Yield Ranks	3941.64
Nearest 8 Neighbors	1779.48
Nearest 16 Neighbors	2354.49
Nearest 8 and 16 Neighbors	2158.75
Nearest 8 and 16 Neighbors Unequally Weighted	2035.53

Table 11. Experiment one, second year. Rank mean yields and ranks of average ranks for the nearest neighbor procedures.

Cultivar Number	Rank Mean Yield	Ranks of Average Ranks			
		NN1*	NN2*	NN3*	AVN12*
1	11	12	8	10	11
2	3	3	3	3	3
3	8	13	7	9	9
4	22	22	22	22	22
5	7	8	9	8	8
6	4	4	4	4	4
8	5	5	5	5	5
10	2	2	2	2	2
12	15	15	16	16	16
13	12	16	12	14	14
17	6	6	6	6	6
18	16	17	15	17	17
24	24	24	24	24	24
26	20	20	21	21	21
27	14	10	14	11	10
28	21	21	19	20	20
29	19	19	20	19	19
30	23	23	23	23	23
31	25	25	25	25	25
32	18	18	18	18	18
33	9	7	11	7	7
34	10	9	13	12	12
35	17	14	10	13	13
38	1	1	1	1	1
40	13	11	17	15	15

*see p. 25 for abbreviations.

Table 12. Experiment one, second year. The top 25% of entry means as identified by the unadjusted yields and the nearest neighbor adjustments.--These lines have been ordered from the highest (1) to the lowest (6) according to the ranks of average ranks.

Method of Adjustment	Entry Number of Entries in the Top 25% of Entry Means					
	1	2	3	4	5	6
Unadjusted Mean Yields	38	10	2	6	8	17
Nearest 8 Neighbors	38	10	2	6	8	17
Nearest 16 Neighbors	38	10	2	6	8	17
Nearest 8 and 16 Neighbors	38	10	2	6	8	17
Nearest 8 and 16 Neighbors Unequally Weighted	38	10	2	6	8	17

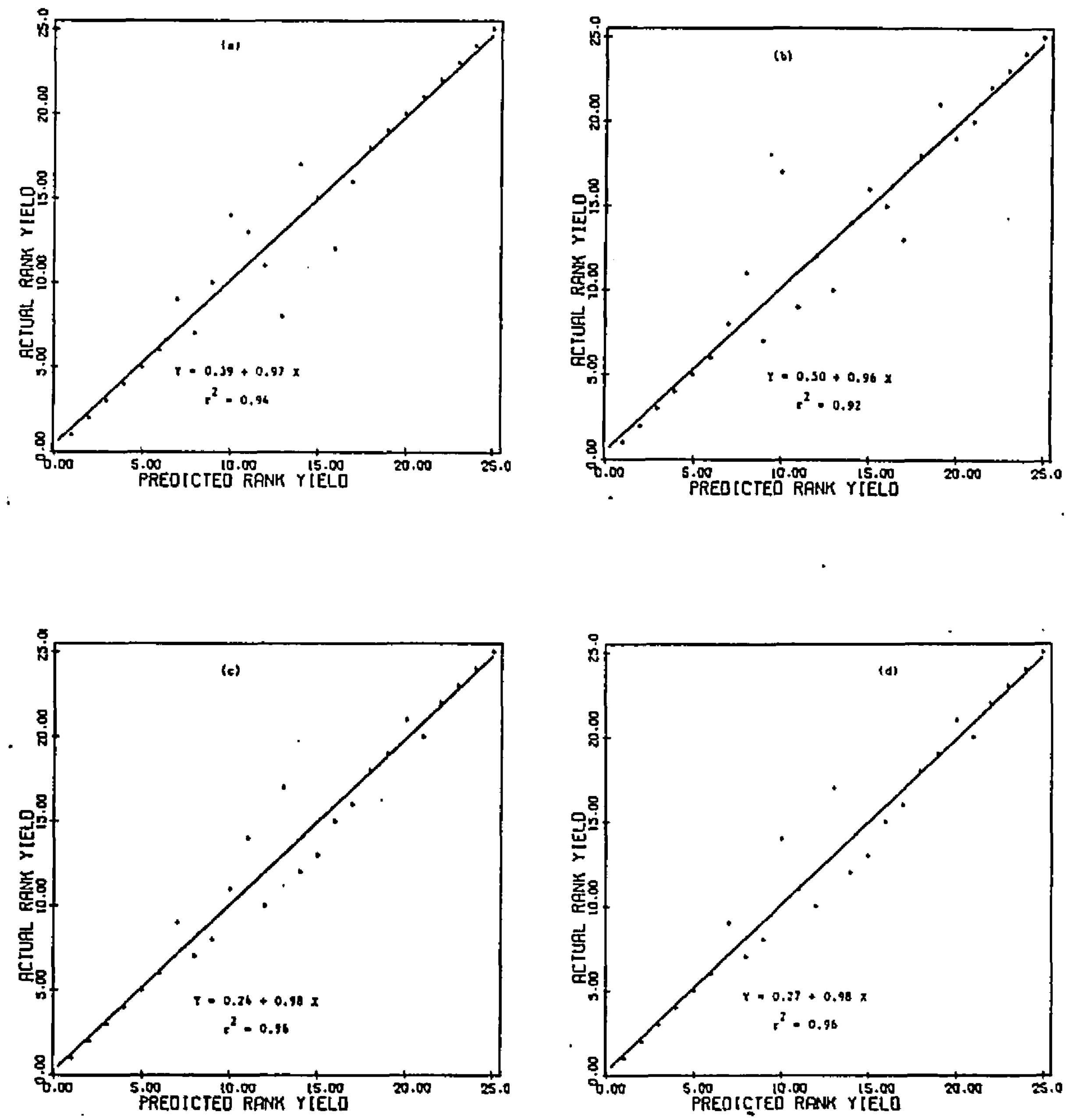

Figure 3. Experiment one, second year. Linear regression models showing relationships between rank mean yield and the rank yields predicted by the nearest neighbor procedures.--(a) nearest neighbor 1; (b) nearest neighbor 2; (c) nearest neighbor 3; (d) average nearest neighbor 1 and 2.

Table 13. Experiment one, second year. Correlation coefficients showing relationships between rank mean yield and ranks of average ranks obtained from the nearest neighbor procedures.--These coefficients are significantly greater than zero at the 0.001 level of probability.

NN1	0.97			
NN2	0.96	0.93		
NN3	0.98	0.98	0.98	
AVN12	0.98	0.98	0.97	1.00
	RY	NN1	NN2	NN3

Table 14. Experiment one, third year. Mean squares for grain yields of the 25 entries.

Source	D.F.	Mean Squares
Total	149	15901.40
Entries	24	204446.17*
Replicates	5	116244.44
Error	120	98178.15

$*P \leqslant 0.05$

Table 15. Experiment one, third year. Mean grain yields (grams/plot) of the lines separated by the LSD procedure.

1977 Entry Number	Mean Yield
24	1240.83
30	1289.67
40	1438.83
4	1454.50
31	1460.67
18	1513.83
28	1517.17
8	1561.50
13	1574.33
32	1579.19
6	1590.00
34	1592.67
3	1599.17
12	1612.00
35	1665.83
17	1670.00
26	1706.00
33	1760.67
38	1763.83
10	1764.33
27	1849.17
1	1850.50
29	1854.33
2	1902.67
5	1975.50

LSD 0.05 = 358.17
C.V. = 19.18

Table 16. Experiment one, third year. Error mean squares for ranks derived from the various adjustment procedures.

Method of Adjustment	Error Mean Squares
Unadjusted Yield Ranks	4421.65
Nearest 8 Neighbors	1722.64
Nearest 16 Neighbors	2308.26
Nearest 8 and 16 Neighbors	2047.14
Nearest 8 and 16 Neighbors Unequally Weighted	1956.05

The RAR for each procedure are given in Table 17. From this table the top 25% of the lines which showed the highest yield potential were selected and listed in Table 18. Comparisons between RMY and RAR in their ability to identify the yield potentials of the same lines were achieved through regression equations and correlation coefficients in Figure 4 and Table 19, respectively.

Experiment Two: Density-dependent Yield Prediction

First Year

The analyses of variance for the yield components are presented as mean squares in Table 20. Except for productivity and seed number, which were marginally variable, the entries did not show any differences for the remaining characters.

The mean grain yields were not subjected to the usual LSD procedure because variation in seed weight was equal to zero at the 0.05 level of probability. However, the ordered mean yields are shown in Table 21 for the purposes of comparing the superior plants identified by the rank mean yields of the two experiments.

Table 22 contains the matrix of correlations within spaced plant parameters, and between those and crop yield. Tiller number, productivity, seed weight, seed number, and straw weight were all significantly correlated. The association between tillers on one level, and harvest index, number of kernels per tiller, and average seed weight on the other were very low and negative. Seed weight was highly correlated with harvest index and average seed weight, but seed number

Table 17. Experiment one, third year. Rank mean yields and ranks of average ranks for the nearest neighbor procedures.

Cultivar Number	Rank Mean Yield	Ranks of Average Ranks			
		NN1*	NN2*	NN3*	AVN12*
1	4	3	2	2	2
2	2	2	4	3	3
3	13	14	17	15	14
4	22	20	23	23	20
5	1	1	1	1	1
6	15	12	11	12	13
8	18	18	16	18	18
10	6	9	9	9	9
12	12	13	19	17	17
13	17	22	13	19	22
17	10	11	10	10	10
18	20	19	21	20	19
24	25	25	25	25	25
26	9	10	8	8	8
27	5	5	5	5	5
28	19	23	22	22	23
29	3	4	3	4	4
30	24	24	24	24	24
31	21	21	20	21	21
32	16	15	15	13	13
33	8	7	7	7	7
34	14	16	14	14	15
35	11	8	12	11	11
38	7	6	6	6	6
40	23	17	18	16	16

*see p. 25 for abbreviations.

Table 18. Experiment one, third year. The top 25% of entry means as identified by the unadjusted yields and the nearest neighbor adjustments.--These entries have been ordered from the highest (1) to the lowest (6) according to the ranks of average ranks.

Method of Adjustment	Entry Number of Entries in the Top 25% of Entry Means					
	1	2	3	4	5	6
Unadjusted Mean Yields	5	2	29	1	27	10
Nearest 8 Neighbors	5	2	1	29	27	38
Nearest 16 Neighbors	5	1	29	2	27	38
Nearest 8 and 16 Neighbors	5	1	2	29	27	38
Nearest 8 and 16 Neighbors Unequally Weighted	5	1	2	29	27	38

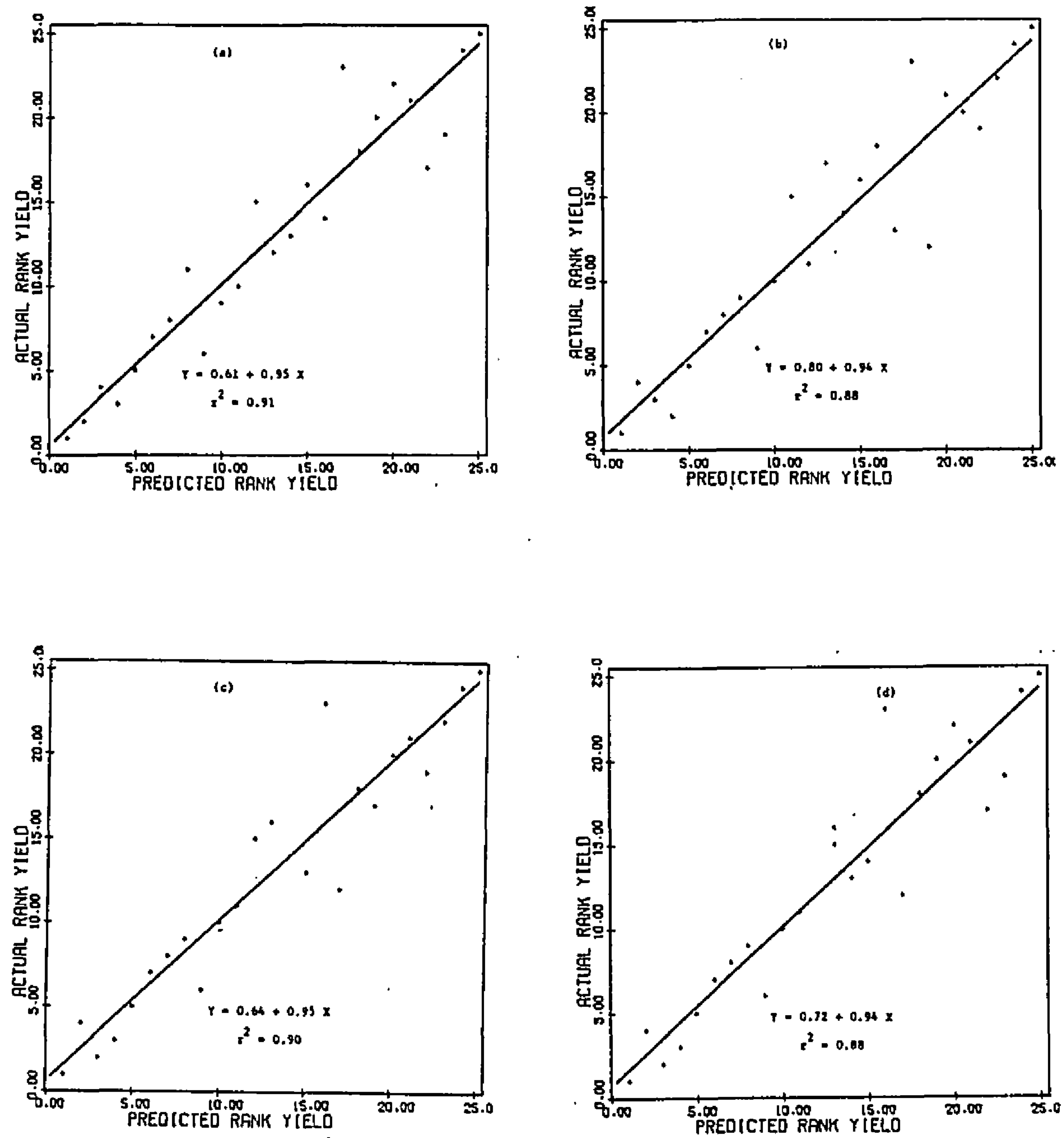

Figure 4. Experiment one, third year. Linear regression models showing relationships between rank mean yield and the rank yields predicted by the nearest neighbor procedures.--(a) nearest neighbor 1; (b) nearest neighbor 2; (c) nearest neighbor 3; (d) average nearest neighbor 1 and 2.

Table 19. Experiment one, third year. Correlation coefficients showing relationships between rank mean yield and ranks of average ranks obtained from the nearest neighbor procedures.--These coefficients are significantly greater than zero at the 0.001 level of probability.

NN1	0.95			
NN2	0.94	0.93		
NN3	0.95	0.98	0.98	
AVN12	0.94	0.98	0.95	1.00
	RY	NN1	NN2	NN3

Table 20. Experiment two, first year. Mean squares for yield components of spaced plants.

Source	D.F.	Tiller Number	Productivity	Seed Weight	Seed Number	Straw Weight	Harvest Index	Number of Seeds Per Tiller	Average Seed Weight
Total	159	80.78	1117.37	260.67	236990.17	366.47	0.003	190.51	0.001
Entries	39	96.79	1413.76*	323.19	291460.16*	412.92	0.003	189.52	0.000
Replicates	3	274.56	4465.04	623.20	968206.82	1960.09	0.007	306.09	0.001
Residual	117	70.48	932.74	229.32	198594.98	308.27	0.003	187.73	0.001

*P $\leqslant$ 0.05

Table 21. Experiment two, first year. Mean grain yields (grams/plant) of entries.--LSD was not applied to this data because the ANOVA F-test was not significant at the P = 0.05 level.

1977 Entry Number	Mean Yield
20	29.00
30	30.25
33	33.00
3	34.25
35	34.25
1	34.50
24	34.50
21	35.00
15	35.75
10	362.5
29	36.25
34	38.00
39	38.25
11	39.00
31	39.50
16	40.00
18	40.25
37	41.75
19	42.50
27	43.00
5	44.75
38	44.75
13	45.00
36	45.25
28	45.75
17	46.50
8	47.00
40	48.25
25	49.50
22	50.75
26	50.75
7	51.50
12	51.75
32	52.25
6	52.50
2	53.00
14	53.25
23	53.75
9	67.75
4	69.75

Table 22. Experiment two, first year. Correlation matrix showing relationships within yield parameters of single plants, and between those characters and crop yield.

	Y1 Tiller Number	Y2 Productivity	Y3 Seed Weight	Y4 Seed Number	Y5 Straw Weight	Y6 Harvest Index	Y7 Number of Kernels Per Tiller	Y8 Average Seed Weight	Crop Yield
Y1		0.71***	0.63***	0.74***	0.72***	-0.07	-0.20	-0.16	0.12
Y2			0.96***	0.77***	0.96***	0.09	0.15	0.32*	0.20
Y3				0.79***	0.85***	0.38*	0.25	0.36**	0.15
Y4					0.70***	0.21	0.48**	-0.25	0.15
Y5						-0.17	0.04	0.26	0.22
Y6							0.32*	0.26	-0.10
Y7								-0.23	0.19
Y8									0.02

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001
D.F. = 39

was negatively related to the latter. Though not significant, it suggested a tendency for average seed weight to decrease with larger seed number.

Seed weight in spaced plants demonstrated a highly significant and positive correlation with all the yield components except number of kernels per tiller. This result indicated that any of these characters could be used for the purpose of predicting yield potential of spaced-planted entries. However, the correlations between these characters and crop yield were mostly positive but small and insignificant. To confirm these findings, simple regressions of crop yield on individual spaced plant parameters were determined. The coefficients of determination (r^2) ranged from 1% to 8%, and none of the beta coefficients was different from zero at $P \leq 0.05$ level of significance (Table 23). Hence the results in Tables 22 and 23 could not be used for the purposes of predicting crop yield potential.

The correlations for the first year can be summarized as follows:

1. Tiller number, productivity, seed weight, seed number, and straw weight demonstrated strong positive associations.

2. While productivity and yield were correlated with average seed weight, only yield was positively related to harvest index.

3. In terms of crop yield, all the correlations, except for harvest index, were positive but not significant.

Second Year

Table 24 shows the mean squares for the yield components of spaced plants in the second year. The lines were highly variable for

Table 23. Experiment two, first year. Simple regression analyses of crop yield regressed on spaced plant parameters.

Variable	Intercept	Beta Coefficient	F-Value	r^2
Tiller Number	1360.45	5.27	0.59	0.01
Productivity	1294.70	2.20	1.53	0.04
Seed Weight	1358.44	3.45	0.36	0.20
Seed Number	1349.11	0.12	0.34	0.02
Straw Weight	1264.33	4.56	0.17	0.05
Harvest Index	1878.93	-821.83	0.40	0.10
Number of Kernels Per Tiller	1226.02	5.83	0.24	0.36
Average Seed Weight	1471.61	1155.72	0.91	0.08

F (0.95; 1, 38) = 4.08

Table 24. Experiment two, second year. Mean squares for yield components of spaced plants.

Source	D.F.	Tiller Number	Productivity	Seed Weight	Seed Number	Straw Weight	Harvest Index	Number of Seeds Per Tiller	Average Seed Weight
Total	99	35.48*	498.49	132.83	93033.58	175.72	0.01	194.08	0.00
Entries	24	60.31**	986.53***	283.83***	191460.25***	357.69***	0.02	532.42***	0.00
Replicates	3	40.57	1132.92	238.14	193420.97	391.17	0.01	143.16	0.00
Residual	72	26.99	309.37	78.11	56041.88	106.10	0.00	83.43	0.00

*$P \leq 0.05$
**$P \leq 0.01$
***$P \leq 0.001$

all the parameters examined. In Table 25 are listed the mean grain yields for the 25 entries which were ranked according to the LSD procedure. Relationships within these variables, and between the latter and crop yield were also investigated. The results are presented in Table 26. There were differences between these and similar results for the first year (Table 22). Tiller number displayed low and negative correlations with most characters except number of kernels per tiller. Productivity was not linked to harvest index as before. But productivity and seed weight were strongly correlated with the other yield components. In the second year also the number of kernels per tiller showed higher and more significant correlations with other characters than in the first year.

However, the associations between those characters and yield from solid seeding were low and non-significant. Simple regression coefficients shown in Table 27 revealed that the use of such parameters for within-year, across-density predicitons was inappropriate. The F-tests for the individual beta values were not different from zero at $P \leqslant 0.05$ and the r^2 ranged from 1% to 13%.

Results for the separate years were neither stable nor satisfactory for the prediction of yield potential at a higher planting density. A single equation which would cover both years was then considered necessary. Data for the entire experiment were pooled for correlation and regression analyses.

A greater number of yield components showed stronger associations than for the separate years. As shown in Table 28, productivity was

Table 25. Experiment two, second year. Mean grain yields (grams/plant) of entries ordered by the LSD procedure.

1978 Entry Number	Mean Yield
4	14.00
12	17.00
31	17.25
2	18.00
30	18.00
17	18.25
24	18.75
40	19.50
32	23.00
28	24.00
10	24.50
6	25.00
5	25.75
18	26.75
33	27.25
8	28.00
26	28.25
27	28.50
13	28.75
3	30.75
1	31.75
29	32.00
13	35.00
34	45.25
35	49.00

LSD 0.05 = 12.46
C.V. = 33.77

Table 26. Experiment two, second year. Correlation matrix showing relationships within yield parameters of spaced plants, and between those characters and crop yield.

	Y1 Tiller Number	Y2 Productivity	Y3 Seed Weight	Y4 Seed Number	Y5 Straw Weight	Y6 Harvest Index	Y7 Number of Kernels Per Tiller	Y8 Average Seed Weight	Crop Yield
Y1		-0.03	-0.06	0.05	0.01	-0.19	-0.45	-0.24	-0.01
Y2			0.86***	0.53**	0.89***	0.16	0.42*	0.60***	0.34
Y3				0.78***	0.54**	0.62***	0.69***	0.47*	0.30
Y4					0.19	0.73***	0.83***	-0.16	0.10
Y5						-0.29	0.09	0.58**	0.29
Y6							0.77***	-0.03	0.13
Y7								-0.06	0.11
Y8									0.36

*P ⩽ 0.05
**P ⩽ 0.01
***P ⩽ 0.001
D.F. = 24

Table 27. Experiment two, second year. Simple regression analyses of crop yield regressed on spaced plant parameters.

Variable	Intercept	Beta Coefficient	F-Value	r^2
Tiller Number				
Productivity	697.90	5.57	2.92	0.11
Seed Weight	822.78	9.59	2.27	0.09
Seed Number	975.21	0.13	0.24	0.01
Straw Weight	750.23	8.29	2.12	0.08
Harvest Index	866.08	524.37	0.39	0.02
Number of Kernels Per Tiller	971.28	2.57	0.28	0.01
Average Seed Weight	539.56	15954.98	3.45	0.13

$F(0.95; 1, 23) = 4.17$

Table 28. Correlation matrix showing relationships within yield parameters of spaced plants, and between those characters and crop yield for the combined two-year data.

	Y1 Tiller Number	Y2 Productivity	Y3 Seed Weight	Y4 Seed Number	Y5 Straw Weight	Y6 Harvest Index	Y7 Number of Kernels Per Tiller	Y8 Average Seed Weight	Crop Yield
Y1		0.72***	0.69***	0.76***	0.70***	0.26*	0.09	-0.16	0.48***
Y2			0.96***	0.85***	0.96***	0.40**	0.46***	0.29*	0.60***
Y3				0.90***	0.84***	0.63***	0.59***	0.25*	0.58***
Y4					0.73***	0.62***	0.68***	-0.16	0.57***
Y5						0.14	0.30*	0.30*	0.55***
Y6							0.71***	0.02	0.37**
Y7								-0.12	0.39**
Y8									0.14

*P ⩽ 0.05
**P ⩽ 0.01
***P ⩽ 0.001
D.F. = 64

highly related to the rest of the characters. The results also showed significant correlation among straw weight, harvest index, and number of kernels per tiller. Harvest index was consistently related to yield within spaced plants for the entire experimental period.

With regard to crop yield, all the correlation coefficients were significant at the $P \leq 0.01$ level, except for average seed weight. Any of these components could be used in a prediction equation for yield at higher seeding rates. However, the best choice would be the character which showed the highest simple correlation with the dependent variable. That character was productivity. The regression equation for productivity regressed on crop yield was: Crop yield = 7.86 (Productivity) + 672.63. With 25% selection intensity, the following entries were identified as expressing estimates of superior yield potential: Entry numbers 4, 9, 6, 12, 23, 25, 14, 2, 26, 7, 32, 40, 17 22, and 8.

Two stepwise regression models were constructed from the pooled data. The first was intended to identify those variables which together contributed significantly to yield in spaced plants. The second model related the yield components of spaced plants to crop yield. Seed weight (yield) was not included in the latter analyses because it was used as the dependent variable for the first equation. Both models were intended to show those variables which were common to the two densities. The stepwise regression procedure accepts variables into the equation according to their order of importance. In Table 29, productivity entered the sequence first and tiller number last. Average seed weight

Table 29. Final equation in a stepwise regression analysis of seed weight (yield) regressed on other variables within spaced plants.--Only productivity (Y2) and straw weight (Y5) contributed significantly to the model.

Variable	Coefficient	F-Value	Significance	Intercept	r^2
Productivity (Y2)	0.95	682.76	0.00	-2.94	0.99***
Straw Weight (Y5)	-0.91	208.29	0.00		
Harvest Index (Y6)	4.40	0.80	0.37		
Seed Number (Y4)	-0.04	0.37	0.54		
Number of Seed Per Tiller (Y7)	-0.01	0.77	0.38		
Tiller Number (Y1)	-0.01	0.66	0.42		

***$P \leq 0.001$

had a very low F-value of 0.18, so it was rejected from the model. The results presented in Table 29 indicate that productivity and straw weight contributed significantly to the equation for spaced plants.

When the mean yields of the entries at normal cultural density were regressed on the single plant parameters, the r^2 value was increased from 13% for separate years to 42% for both years combined (Table 30). Hence putting several variables into one model should make the prediction equation more precise. The cross-year stepwise regression approach predicted the following entries as having superior yield potential: Entry numbers 4, 9, 6, 23, 14, 12, 25, 26, 2, 7, 32, 40, 22, 17, and 8. The two models identified almost the same entries, which suggests the possibility of a relationship between those two seeding rates.

Table 30. Final equation in a stepwise regression analysis of crop yield regressed on spaced plant parameters for the combined two-year data.

Variable	Beta Coefficient	F-Value	Significance	Intercept	r^2
Productivity (Y2)	-34.93	3.95	0.05	-296.14	0.49**
Harvest Index (Y6)	3183.92	2.32	0.13		
Straw Weight (Y5)	57.16	4.37	0.04		
Tiller Number (Y1)	54.71	6.13	0.02		
Number of Kernels Per Tiller (Y7)	26.61	4.57	0.04		
Average Seed Weight (Y8)	29134.87	3.28	0.08		
Seed Number (Y4)	-0.38	0.41	0.53		

**$P \leq 0.01$

DISCUSSION

Experiment One

Nearest Neighbor Procedures

The statistical analyses and subsequent results from the nearest neighbor procedures followed the same format in each year of the entire experimental period. Even though the results were presented according to the experiments and years, similar results fro all three years will be discussed in the same category.

Analysis of Variance for Cultivar Grain Yield

The results for the analyses of variance (ANOVA) revealed a high degree of heterogeneity within the cultivars examined. In both experiments, treatments were assigned at random to the experimental units within blocks, but the blocks were formed in a decidedly non-random fashion. Hence, statistical tests for blocks or replicates were not performed.

Selections for those lines were from populations ranging from the F_4 to the F_8 generations. Hence they were all expected to be homozygous. Any variation within rows was due to residual heterozygosity. Some entries would have a higher amount of that type of variation than others.

Comparisons of Mean Yield

Mean grain yields of the cultivars were compared through the Least Significant Difference (LSD) procedure at the modest probability level of 0.05. The results in Tables 3, 9, and 15 for years one, two, and three, respectively, show highly overlapping groups of means. In Table 3 only line 29 was significantly different from the rest. In the second year (Table 8), three cultivars fell in one group, and the rest in the other. But the large range between the smallest and largest mean values (338-1455 grams/plot) might be due to the uncontrolled error such as fertility gradient and drastic weather changes which occurred that year. None of the cultivars grown in the third year was different from its cohorts in yielding capability.

Gates and Bilbro (1973) characterized the LSD as the smallest yardstick of Duncan's Multiple Range tests. In fact, it is less conservative than Duncan's. Though it is simple to use, those authors noted that it is undesirable as a procedure for mean separation. But the results shown in Tables 2, 8, and 14 justified the use of that procedure, since the F-tests for the cultivar mean squares were all significant. In such situations, the LSD is known to perform very well.

The following varieties were included in this study: Reliance (cultivar number 32), Gus (34), Kombar (37), CM67 (38), Valbar (39), and Arivat (40). These are standard, high-yielding varieties that are well adapted to the western United States. In conventional yield trials, these varieties could be used as control plots planted systematically in the experimental area. The value of the test plot would be determined in the light of that of the local check plot. In this instance, the six varieties were entered as unknowns and their performances observed on the basis of the assumption supporting the nearest neighbor adjustments.

Multiple comparison procedures are appropriate in situations where the objective is to pick the winner or winners from among a set of qualitative treatments like variety trials (Peterson 1977). The amount of overlapping of the cultivars' means for the three years demonstrated that the standard varieties were not distinctly superior to any of the trial lines. It is because of this and other weaknesses in the use of standard control varieties that Jensen (1974) proposed the floating check concept.

There are other explanations for the apparent homogeneity of mean yields. In *Lolium*, Vasek and Fergusson (1963) observed that certain populations were extremely variable when considered alone, but they could fall into a virtual continuum when treated with other populations. Perhaps a similar situation had operated in these barley lines. Additionally most of them had the same genotypic base, Composite Cross XXXII. The selection of those entries as distinct taxa must have been due to criteria other than yield potential.

Analysis of Variance for Ranks Derived from Yield Adjustments

Comparing the ANOVAs of the ranks of the adjusted yields with those obtained without adjustments showed the most striking changes were the reductions in the mean square error statistics. Results in Tables 4, 10, and 16 demonstrate clearly the advantages of yield adjustments with respect to experimental efficiency. The precision of inferences from field data, and the confidence associated with it, depends on the size of this parameter. Any treatment design which reduces the experimental error drastically is generally preferred by researchers.

These results were consistent for the entire experimental period. They also agreed with those of similar studies in wheat (Knott 1972; Townley-Smith and Hurd 1973). In hybrid yields trials with maize and sorghum, Scheuring (1979) observed comparative advantages in adjusting yield data. However, the error mean square reductions he obtained were not consistent with the configurations he used for the adjustments. He concluded that while the moving average adjustments reduces variation within local configurations, it does not do so between configurations. The nearest neighbor procedure, on the other hand, showed definite and systematic trends for such reductions. For instance, for the first year (Table 4) the pattern which resulted in the least variance was the nearest 8 neighbors. The nearest 8 and 16 neighbors unequally weighted, the nearest 8 and 16 neighbors, and the nearest 16 neighbors followed in order of increasing variances. The same trends were seen for the second and third years in Tables 10 and 16, respectively. The nearest neighbors were the most efficient, being the most contiguous with the entry to be adjusted. When the effects of the 8 and 16 nearest neighbors were considered in direct proportion to their weighted distances from the entry, smaller mean squares were obtained than in the case where the same neighbors were considered just as 8 and 16 (24 nearest neighbors). The configuration which had a complete border between them and the entry (i.e., nearest 16 neighbors) produced the largest variance. This configuration is therefore unsuitable for yield adjustments.

Comparative Rankings of Cultivar Yield Potentials

The goal for this study was to use the nearest neighbor methods to predict the cultivars with the highest yield potential. Results in Tables 5, 11, and 17 rank the lines according to their performances in the adjustment procedures. Each row in a table presents the average ranks for each cultivar relative to a specific configuration. For instance, line number 1 in Table 5 ranked 23, 22, 18, 18, and 18 out of 40 for mean yield, nearest 8 neighbors, nearest 16 neighbors, nearest 8 and 16 neighbors, average of nearest 8 and 16 neighbors, respectively. In the same table, line number 2 ranked 1 out of 40 for all the methods. Obvious from these results is the relation between rank mean yield to the ranks of average ranks. In most cases, ranks obtained from the latter were almost equivalent to the ranks of mean yields. The RARs resulted from deviations of nearest neighbor means from some entry in the matrix of experimental plots. As a working assumption, genotype identity was not important in evaluating the lines. The results of the LSD treatments of mean yields supported this approach clearly. Since all the entries were treated similarly, an entry with a high yield potential would express that attribute regardless of its microenvironment. That plant should produce a higher deviation from its nearest neighbor means wherever it was situated in the matrix. The corresponding low means of the ranks for that line would place it in the superior class with entries which showed similar potentials.

Only the RARs for the individual methods are shown in Tables 11 and 17 for the second and third years, respectively. There were definite fluctuations in rank orders for the lines from year to year. Entry number 29, for example, was ranked 40, 19-20, 3-4 in the first, second, and third years, respectively.

The degree of probable error resulting from sudden and unpleasant seasonal changes, and also from handling the experimental material, must have contributed in part to such inconsistencies in ranks. Perhaps some outcrossing and genetic recombination were still operative in some lines, making them less stable and fit. In both tables also the RARs are closely related to the RMYs.

Selection of Entries Based on Nearest Neighbor Predictions

It is possible to select desirable plants by ordering the populations either by sample means or variances. In this instance, 25% of the cultivars which were identified by these patterns as exhibiting the highest yield potentials were selected and ranked from the largest to the smallest. A 25% selection intensity resulted in retaining 10 lines in the first year and 6 lines in the second and third years. Those selections are included in Tables 6, 12, and 17.

One of the objectives of this study was to examine whether the selection methods generally identified the truly superior, and the same lines. For the first aim, the number of predicted genotypes that occurred in common under all the methods within each year, and in all possible pairs of the three years, were determined. In the first year, the procedures picked out the same entries for superior performance, though with a few exceptions such as entries number 40, 12, and 13. The results for the second year in Table 12 showed some degree of consistency. Except for entry number 17, all the others, numbers 38, 10, 2, 6, and 8, were included in the selections for the first year. That could indicate some amount of stability in those particular genotypes. But the third year results in Table 17 did not follow that trend. Apart from line number 29, the selections were similar more to those for the first year. When the selections for the entire experiment were considered together, those of the first year appeared more appropriate for yield prediction than those for the other years. The results for the second and third years were not as compatible as both years compared with the first. The entry numbers showing high yield potential are as follows:

Year 1: 2, 6, 10, 38, 27, 5, 25, 4, 8, 40, 3, 13

Year 2: 38, 10, 2, 6, 8, 17

Year 3: 5, 1, 2, 29, 27, 38, 10

These entries are presented in rank order also. According to this summary, entries 2, 38, and 10 showed the highest potential followed by 6, 8, 5, and 27. The former group appeared in the top 25% in all three years, while the latter set appeared in only two of the three years. Of these, there was only one standard variety, number 38 (CM67).

A 25% selection intensity applied to the 25 lines resulted in fewer selections than when applied to 40 lines. It should be possible to obtain a larger number of similar lines within the high yielding bracket for all three years if the selection intensity were lowered proportionately; that is, to about 40% for the last two years. But that approach would negate the assumption for this study. If a line is good, it should fall in the top 25%. The test of such quality for any cultivar would be its consistent selection regardless of years and changes in number of lines tested. Any cultivar that fell outside the 25% limit was considered unsuitable for selection at that time. This approach stems from a popular view of plant breeders that it is better to get rid of a good line than to retain a bad one during variety trials. Allard (1960) cautioned breeders in this way:

> The beginning plant breeder must develop an attitude of ruthlessness in selection. He must dispel the feeling that among the plants he discards may be the one that will lead to the variety he has in mind. Unless he keeps his natural inclination under control, he will shortly find himself overwhelmed with materials that he should have discarded, and his effectiveness as a plant breeder may be impaired or lost.

It could be very expensive in resources to retain and manage a bad line only to discover in the end that it had poor and undesirable qualities.

There are statistical tests that can evaluate the reliability of these rankings, within and between years, and these are commonly applied in animal breeding. In the absence of such tests, the chances of making any of the two statistical errors are always present. An example of that was the behavior of entry number 29 during the three-year period. Becker (1961) gives an example of that situation in poultry.

The lines used for this study could not be subjected to such tests either. In the first place, most of them were new selections about which nothing was known. Even the six standard varieties included had never produced consistent yields that could show their relative ranks. Hence there was nothing like good or poor performers which were to be yield tested and the data treated statistically to ascertain such characteristics. In effect, the choice of those cultivars for study was governed solely by the null hypothesis of homogenous yield potentials.

The question of those patterns identifying the same lines was investigated with regression and correlation statistics. Figures 2, 3, and 4 show regressions of rank mean yield on predicted rank yield for the first, second, and third years, respectively. The range of beta values were high and very similar irrespective of years. They all deviated from 1.00 at the 0.001 level of significance. The coefficients of determination, r^2, were large for every procedure in each of the three years. On average about 90% of the variation in rank mean yields was accounted for by linear regression on the RAR variables. Those analyses indicated that the RARs derived from the nearest neighbor procedures were reliable in predicting the yield potentials of the lines. In fact, each adjustment procedure was equivalent to the rank mean yield for identifying the same lines in most cases.

The correlation coefficients in Tables 7, 12, and 18 were large and uniform. For each year, those values were equivalent to the beta coefficients in Figures 2, 3, and 4. Though both coefficients always carry the same sign, they will not be equal. Those similarities observed in the above tables and figures suggested that the variances for the RMYs and RARs were equal.

It is generally believed that correlations are stronger between contiguous plots. In fact, Wiebe (1935), and Briggs and Shebeski (1968), obtained data which indicated that correlations between yield of rows in a nursery were inversely proportional to the distance between the plots. By analogy, the correlation between rank yield and rank of the first nearest neighbors should be stronger than that with the second neighbors. The results for all three years were different from those cited above as shown by the large degree of homogeneity among the correlations between RMY and RARs. The methods of yield adjustment involved mostly related plants within each configuration. Also most of the entries used for this study had the same genetic background, hence would behave similarly under the same experimental conditions. The very high correlations among the nearest neighbor comparisons demonstrated that the patterns represented a satisfactory unit of soil uniformity.

This experiment applied the nearest neighbor technique in variety improvement. For that procedure, genotype allocation in the field was random and the evaluation of each entry was based on individual performance. Each pattern was a unit of mobile checks that served to evaluate each individual plot. A high degree of local control was imposed by the individual configurations. Comparing single plants within small areas reduced environmental differences substantially. Yield differences under such conditions should be due mainly to genetic rather than environmental differences. This method incorporated the principles of blocking, and of floating checks, into a very efficient unitary system for selection.

In principle, the above method has some similarities with Fasoula's (1980) honeycomb technique. They differ widely, however, in practical applications. The honeycomb appraises "gross" yield potential. For that purpose, extreme care is adopted to eliminate the effects of competition and soil heterogeneity. Horticultural crops like lettuce may be suitable for such designs; but more land and a completely different class of farm machinery and cultural practice will be required if the honeycomb is to be used in programs for cereal improvement. In short, the honeycomb procedure does not simulate current agricultural practice.

The two important steps in breeding superior yielding lines in cereals are: (1) identification of promising crosses, and (2) effective selection within those crosses. The first step involves making comparisons of replicated trials and selecting promising crosses. Since the second step deals with uniquely different genotypes, field potential must be evaluated in unreplicated trials. The nearest neighbor procedure was conducted on genotypes which were in the second stage of the breeding program. Individual entries were treated as a group of unreplicated unknowns which were genotypically distinct. This approach offered the advantages of evaluating a larger number of entries at one time than if replications were used.

Throughout the experimental period, the error mean squares derived from the individual nearest neighbor configurations were significantly less than those for the unadjusted yields. In statistical terms, those patterns were more efficient than rank mean yields for the purposes of selection. Among the four configurations, the nearest eight neighbors, which were closest to the entry of interest, showed the least error mean square, and hence were the most efficient.

It must be noted, however, that those adjustments are far more demanding in terms of time and labor than selecting through rank mean yield. When the RMYs and RARs were subjected to functional analyses, they identified the same superior lines in most cases. It would therefore be more rewarding in regard to practical economy, to use rank mean yield alone in predicting promising lines. With reduced efficiency, the chances of including a couple of poor lines always exist. But that error should be adequately compensated by the larger number of lines that can be evaluated at any one time, and also by the benefits arising from savings in resources.

Experiment Two

Variation in Spaced Plant Characters

The first and second year results for the analyses of variation in the yield components are included in Tables 20 and 24, respectively. While those variables appeared uniform in the first year, they demonstrated a high degree of variation in the following year. Having basically the same genotypic background, such changes could be due more to environmental than genetic factors. Hence selection for yield and its components in those lines should be performed only when the breeder is certain about the heritable entity of the variation for each character.

Mean Yields of Entries

Mean yields for the spaced plants were calculated for two reasons: (1) to determine the range of variation in the mean performance of the lines, and (2) to find out whether these results and similar observations in the first experiment would identify the same entries for high yield potential. The mean yields in Table 21 were not treated according to the LSD procedure, but a glance at that table reveals a homogenous group of means. Table 25 contains the same trends. These findings further support similar results in the first experiment. Uniformity in mean performance can be explained by common genetic background of the entries. In addition, the field designs and treatments were always such that incidental variability arising from factors such as soil heterogeneity were minimized. These results did not identify the same superior lines as those for the first experiment. Correlation coefficients for yield at the two densities confirmed the non-association between those treatments.

Correlations Within Characters of Spaced Plants

The extensive research into the nature of associations among yield components is based on the fact that plant organs are intertwined into a complex pattern of relationships. Identifying such patterns could make the prediction of yield potential easier and thus expedite selection for yield. Tables 22 and 26 contain the results of the correlation studies for both years. Highly positive correlations were revealed among most of the variables in both years. Notable among these were productivity, seed weight, seed numbers, and straw weight. In the first year tiller number was also related to those components. The expression of yield in cereals depends on the accumulation of assimilates, translocation, and storage in the sink. In the first year it appeared that none of these activities was limiting, hence the strong links within variables Y1 to Y5, in Table 22.

In the second year, however, tiller number displayed extremely poor correlations with other parameters. There was a consistent negative association between tiller number on one hand, and number of kernels per tiller and average seed weight on the other. The variation in correlations over time could be seen in the context of developmental trends in cereals. In barley, yield components are determined at different stages in the development of the plant. For instance, tillers which appear after the main culm has produced five to seven leaves infrequently survive to head emergence. When they do, they are likely to produce small spikes with similar sizes of seeds. While kernel number is determined before spike emergence, kernel size (average seed weight) is determined partly during vegetative growth. Size depends primarily on post-fertilization developments (Rasmusson and Cannell 1970). These facts should explain not only the positive correlation between tiller number and seed weight, but also the negative association of that character with number of kernels per tiller and average seed weight in both years. Annual differences in tillering could also be responsible for the inconsistent correlations with other characters.

Harvest index was negatively related to tiller number and straw weight, but positively linked to productivity and seed number. Most of these relationships were too small to be important. However, they were in line with the very definition of that parameter. Harvest index, the grain weight/total weight ratio, would decrease with high tiller number and larger straw weight. Strong positive correlations were obtained among harvest index, grain yield, and seed number. Those findings were comparable to the observations of Fischer and Kertesz (1976), again in wheat.

Seed number and seed weight were consistently associated significantly throughout the experiment period. Hence, 1000-seed weight should prove a good index to yield even in spaced plants (Hsu and Walton 1971; Nass 1973).

That some characters were highly correlated was no surprise. Such yield components were obtained in the manner that influenced their conduct in the functional analysis. For instance, productivity was the sum of seed weight and straw weight, which made correlation within them a matter of expectation. Some components like tiller number were not so stable, as shown in Tables 22 and 26. There were also changes within number of kernels per head and average seed weight, with the former being more variable over years. The number of kernels per head varies with the environment, but average seed weight is very stable. In terms of selection, this parameter should be advantageous in all environments. Since it is the last to develop, it is hardly affected by compensating changes in other components (Rasmusson and Cannell 1970).

These results were corroborative with numerous other correlation studies in the literature. They showed that yield components are differentially affected by variation in the environment. Developmental allometry, which relates the development of every organ to the rest of the plant, must always operate to effect component compensation. The net result of all those activities would be small, often negative, associations between plant parts (Adams 1976; Hamid and Grafius 1978).

Relationship Between Spaced Plant Parameters and Crop Yield

The correlations in Tables 22 and 26 were intended to relate yield components in spaced plants to crop yield. Small and often nonsignificant relationships were revealed by the analyses in both years. There were also changes in the behaviors of tiller numbers, harvest index, and crop yield. While average seed weight showed the lowest positive link with crop yield in the first year, it displayed the highest correlation value with yield in the following year. Productivity on the other hand maintained a stable second highest association with yield for both years.

These results were different from those obtained from experiments in wheat. Syme (1972) obtained highly significant correlations between crop yield on one hand, and straw weight (r = -80.0), harvest index (r = 0.85), and grains per ear (r = 0.75) on the other, of single potted plants in the greenhouse. McVetty and Evans (1980) obtained highly significant correlations between single F_2 plant parameters such as kernel number (r - 0.43**), kernels per tiller (0.37**), and harvest index (r - 0.31**), and bulk F_4 yield.

It was apparent from these results that spaced plant parameters were not valuable for prediction of yield at normal commercial density. The tables containing simple regression coefficients confirmed the poor correlations between those two sets of density treatments. The data also confirmed the fact that plant phenotype is never stable; it varies with changes in genotype and environment. Hence, any attempt to predict yield potential under such conditions must take into account the fact that the importance of the variables in the prediction equations varies with years and environments. A unified equation which could relate the important yield parameters integrated over time, should be more comprehensive than similar models for separate years. For that reason the two-year data, both for the dependent and the independent variables, were combined and subjected to the appropriate analyses.

Prediction of Yield Potentials

Spaced Plants. Results from the analyses of the combined data indicated that correlations between yield (seed weight) and other components within spaced plants were comparable to those within high-density seeding in barley (Salih 1975). It should be noted, however, that the correlation coefficient shown in the correlation matrix, between two variables, is a measure of the degree of linear relationship between them. However, the fact that two variables are associated does not imply any cause and effect relationship. Both may be influenced by other variables in a way that gives rise to a high correlation. To assess that influence, the relevant variables in the matrix would have to be evaluated simultaneously. In this study, seed weight (yield) was associated with productivity, seed number, and straw weight. But productivity in turn was the sum of seed weight and straw weight. Therefore that component can be considered to have influenced the correlations mentioned immediately above. In spaced plants then, productivity could serve as the main predictor of yield potential.

The results in Table 29 went further to support the claim for this parameter being the most suitable index of yield potential in single plants. Only productivity and straw weight contributed significantly to the regression equation which had a high reliability factor, r^2 = 0.99.

Yield at Cultural Density. The subsequent stage in the analyses was to relate the important yield components in spaced plants to crop yield. Could the same parameters predict yield at solid-seeding density? Tables 28 and 30 contain data which attempted, in part, to answer that question. In Table 28, the component which demonstrated the highest positive relation with crop yield was productivity. McVetty and Evans (1980) obtained very similar results when they attempted to construct a single regression model from data pooled over crosses and environments in wheat. The 25% of the entries which were identified by the simple regression equation containing productivity alone, were included in the previous chapter.

Fitting all the variables in the stepwise regression equation produced the results in Table 30. The important contributors to the model were, in their order of usefulness, biological yield, straw weight, tiller number, and number of kernels per tiller. There was a reduction in the r^2 from 0.99 down to 0.49 with the inclusion of more variables. Yet the latter r^2 value was still greater than zero at the P = 0.01 level of significance.

The top 25% of the entries which showed superior yield potential estimates were included in the Results section. A comparison of both selections would indicate that the entries identified by the two models were similar for the most part.

The advantages of using yield and yield components of spaced plants to predict crop yield were noted by Syme (1972). The first is the economy of seed and effort. It also has potential applications for segregating populations. Moreover, it can predict relative yield over many environments. What this scheme may not measure, is yield stability.

Predictions of crop yield potential from yield on single plants in early generations of wheat have been ineffective (Shebeski 1968; Knott 1972). Grain yield in spaced plants may be related to the ability of the plants to occupy more space and intercept more light. In the crop situation, Fisher and Kertesz (1976) surmised that full light interception may be reached rapidly, and yield could be more a function of the distribution of photosynthate than of photosynthesis per unit of light captured. In short, the net effect of competition would have a negative impact on grain yield.

Multiple correlations and regressions are often used to predict yield from yield components. The relationships often investigated come from similar or different densities and environments. Equations derived from these calculations are usually based on the assumptions that: (1) genotypes under test respond similarly to those from which the equations were derived; (2) the range of field environments used to derive the equations was applicable to the region for which the cultivars were being grown; and (3) relationships between the variables are always linear.

Every characteristic of every living organism is an interaction-product of a specific genetic constitution and a specific environment. The plant breeder should always realize that the phenotype of a plant is the result of all the genes interacting with each other and with the environment (Ramage 1980). The above assumptions are therefore untenable in the light of this basic tenet in genetics. Preliminary studies into the relationships between spaced plant parameters and crop yield using scatter diagrams revealed that actual relationships existed. But they were not always linear as it is often assumed.

There were certain amounts of inconsistencies in the correlations from year to year as shown by the present results. Hence, equations derived from individual years would be inadequate for the purposes of prediction. Also, cultivar and density interactions for grain yield have been observed within small grain species. This means that selection procedures whereby cultivars are evaluated on the basis of performance at a low seeding rate, may fail to reveal genotypes with the potential for high productivity under other arrangements (Kirby 1967; Finlay, Reinbergs, and Daynard 1971).

It appeared that determinations made from pooled data could serve as reliable predictive tools. As shown in Table 28, however, most of the independent variables used in the regression equations were intercorrelated. Regression coefficients become imprecise under such circumstances. In fact, little or no additional information can be obtained by increasing the number of such variables in the equations. Two parameters should be as good as six so long as they are highly related. The entries identified by the simple regression with productivity alone, and the stepwise multiple regression with four variables were similar in most cases. One solution to this problem is to use only one of the variables in the highly correlated set to represent the common underlying dimension (Kim and Kohout 1975). Analyses of the pooled data demonstrated that productivity or biological yield adequately represented that variable.

Plant breeders and agronomists show little interest in biological yield as opposed to harvest index. According to Donald and Hamblin (1976) this attitude has seriously limited the understanding of cereal performance and biotype behavior. Those authors observed that in most experiments the correlation of harvest index with plot grain yield was far below 1.0, because productivity was highly variable. Therefore, it would be wrong to consider harvest index alone as estimates of early generation yield potential, because grain yield depends both on biological yield and harvest index. It is obvious from the results of this investigation that productivity, not harvest index, was the main predictor of yield potential of the entries examined.

SUMMARY AND CONCLUSIONS

Modern crop production requires more sophisticated methods which can evaluate a large number of genotypes in mass plantings. In this regard, improved methods of yield testing which are more reliable than the "mean yield" criterion, are always being investigated. In this study, the nearest neighbor procedure and the use of spaced plant parameters in predicting crop yield were examined.

The nearest neighbor yield adjustments were applied to data obtained from conventional yield trials. These trials were conducted for three years. Adjustments involved comparisons of yield of the trial line (entry) with the mean of its nearest neighbors. Four configurations were examined. For each pattern the entry to be adjusted always occupied the center of the rectangle of neighbors. Genotypes were randomly located in the field and their evaluations were based on individual performance. The values derived from the deviations of the entry from the nearest neighbor means determined the rank of the particular entry among its cohorts.

Error mean squares of those ranks were computed to see which pattern was the most efficient statistically. Results for the three years showed definite trends in error variances based on configurations. The unadjusted yield data always produced the highest mean square due to error. Among the nearest neighbors, the first nearest neighbor always produced the smallest error variance, hence the highest efficiency.

For each pattern, the average ranks for individual genotypes were determined. Entries which fell in the top 25% of the yield curve were selected as having high yield potentials. Selections were hardly consistent over years, though some entries, e.g. numbers 2 and 38, always fell within the top 25% yielders each year.

Comparisons of selections based on rank mean yield and ranks of average ranks derived from the nearest neighbors indicated that the two sets of procedures identified almost the same genotypes with high yield potentials.

Selection using mean yield is less accurate than the nearest neighbors procedure, as shown by the results of this study. However, a larger number of lines can be evaluated more easily through the former method. This study therefore supports the continuing use of mean yield in evaluating genotype performance.

The effectiveness of spaced-plant components in predicting crop yield was also examined for two years. Yield and yield components within spaced plants demonstrated unstable correlations during individual years. In those years also the correlation and regression studies on spaced plant characters and crop yield indicated that spaced plants were poor predictors of yield at normal planting densities.

Highly significant correlations and regression coefficients were obtained when data for both years were combined and analysed together. These analyses revealed that the most important spaced plant parameter that could be used for that purpose was productivity (biological yield or total weight).

The advantages of this method are the economies in land and effort during genotype evaluation. However, there are many experimental results in the literature showing highly significant genotype/density interactions. Moreover, it is well known, especially in barley, that selections based on spaced plants perform poorly when seeded more densely under normal cultivation. Therefore in practice it is better to select from the same density at which subsequent generations will be cultivated.

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