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Visual selection for grain yield may be a limiting factor in identifying superior yielding genotypes in a breeding program. This investigation was conducted (1) to compare the effectiveness of visual selection for grain yield by three selector groups representing different levels of plant breeding experience, and (2) to examine the association of selected traits with the process of evaluating plots visually for grain yield.

The germplasm evaluated consisted of fifty non-segregating, diverse genotypes selected to include a wide range of expression for phenotypic characters. They were grown in solid-seeded, two-row plots with three replications in a randomized block design during 1981-1982. Data were collected on a plot basis for grain yield and twenty-two agronomic traits.

Eighteen selectors were placed in three groups comprised of two plant breeders, eight graduate students, and eight summer student workers, respectively, from the Oregon State University cereal breeding program. Evaluations were made on two separate days by scoring each of the 150 plots on a scale of 1 to 5 for grain yield.

The plant breeder selectors were the most successful of the three groups in discriminating both high and low yielding plots. The two best graduate student selectors were similar in ability to the plant breeders in scoring plots for high yield, although not in scoring for low yield. The remaining graduate student and summer worker selectors were generally not able to score more low and high yielding plots "correctly" than would be expected if selection were done at random.

Considered individually, the most effective selectors failed to select several high yielding plots. However, when selections of the four most effective selectors were combined, only one of the twenty highest yielding plots was omitted.

Results comparing trait association with actual plot grain yield and with selector scoring for plot grain yield suggested "biases" for or against certain traits. Biases for later heading and maturing plant types with wide flag leaves were common to all selector groups when visually selecting for high yield, as were earlier heading and maturing entries with narrower flag leaves when selecting for low yield. The plant breeder selectors were notable for lack of trait biases relative to other selector groups. In contrast, the summer worker selectors tended to overemphasize several spike characteristics whether selecting for high or low yield. Results suggested several other trait biases of individual selectors and selector groups.

ASSOCIATION OF SELECTED TRAITS WITH VISUAL SELECTION FOR YIELD IN WHEAT (*TRITICUM AESTIVUM*, L. em THELL.)

by

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INTRODUCTION

Visual selection is the oldest form of plant breeding. By approximately 3000 B.C. in the Old World and by 1000 B.C. in the New World, essentially all our important food crops had been domesticated (Briggs and Knowles, 1967). It was through visual selection based on observable yield, disease resistance, environmental tolerance, and usefulness of plants that led directly to most of today's successful crop cultivars.

The advent of statistical methods and improved field plot technique made it possible to more effectively identify genetically superior plant types, particularly in advanced generations of experimental lines which can be replicated within and across environments. Yet, with many autogamous crops, the commonly used pedigree method relies on phenotypic selection in early generations after a cross. When breeding objectives are to improve simply inherited traits, visual selection is effective. However, quantitatively inherited traits like grain yield are difficult to evaluate before homozygosity is reached, due to large numbers of both major and minor genes, and large genotype by environment interactions.

Proceeding on a simplified assumption of twenty-one independent loci for grain yield with two distinct parents in a wheat cross, Sneep (1977) has pointed out that the smallest complete

F_2 would contain 4,398 x 10^9 genotypes. Since simple and reliable methods are not yet available for accurately predicting the best parental combinations to use in a pedigree program, breeders must of necessity evaluate progeny from a number of crosses in populations as large as the constraints of time, labor, land and capital will permit. As breeding programs have increased in size, visual selection has continued to be used as a screening tool to reduce populations in early generations to a size suitable for yield trial evaluation. As a result, most wheat cultivars today are the product of selection by phenotype for as many as five or six generations before performance testing in yield trials is initiated. The visual selection of individual plants and lines before yield testing is based on an individual's subjective evaluation. The time and effort spent in visual evaluation may produce results that are no better than if selection were done at random. This is especially true if phenotypic criteria used to evaluate agronomic worth have a neutral or negative association with actual grain yield potential.

The process of visual selection may therefore be a limiting factor in identifying superior yielding genotypes. Considerable waste of time and resources may also result due to the propagation of poor yielding strains. Little information is available which evaluates effectiveness of visual selection for grain yield and specific traits of the experimental population.

The objectives of this investigation were (1) to compare the effectiveness of visual selection for grain yield by three selector groups representing different levels of plant breeding experience, and (2) to examine the association of selected traits with visual selection by individual selector and selector group.

LITERATURE REVIEW

Effectiveness of Visual Selection for Yield

In the pedigree method of plant breeding, rejection of plants in early segregating generations is still based on visual evaluation. Allard (1960) emphasized the need for quick evaluation rather than precise measurement when screening large numbers of individuals or lines. The effectiveness of visual selection when dealing with highly heritable characters has been demonstrated repeatedly. However, for grain yield and other quantitatively inherited traits, the effectiveness of visual discrimination is debatable. Efforts have been made in several crops to evaluate early versus late generation selection as to the effectiveness of selectors in identifying high yielding genotypes. Selected literature will be presented in ascending order from F_2 segregating populations through yield trials.

F_2 Generation

Working with F_2 wheat populations, Boyce et al. (1947) found that experienced selectors were able to select single plants which yielded above the mean yield of all plants in the same plot. Noting that selector efficiency decreased as selection intensity was relaxed from 5% to 20%, they suggested that personal bias for certain plant types operated more at low selection intensities.

Shebeski (1967) visually selected 440 single plants from an

F_2 wheat population. He found no significant difference between the mean yields of F_3 lines derived from selected plants and the mean yields of lines derived from unselected plants. McGinnis and Shebeski (1973) hypothesized that conclusions of ineffective yield selection in the F_2 generation were perhaps due to imprecise experimental technique. They increased precision by minimizing interplant competition in the F_2 and further minimized interline competition in the F_3 generations. When this was done, the three wheat breeders involved were successful in identifying high yielding F_2 wheat plants, choosing six, nine, and ten, respectively, of the ten highest yielding plants. There was, however, no significant correlation between F_2 plant yield and F_3 plot yield.

Knott (1972) selected F_2 plants from eight wheat crosses. Unlike the results of McGinnis and Shebeski (1973), his analysis of the yield of F_3 lines from selected and control F_2 plants showed statistically significant differences in favor of the selected lines. However, Knott thought the gain from visual selection was not large enough to be of value in a wheat breeding program.

In a study by Frey (1962), using F_2 populations derived from two oat crosses, individual plants were designated 'good' or 'poor' for potential yield. Additional selections were made at random, with all categories of F_2 derived lines subsequently yield tested in F_4 and F_5 generations. The relationship between visual evaluation of F_2 plants and their progeny yields was not strong. For one cross, the mean yields of the three categories ('good', 'poor', random) were approximately equal. For the second cross, only the 'poor' category yielded significantly different (lower) than the random class.

Wilcox and Schabaugh (1980) hypothesized that the effectiveness of visual selection for yield should be greater if plant to plant variability were increased, as would be the case in progeny derived from crosses between adapted, superior parents and less adapted plant introductions. They therefore selected phenotypically superior soybean plants in the F_2 through F_4 generations derived from twelve crosses, nine between superior cultivars and plant introductions, and three crosses among superior cultivars. However, yields of lines derived from selected plants did not differ from lines derived from randomly selected plants. Selection for yield in crosses involving plant introductions was no more effective than in crosses among superior cultivars.

F_3 Generation

Boyce et al. (1947) also attempted to choose superior yielding spaced planted F_3 plants, noting that the primary aim of selection at this stage is to retain as high a percentage as possible of the highest yielding lines. Although selectors were again successful in choosing plots higher than the population mean, the authors recommended a low selection intensity. Many high yielding lines were rejected at high intensities of visual selection.

Working with spring wheat, Briggs and Shebeski (1970) utilized plant breeders and graduate students to visually select the highest yielding plots from an F_3 nursery of 828 lines. A positive selection pressure of 10% resulted in selected lines yielding significantly more than random lines. Selectors chose more lines from the highest yielding 10 and 25 lines than would be expected by random selection. However, three of the 10 highest yielding plots were not identified by any of the selectors, nor were six of the highest 25. The authors concluded that this rather limited ability to select high yielding lines supports the use of low selection pressure for yield.

McKenzie and Lambert (1961), working with two barley crosses, retained lines from the F_3 generation, partly on the basis of a yield rating of 1 to 5. They found a poor relationship between visual ratings for yield and replicated yield trials in the F_6 generation.

In another study on F_3 barley populations, Atkins (1964) selected individual plants in a space-planted F_3 nursery derived from a single cross. Plants were evaluated visually for several characteristics considered to be associated with high grain yield and then categorized as 'good' or 'poor.' A group of 25 plants was selected for each category and compared for grain yield in the F_5 through F_7 generations with the progeny of 25 randomly selected

F_3 plants. Yield differences between the three groups ('poor,' 'good,' and 'random') were significant at the 1% level in two of the three seasons of evaluation; however, the mean yield difference among groups was only one bushel per acre. In addition, the number of lines in the F_5 to F_7 generations that traced to plants rated 'good' in the F_3 was small, the greatest number of high yielding lines, in fact, coming from the 'random' class. A significant relationship was shown between lines classified as 'poor' in the F_3 generation and low yielding lines in the F_5 to F_7 generations. High yielding lines did not show this relationship.

Superior soybean phenotypes in the F_3 and F_4 generations were visually selected by Voight and Weber (1960) in a typical pedigree breeding program. Yield trials were conducted for the F_5 selected lines and compared with yield trials of lines selected by a bulk system of breeding and a third system involving generation (F_4) yield testing. They found that the F_5 mean yields of visually selected lines by the pedigree method did not differ significantly from means of the bulk system lines. Both bulk and visually selected lines had F_5 mean yields significantly inferior to lines selected by early generation yield testing.

Hanson et al. (1962) summarized the results of three experienced soybean breeders, who placed 45 F_3 soybean lines into three groups of 9, 9, and 27 (highest 20%, next 20%, and lowest 60%) in seed yield, respectively. The authors found poor correlations among the breeders with regard to visual concepts of plot yield, and also between visual concepts of yield and actual plot yield. They concluded that unless there are extreme values of yield in the expression of a cross, visual discrimination should be used primarily to discard poor types.

Using four oat crosses, Stuthman and Steidl (1976) compared the progenies of 'high' and 'low' visually selected F_3 lines with random selections. 'High' selections from three of four populations yielded more than the random group, but significantly less than random in the fourth population. Similarly, 'low' selections from three of the four populations yielded less than the random group, but were equal to the random group in the fourth population. Supporting Hanson et al. (1962), the downward selection differential between random and low selections were consistently larger than the upward differential. Poor yielding plots were more effectively identified than superior ones.

In Salmon and Larter's (1978) study on space-planted populations of F_3 triticale, experienced plant breeders, novice graduate students and inexperienced summer workers each identified those lines he/she predicted would yield higher than the nearest check variety. The mean yields of the 20 highest plots as judged by the plant breeders were not significantly different from the actual highest 20 lines in yield as measured at harvest. Although the other two groups were not as successful, even the least experienced selector was able to identify lines higher than would be obtained by random sampling. The authors attributed greater selector success in this study as compared to others to the greater variability of expression of plant characteristics in triticale. Also, success might have been due to the greater variability in the populations within which selections were made.

F_4 and F_5 Generations

In a continuation of the study previously noted, McKenzie and Lambert (1961) practiced divergent visual selection with F_4 and F_5 lines from two barley crosses. Head rows in the F_4 and F_5 generations were visually rated as 'good' or 'poor' for potential yield. However, it was found that yield testing in the F_6 generation showed no significant difference between 'good' and 'poor' selections.

Frey (1962) classified single plants and progeny rows in the F_5 generation as 'good,' 'random ' and 'poor.' Subsequent yield testing showed no difference between rating categories based on single plant selections. However, yield tests conducted in the F_6 generation showed that ratings given to F_5 progeny rows were effective. The mean yield advantage was 3.5 bushels per acre between rows designated 'good' and 'random,' and 12.5 bushels per acre between 'good' and 'poor' rows. In explaining the relative effectiveness of selecting among F_5 progeny rows versus the ineffectiveness of single plant selection in F_5, Frey (1962) suggested that "the phenotypic expression of single plants was so confounded with environmental influence that visual selection based upon them was ineffective."

Kwon and Torrie (1964) tested the ability of one experienced plant breeder and two graduate students to visually discriminate soybean lines for seed yield. Two populations were examined at one location in the F_3 and at two locations in the F_4 and F_5 generations. Using a visual yield scale of 1 to 9, the observers were equally adept at discriminating the extremes for seed yield when differences among plots was large, but not when differences were small. The three selectors were more successful in identifying lines from the lowest actual yield quartile than correctly placing lines in the highest yield quartile. However, the expected gain for yield using visual selection was only 50% as efficient as actually measuring plot yield and advancing the same proportion of lines.

In a study utilizing spring wheat, Mann (1975) asked six wheat breeders, four graduate students, and two summer student employees to visually select for yield among F_4 and F_5 head rows, which were then placed in F_5 and F_6 yield nurseries the following year. Selectors were successful in selecting lines which yielded significantly more than the family mean yield in only two of eleven F_4 families. In seven additional families, selectors performed worse than would be expected from random selection. Selectors were again worse than random expectation in predicting the highest ten yielding lines. At one of the locations in the study, the highest three yielding lines were selected only twice among all twelve selectors. Previous breeding or selection experience made little difference in ability to predict yield.

Yield Trials

Townley-Smith et al. (1973) reported the ability of three wheat breeders, two wheat technicians and four other crop research workers to select at a 25% level the highest yielding lines of wheat in an advanced generation yield trial. The mean yield of selected lines was only slightly better than the mean yield of all lines. Many of the highest yielding lines were not selected by anyone in the study. Interestingly, the selections of the wheat breeders had the lowest yields, while those of the technicians had the highest yields.

Ricci and Gargiulo (1980) used a scale of 1 to 4 to assess the yield of 336 plots of non-segregating lines of wheat just before harvest. A comparison of scores with actual yields by weight showed a correlation coefficient (r) of 0.67. The highest rate of coincidence between scoring and actual yield occurred in the highest yield category. The authors concluded that visual assessment of yield could be used effectively in the selection of wheat lines.

Association of Traits with Visual Selection for Yield

Ideally, a plant breeder would like to identify plant characteristics in as early a generation as possible that are likely to contribute to high economic yield under the range of climatic and management conditions likely to be encountered during the life of the crop (Wilson, 1981). A group of characteristics would then be used to identify the crop ideotype (Donald, 1968).

Improving one trait, such as grain yield, by selection for other related traits is a form of indirect selection. Most often the suggested criteria for indirect selection for yield have been yield components or harvest index or a combination of the two (McVetty et al., 1980). Many research studies have implied strong associations between individual components of yield and yield itself. Austenson and Wilson (1970) and Hsu and Walton (1971) considered number of spikes per plant as the most important determinant of single plant yield in spring wheat. Pinthus (1968) and Rawson (1970) found spikelet number to be crucial. Selection for high kernel weight has been implicated as a means of increasing overall grain yield by Lebsock and Amaya (1969), Knott and Talukdar (1971), and Sidwell et al. (1971).

However, yield components have not been used extensively as selection criteria by plant breeders. According to Frey (1971), this is because (1) the relationship between yield and yield components is often nonlinear; (2) the environment affects the relationship between yield and yield components; and (3) collection of yield component data appears no easier nor less expensive than collecting yield data itself. In addition, yield components have frequently shown compensating effects and negative inter-correlations, making it difficult to establish potential breeding values for any one individual component (McNeal et al., 1978).

Several investigators have found significant correlations between harvest index and yield. Syme (1972) found that the harvest index of potted plants in the greenhouse accounted for 71.7% of the yield variability of the Fifth International Spring Wheat Yield Nursery. Fischer and Kertesz (1976) reported the superiority of harvest index over individual plant yield as a predictor of yield trial results in spring wheat. Nass (1973) concluded that spikes per plant, individual plant yield, and harvest index considered together would effectively lead to higher yielding plant types.

Donald and Hamblin's (1976) review paper on biological yield and harvest index stated that "the lack of interest by plant breeders and many agronomists in biological yield has seriously limited the understanding of cereal performance and biotype behavior." It was recommended that harvest index be combined with cultivars having high biological yield to increase total grain yield. Using that idea as a point of departure, McVetty and Evans (1980) reported that a combined index selection procedure utilizing biological yield, harvest index, and height may be useful in increasing yield in spring wheat.

Considering more visually assessable plant traits, Frey (1962) pointed out that the selection index most used by plant breeders was a "mental picture" derived from experience. He noted that many plant characteristics may be used, not all of which are associated with high productivity. Watson et al. (1958) concluded that grain yield in cereals was mainly determined by photosynthesis in the flag leaf and head after head emergence. Quinlan and Sagar (1965) also observed the importance of the head and flag leaf in providing assimilates for grain formation in wheat. McNeal and Berg (1977) evaluated five spring wheat crosses over a six-year period and concluded that flag leaf area alone was not a good index of plant performance, but rather that head and awn characteristics, in addition to flag leaf sheath and other leaf areas, ought to be considered.

Nass (1973) found that the morphological characters leaf area, flag leaf width, and total photosynthetic area above the flag leaf node were correlated significantly with yield per spike. Similarly, Simpson (1968) reported a significant correlation between grain weight per plant, flag leaf area, and total photosynthetic area above the flag leaf node. Walton (1969) found a significant positive correlation of 0.76 between peduncle extrusion length and grain yield. In a later study by Walton (1971), the second largest factor in explaining yield in a factor analysis included peduncle extrusion length, flag leaf length, flag leaf width, and flag leaf area.

Ledent and Moss (1979) investigated the relationship of thirty-seven morphological characters with shoot yield for four winter wheat cultivars in Belgium and two spring wheat cultivars in Minnesota. The characters most closely related to grain yield per shoot were kernel number, awn dry weight, sheath and stem dry weight, and leaf dry weights. The number of spikelets was also closely related to yield, whereas leaf length and width characters, extrusion heights, and leaf angles were all poorly correlated with yield per shoot.

Briggs and Aytenfisu (1980) noted that investigations of morphological characters and their relation to yield were lacking in seeding rate and seeding date information. They found that morphological characters showed as many interaction effects among genotypes, dates and rates of seeding as yield components. The most consistent general relationship across genotypes was a negative one between yield and peduncle extrusion length. They recommended selection for short peduncle length, long heads, and large flag leaf laminae and sheaths in breeding for increased grain yield.

The relations of morphological characters to yield in high yield conditions were recently considered by Ledent (1982). Included in the study were leaf area, leaf dry weight, leaf area duration, maximum width of the upper two laminae, peduncle length, and other traits. It was concluded that yield per shoot but not yield per unit area was related to plant morphology.

In summary, for grain yield and other complexly inherited traits, the identification of individual plant characteristics which may be associated consistently with a high level of expression for the complex trait has not been accomplished. Yet the above investigations suggest several plant morphological characters that may be of interest to the plant breeder in the process of visual selection. Several studies reviewed in this investigation with regard to selector effectiveness in visual selection for yield also examined the relationship of plant characteristics to selector decisions.

McKenzie and Lambert (1961) reported that the 'good' selections were slightly but significantly taller and later in the progeny of two barley crosses than the selections designated as 'poor' in potential yield. Atkins (1953), in an earlier study with barley, however, did not find any significant differences in height or maturity due to selection pressures. Similarly, Frey (1962), in a study with oats, found mean test weight, heading dates, and plant height to be uniform among 'good,' 'random,' and 'poor' groups, implying that "F_2 plant phenotype desirability was not related to these characteristics." Stuthman and Steidl (1976) reported that all increases in oat yield in selected versus random groups were accompanied by significantly later maturity. Correspondingly, every decrease in yield from random was accompanied by earlier maturity. Correlated responses in other traits when selecting for yield were considered biases by the authors, but not large enough biases to be of serious disadvantage in selection.

Mann (1975), in his study with winter wheat, noted from the high rate of selector concurrence, that selection certainly was not at random, despite the fact that failure to select better than random made it appear so. He concluded that morphological characteristics of the plots were influencing visual selection, but offered no specific examples as he had only measured plant height, which was insignificantly related to selection.

Hanson et al. (1962) found that the visual concept of seed yield in soybeans was influenced by number of pods, maturity, lodging, and height, and that individual selectors were affected differently. In that investigation, maturity and seed yield had a phenotypic correlation of +.51, and yet maturity was a major factor in only one selector's scoring for yield. Of traits less related to yield, plant height influenced two of three selectors, and lodging was found to be the most important bias factor in selection. Extreme lodging accounted for much of the missclassification of the 35 plots which all observers placed in the lowest yielding 60% of all plots, but were actually in the highest yielding 20%.

Kwon and Torrie (1964), also working with soybeans, found that the correlations of yield scores with height, lodging, and maturity were usually larger than those correlations between each trait and actual yield. They also used the difference between the trait-yield correlation coefficient and the trait-score correlation coefficient as a measure of selector bias. A large difference would indicate that the selector was not using the trait in a way appropriate to the trait's actual correlation with yield. This approach pointed to maturity as a greater source of bias than height or lodging. In general, Kwon and Torrie (1964) found that plots high in yield and correctly classified were taller, later, and more lodged, whereas plots low in yield and correctly classified were shorter, earlier, and more resistant to lodging than their respective misclassified counterparts.

Wilcox and Schabaugh (1980) reported that tall, later maturing soybean plants appeared to the selector as phenotypically superior, but in fact were not superior to unselected plots. It was noted that maturity and plant height were positively associated in soybeans, and so a tendency to classify either taller or later plants as superior could result in a change in both directions.

In summary, Frey's (1962) statement concerning selectors' biased use of plant characteristics in visual selection is supported by the above investigations, with selectors most often biased for later maturing plant types. Lodging and plant height also were frequently cited as factors biasing selectors' efficiency in choosing high yielding plots. However, disagreement existed across crop species and across studies on the same crop species as to the significance of various bias factors' effect on success in visual selection.

MATERIALS AND METHODS

Materials

The material selected for use in this study consisted of 50 diverse genotypes. With the exceptions of the cultivars 'Yamhill', 'Stephens', 'Maris Hobbit', 'Nugaines', 'Druchamp', and 'Lewjain', and a single selection from the Western Regional Soft White Winter Wheat Performance Nursery, all selections were from advanced generations of the Oregon State University (OSU) cereal breeding program. The majority of the lines used were the result of three-way and more complex crosses between winter and spring types. Pedigrees and selection numbers used in the OSU cereal breeding program and means for selected traits are listed in Appendix Table 1. All lines selected were subjected to prior yield testing in winter environments in Corvallis, Moro, and Pendleton, Oregon.

An effort was made to include the widest possible range of expression of phenotypic characters, such as height, spike length, awnedness, tillering, and leaf dimensions. Appendix Table 1 shows the line means averaged over three replications for several traits, demonstrating the phenotypic diversity present in the experimental population.

Experimental Plots

All 50 lines were grown in a randomized block design with three replications at Hyslop Agronomy Farm, located eleven kilometers northeast of Corvallis, Oregon. The soil type is a Woodburn silt loam. A single replication consisted of one plot of each of the 50 lines. Each plot consisted of two rows, five meters in length, with spacings of 30 cm between rows. Plots were seeded at the rate of 120 kg/ha.

The date of planting was October 24, 1981, and the experiment was harvested on August 9, 1982. Precipitation during the 1981-82 growing season was 1376 mm, 719 mm of which was received during the winter months. The lowest average minimum daily temperature for a month was 0.4°C in January, whereas the highest average maximum daily temperature was 24.4°C in July. Details of all monthly temperature and precipitation data are presented in Appendix Table 2.

Nitrogen fertilizer as urea (46-0-0) was applied to the experimental area in three split applications: 33 kg/ha at planting time, 56 kg/ha at tillering stage, and 56 kg/ha at early jointing stage. A week prior to planting, the soil was fumigated with a mixture of methyl bromide (66%) and chloropicrin (34%) at the rate of 420 kg/ha. This was done to control weeds and soil-borne diseases such as root rot (*Pseudocercosperella herpotrichoides*) and take-all (*Gaeumannomyces graminis* var. tritici). No other herbicides were applied as weed control from fumigation was excellent. As a precaution against possible infections by *Septoria tritici* and *Puccinia striiformis*, two applications of Tilt (.23 kg A.I./ha) were applied in the spring of 1982.

Weather conditions, the high seeding rate, and a presumed increased response to nitrogen due to soil fumigation resulted in a large number of plots showing varying degrees of lodging after heading. Lodged plots were staked and loosely tied with baling twine to prevent damage to adjacent plots.

Selection

On two dates (trials), July 20 and 21, three groups of selectors were asked to visually score each of the 150 plots for grain yield. The three groups consisted of two experienced plant breeders, eight graduate students, and eight inexperienced summer student workers, respectively, from the OSU cereal breeding program. The selectors were asked to visually evaluate each plot for grain yield on a scale of 1 to 3, with '1' representing the highest 25% of all 150 plots, '2' the middle 50%, and '3' the lowest yielding 25%. In addition, selectors were asked to further differentiate the plots for yield by circling the '1' or '3' if he/she felt that the plots were part of the highest or lowest 10% of all plots in yield, respectively. This resulted in a five-point yield scale, with scores representing the following categories:

① Top 10%
1 Next 15%
2 Middle 50%
3 Next 15%
③ Bottom 10%

The scores were analyzed on the computer as 1 through 5, respectively.

Measurements

1. The heading date for each plot was recorded as the number of days from January 1, 1982, to the date when 50% of the spikes had emerged from the flag leaf sheath.
2. Maturity date was recorded as the number of days from January 1, 1982, to the date when 50% of the spikes had lost color in their glumes and main axes.
3. Plant height was measured in centimeters from ground level to the tip of the tallest spike, excluding awns, at four random positions within each plot. The mean of these four measurements was recorded as plant height.

Twenty tillers per plot were selected randomly and formed the basis for measurements 4 through 11, each of which is the mean value of twenty measurements.

4. Flag leaf length was measured in centimeters from the base to the tip of the leaf.
5. Flag leaf width was measured in centimeters at the widest part of the leaf.
6. Peduncle extrusion length was measured in centimeters and included the length of peduncle from the auricles of the flag leaf to the base of the spike.
7. Spike length was measured in centimeters from the base to the tip of spike, excluding awns.
8. Spike width was measured in centimeters at the widest part of the spike.

9. The total number of fertile spikelets per spike was counted on each of the twenty spikes and the mean recorded as spikelets per spike.
10. The twenty spikes were threshed by hand, and the total number of kernels was counted using a Model 850-2 Old Mill Company Electronic Seed Counter. The total number of kernels was divided by twenty to obtain the measurement kernels per spike.
11. Kernels per spikelet were computed by dividing the number of kernels per spike by the number of spikelets per spike.
12. The basal florets on the spikes of several lines showed varying degrees of sterility. Each plot was scored on a scale of 1 to 3 for this characteristic, with '1' representing a moderate expression of basal sterility, and '3' representing a pronounced expression of the characteristic.
13. Lax spikes, even if present in the same numbers per plot as erect spikes, may tend to appear more numerous by virtue of their space-filling effect. Selectors might be biased in favor of plots with lax spikes; therefore, each plot was scored on a scale of 1 to 4 for spike erectness, according to the angle of deviation of the spikes from the vertical. Plots with spikes showing little or no deviation from the vertical (0-10°) were rated '1' (erect) while those plots having spikes with large deviations from the vertical (80° or more) were rated '4' (very lax). Ratings '2' and '3'

represent intermediate positions of approximately 30 and 60°, respectively.

14. The lateral spread of tillering might bias selector decisions by the degree to which horizontal space was filled in the plots. Spreading types of tillering might be favored or disfavored when contrasted with more closed, upright tillering patterns. Based on this assumption, each plot was scored according to tiller spread, or crown type, as '1' (closed), '2' (intermediate), and '3' (open).
15. There were a number of off-type plants within some plots, and no roguing was possible due to the need to measure yield. Selectors might be biased against plots with a number of off-types present, due to an uneven, ragged appearance; therefore, each plot was scored for plot uniformity on a scale of '1' (poor) to '4' (excellent).
16. The percent of lodging in each plot was noted on a scale of 0 to 100. All plots that had lodged were picked up and supported by stakes to permit evaluation and to prevent damage to adjacent plots.
17. Absence or presence of awns was noted as a possible bias factor in selection.

At the time of harvest, each plot was trimmed to 4.25 meters, to eliminate end of row border effects, and to insure that comparisons of grain yield were based on a uniform plot length. Two 0.5 meter random samples of all plant material above ground level were taken, one from each row of the plot, in order to calculate measurements 18 to 21.

18. The total number of spikes in the two 0.5 meter samples were counted and listed as spikes per linear meter.
19. Biological yield was calculated as the total weight in grams of all plant parts (excluding roots) of the two 0.5 meter samples. Weights were recorded on a Mettler PS15 electronic balance.
20. The two 0.5 meter samples were threshed in a stationary Vogel grain harvester and the grain cleaned. Harvest index was determined as the ratio of grain weight (yield) to biological yield (as calculated in 19 above).
21. 1000 kernels from the 0.5 meter samples were counted using the Model 850-2 Old Mill Company Electronic Seed Counter, and then weighed to determine 1000 kernel weight.
22. The remaining plot was harvested by hand, threshed in a stationary Vogel harvester, and the grain weighed on a Mettler PS15 electronic balance. Total plot yield was determined by combining the grain weights of all samples harvested for various measurements of agronomic traits.

Data Analysis

The three principal selector groups consisted of the two plant breeders (PB), the eight graduate students (GS), and the eight summer workers (SW). (Table 1 provides a list of nonstandard abbreviations used in this investigation.) On occasion, the subgroup "best graduate students" (BGS) was used to compare the performance of the two most effective graduate student selectors with that of the two plant breeders. A similar subgroup was not created from the eight summer worker selectors, as no two of them were distinctively more effective than the rest.

The effectiveness of selectors in using the visual yield scale of 1 to 5 was evaluated as follows:

1. Simple correlation coefficients were calculated between the visual yield scores of each individual selector and actual plot yield.

2. The scores of all selectors within each selector group were averaged, and simple correlation coefficients were calculated between average selector group scores and actual plot yield.

3. Selections made by each selector in visual yield score classes 1 and 2 were combined as high yield selections; selections in score classes 4 and 5 were combined as low yield selections. Mean yield of high and low yield selections was determined for each selector; Student's t was used to test if these means were significantly different from mean yields of random samples of plots from the experimental population.

4. Selectors were evaluated by use of chi-square goodness of fit analysis on their ability to correctly identify the highest yielding 10, 20, 30, and 45 plots. The number of these plots placed in the highest visual yield score categories (1 and 2) were

Table 1. Nonstandard abbreviations used in tables, figures and text of this investigation.

Abbreviations	Description
YLD	plot yield (grams)
spk/m	spikes per meter
K/spk	kernels per spike
1000K	weight of 1000 kernels (grams)
spklt/spk	spikelets per spike
K/spklt	kernels per spikelet
spk l	spike length (centimeters)
spk w	spike width (centimeters)
stak	staking (1 = staked; -1 = unstaked)
lodg	lodging (0 to 100%)
awn	awnedness (1 = awned; -1 = awnless)
plt ht	plant height (centimeters)
crown	crown type (1 = closed; 2 = intermediate, 3 = open)
bas st	basal sterility (1 = none/minor; 2 = moderate; 3 = pronounced)
unif	plot uniformity (1 = poor to 4 = excellent)
spk lax	spike laxity (1 = erect to 4 = very lax)
HI	harvest index
mat	physiological maturity (days from January 1, 1982)
head	heading date (days from January 1, 1982)
byld	biological yield (grams)
ped	peduncle length (centimeters)
flg l	flag leaf length (centimeters)
flg w	flag leaf width (centimeters)
PB	plant breeder selectors
GS	graduate student selectors
SW	summer worker selectors
BGS	two "best" graduate student selectors, GS3 and GS6
PB1, PB2	the two plant breeder selectors
GS1-GS8	the eight graduate student selectors
SW1-SW8	the eight summer worker selectors
PBA, GSA, SWA, and BGSA	refers to average score per plot over two trials of each selector group

compared with the number of plots expected in those categories if selection were random.

5. Selectors' ability to correctly identify the lowest yielding 45, 30, 20, and 10 plots was evaluated by chi-square analysis analagous to 4 above.

6. Selector group average visual yield scores per plot were ranked from 1 to 150. Mean yields of the highest and lowest 10, 20, 30, and 45 plots were determined for each selector group. Student's t was used to test if these means were significantly different from the mean yield of random samples from the population.

Measured traits were separated into three groups for purposes of analysis (Table 2). Group A traits were those thought to be most easily assessed visually by selectors. Group B traits were thought to be less amenable to visual discrimination, and Group C traits included only the two complex traits, biological yield and harvest index. Regressions described below were first computed using only Group A traits as independent variables. Two further regressions were computed by first adding the Group B traits to the Group A traits as independent variables, and by finally including all measured traits (Groups A, B, and C) as independent variables.

Measured traits were evaluated relative to total plot yield as follows:

1. Simple correlation coefficients were calculated between traits and plot grain yield.

Table 2. Categorization of traits according to ease of visual discrimination.

Group A Traits[+] (most visually assessable)		Group B Traits (less visually assessable)	Group C Traits (complex, least visually assessable)
spk/m	bas st	K/spk	byld
spk l	unif	1000K	HI
spk w	spk lax	spklt/spk	
stak	mat	K/spklt	
lodg	flg l	head	
awn	flg w		
plt ht	ped		
crown			

[+]Abbreviations are explained in Table 1.

2. Three stepwise multiple regressions were computed for plot yield on Group A, B, and C traits, as explained above.

3. The three regressions of number 2 above were repeated with the addition of the average visual yield score per plot of PB1 as another independent variable in each regression.

4. The three regressions of number 2 above were repeated with the addition of the average visual yield score per plot of each individual selector for a total of 18 more independent variables in each regression.

5. The three regressions of number 2 above were repeated with the addition of the average visual yield score per plot of all selector groups (PB, GS, SW, BGS) for a total of four more independent variables in each regression.

Measured traits were evaluated relative to selector scoring as follows:

1. Simple correlation coefficients were calculated between the average visual yield scores of all individual selectors, selector groups, and traits.

2. Three stepwise multiple regressions of average visual yield score per plot on Group A, B, and C traits (as described above) were computed for each individual selector and selector group.

3. Selections made by each selector in visual yield score classes 1 and 2 were combined as high yield selections; selections in score classes 4 and 5 were combined as low yield selections. Trait means of high and low yield selections of each selector were

determined. Student's t was used to test if these means were different from the trait means from random samples of plots from the population.

4. Trait means of the highest and lowest ranked 10, 20, 30, and 45 plots were computed for each selector group. Student's t was used to test for differences between these trait means, and trait means from a random sample of plots from the population.

A variety of descriptive statistical techniques was used to further evaluate the highest and lowest yielding plots and lines, plots most often placed in incorrect score categories, and the consistency of scoring of the same line in different replications. Correlation analysis was also used to evaluate the correlation of selectors' scores among themselves and the consistency of scoring from trial to trial.

Because the traits "staking" and "awnedness" were scored in only two, qualitative classes (staked-unstaked, awned-awnless), they were not included in correlation analyses. In addition, hypothesis tests involving Student's t could not be employed to test whether visually selected plots were more "awned" or "staked" than random selections of plots from the population. Instead of mean values, proportions of plots staked or awned were determined. Confidence intervals were calculated for proportions as described by Steel and Torrie (1980, pp. 559-560).

EXPERIMENTAL RESULTS

The results of this investigation are presented in two principal sections. Section I examines the effectiveness of visual selection for yield, either by using traits alone as predictors of yield, selector visual yield scores alone, or a combination of traits and scores. Included in this section is a detailed examination of selector ability to utilize the visual yield scale to discriminate yield differences among plots. Section II focuses on the scoring process itself, and includes the prediction of individual and group yield visual yield scores, comparisons of the relative importance of different traits to the scoring process, and a more detailed examination of those plots most often scored incorrectly.

Effectiveness of Visual Selection for Grain Yield

Correlations Between Yield and Selected Traits

The correlation coefficient values for grain yield and 20 traits measured on the 150 plots of the experiment are presented in Table 3. It can be seen that plot yield was significantly and positively correlated with kernels per spike, 1000 kernel weight, kernels per spikelet, spike width, spike laxity, harvest index, physiological maturity, biological yield, and flag leaf width. Plot yield was significantly and negatively correlated with lodging, basal sterility, and peduncle length. The often noted effect of

Table 3. Correlation coefficients[†] among yield and twenty traits[‡] measured on each plot.

	spk/m	K/spk	1000K	spklt/ spk	K/spklt	spk l	spk w	lodg	plt ht	crown	bas st	unif	spk lax	HI	mat	head	byld	ped	flg l	flg w
YLD	.06	.19	.26	.14	.17	.14	.41	-.23	.12	.04	-.18	.06	.26	.30	.23	.09	.61	-.25	.03	.18
spk/m		-.38	-.17	-.40	-.26	-.28	-.24	-.24	-.09	.12	.17	.11	-.03	-.31	-.04	.11	.54	.17	-.01	-.30
K/spk			-.25	.75	.81	.59	.54	-.21	-.32	.15	-.20	-.21	.29	.43	.28	.02	-.13	-.33	.01	.23
1000K				-.20	-.18	.19	.15	.03	.15	-.01	-.04	.07	.12	.09	-.11	-.15	.22	.05	.22	.13
spklt/ spk					.25	.42	.41	-.21	-.13	.00	-.15	-.19	.11	.19	.41	.31	-.13	-.29	-.09	.40
K/spklt						.51	.44	-.12	-.34	.22	-.21	-.13	.33	.48	.05	-.26	-.09	-.20	.11	-.02
spk l							.51	.04	-.14	.26	-.36	-.25	.43	.26	.06	-.18	.00	-.06	.17	.09
spk w								-.11	-.19	.10	-.18	-.03	.33	.38	.31	.04	.10	-.35	.14	.29
lodg									.39	-.19	.06	.15	.01	-.33	-.31	-.23	.15	.33	.01	-.29
plt ht										-.35	.06	.22	-.19	-.66	-.40	-.12	.49	.59	.07	-.35
crown											.02	-.10	.25	.30	.46	.27	-.06	-.27	.00	.21
bas st												.13	-.22	-.11	.65	.25	-.06	.00	-.07	.01
unif													-.41	-.19	-.13	.10	.18	.17	.08	.04
spk lax														.41	.18	-.18	.03	-.16	-.03	.03
HI															.45	.12	-.22	-.51	-.06	.34
mat																.77	-.08	-.59	-.12	.63
head																	.01	-.37	-.12	.43
byld																		.19	.10	-.19
ped																			.08	-.47
flg l																				.05

[†] r values of .16 and .21 are needed for significance at the .05 and .01 levels, respectively. N = 150.

[‡] As awnedness and staking were scored yes/no, both were omitted from correlation analysis.

Key to abbreviations

YLD	plot yield	k/spklt	kernels per spikelet	crown	crown type	mat	physiological maturity
spk/m	spikes per meter	spk l	spike length	bas st	basal sterility	head	heading date
k/spk	kernels per spike	spk w	spike width	unif	uniformity	byld	biological yield
1000K	1000 kernel weight	lodg	lodging	spk lax	spike laxity	ped	peduncle length
spklt/spk	spikelets per spikt	plt ht	plant height	HI	harvest index	flg l	flag leaf length
						flg w	flag leaf width

yield component compensation is readily seen by the negative correlations of spikes per meter with kernels per spike, 1000 kernel weight, spikelets per spike, and kernels per spikelet. Also evident from Table 3 is a substantial degree of intercorrelation among traits. These relationships will be referred to further when appropriate.

Regressions of Yield on Traits

Results from stepwise multiple regressions of grain yield on all measured traits are shown in Table 4. The most visually assessable traits constituted the independent variables of the first regression, with the two other sets of less visually discernible traits added subsequently to give three separate regression equations. Approximately 50% of the variation in yield can be accounted for by eight traits that are readily evaluated visually (R^2 = .49). The addition of traits to form the second regression (B., Table 4) accounted for another 7% of the variation in yield, while the inclusion of all 22 measured traits as independent variables (regression C.) resulted in a final coefficient of multiple determination (R^2) of .70, i.e. the final regression analysis accounted for a 70% reduction in the total variation in yield. Three of the visual traits, lodging, plant height, and peduncle length, appeared as significant variables in the results of all three regressions.

Table 4. Results from stepwise multiple regressions of yield on the twenty-two traits measured on each plot.

A. Group A* traits as independent variables	B. Group A + Group B† traits as independent variables	C. Group A + Group B + Group C‡ traits as independent variables
Yield =	Yield =	Yield =
-362.00	-1982.59	-1965.90
2.48 spk/m	3.58 spk/m	340.07 spk w
625.62 spk w	18.78 1000K	-3.73 lodg
-5.59 lodg	359.36 K/spklt	9.78 plt ht
-79.64 awn	-5.52 lodg	3660.55 HI
12.47 plt ht	-99.27 awn	1.83 byld
-59.93 bas st	14.51 plt ht	-19.87 ped
71.53 spk lax	-61.76 bas st	
-23.26 ped	58.80 spk lax	R^2 = .70
	-25.09 ped	
R^2 = .49	192.94 flg w	
	R^2 = .56	

*Group A traits:

spk/m	bas st
spk l	unif
spk w	spk lax
stak	mat
lodg	flg l
awn	flg w
plt ht	ped
crown	

†Group B traits:
K/spk
1000K
spklt/spk
K/spklt
head

‡Group C traits:
byld
HI

Correlations Between Yield and Selector Scores

The correlation coefficients (r) between all individual selector scores and yield, and between selector group scores and yield, are presented in Table 5. The corresponding coefficients of determination (r^2) are also listed. It is interesting to note that both plant breeders' (PB) scores have considerably higher individual correlation coefficients (r) than the average group correlation coefficients with yield for either the graduate students (GS) or summer workers (SW). However, the two highest correlation coefficients among the GS selectors, those of GS3 and GS6, at values of -.53 and -.49, are in the same range as the PB. The scores of these two selectors are further referred to as the "best" graduate student scores (or BGS). The remaining GS scores exhibit correlations with yield from -.04 to -.38, very similar to the SW range of -.13 to -.38. The lowest correlation between yield and individual scores was seen for GS4 (r = -.04).

The selector group correlation coefficients, obtained by correlating with yield the average of all visual yield scores over two trials within each group, were -.58, -.46, -.43, and -.57 for the PB, GS, SW, and BGS, respectively. These group correlation coefficients (r) were generally higher than any individual selector's 'r' value within that same group. This suggests that averaging all scores within selector groups may compensate for random errors by individuals in selection, or for an individual selector's personal bias for or against certain plant types. This

Table 5. Correlation coefficients and coefficients of determination resulting from the correlation between individual selector and selector group scores with actual plot yield.

	r	r^2		r	r^2		r	r^2		r	r^2
PB1†	-.56	.31	GS1	-.30	.09	SW1	-.32	.10	PBA‡	-.58	.34
PB2	-.52	.27	GS2	-.30	.09	SW2	-.13	.02	GSA	-.46	.21
			GS3	-.53	.28	SW3	-.33	.11	SWA	-.43	.18
			GS4	-.04	.00	SW4	-.38	.14	BGSA	-.57	.32
			GS5	-.34	.12	SW5	-.32	.10			
			GS6	-.49	.24	SW6	-.34	.12			
			GS7	-.28	.08	SW7	-.27	.07			
			GS8	-.38	.14	SW8	-.33	.11			

Correlation coefficients are all significant at the 1% level, with the exception of those for GS4 and SW2, which are not significantly different from 0. (N = 150)

†PB1 through SW8 represent 18 individual selector scores averaged over two trials.

‡PBA, GSA, SWA, and BGSA represent the averages of all scores of all selectors within each group over two trials.

relationship did not hold with regard to the GS selectors, because GS3 and GS6 were considerably more successful (showed higher 'r' values) than all other GS selectors.

When the simple correlation coefficient is squared, the resulting simple coefficient of determination is indicative of the proportionate reduction of the total variation in yield that the particular trait explains in a simple linear regression. It can be seen by examining these simple coefficients of determination that very little variation in plot yield was accounted for by SW and GS individual scores, with r^2 values ranging from 0 to 28%. The two PB scores accounted for a reduction of total variation in yield of 31% and 27%, respectively.

Regressions of Yield on Selector Scores

Results of regressions of grain yield on individual visual yield scores and group average visual yield scores are shown in Table 6. It is notable that the regression analysis of yield on individual selector scores accounted for a 43% reduction of the variation in yield (R^2 = .43). This is an improvement of 12% over the amount of variation in yield that can be explained by the single best selector's score, PB1. The scores of PB1 and PB2 were so closely correlated that only one set of scores, PB1's, appeared as a significant variable in the regression results of yield on all individual selectors' scores. In comparisons of the coefficients of multiple determination (R^2) obtained from regressing yield on

Table 6. Results from stepwise multiple regressions of yield on individual selector scores and selector group scores.

A. All individual selector scores averaged over two trials included as independent variables	B. All selector group scores averaged over two trials included as independent variables
Yield =	Yield =
2815.29	2644.47
-171.01 SW4	-109.47 PBA
-101.35 PB1	-113.33 BGSA
-104.26 GS3	R^2 = .36
95.34 GS4	
R^2 = .43	

Group A traits (Table 4) with the R^2 value obtained from regressing yield on individual selector scores, more of the variation in yield was accounted for (49% versus 43%) by the traits than by the selector scores. A stepwise multiple regression of yield on selector group average scores resulted in a final regression equation explaining only 36% of the variation in yield (Table 6) in contrast to the R^2 of .49 resulting from the regression of yield on the visually assessable (Group A) traits.

The effect of using traits and scores together as independent variables in regressions is demonstrated in Table 7. Selector PB1's scores were more highly correlated with yield than other selectors' scores. When PB1 visual yield scores were included in the three regression analyses of yield on traits (compare Table 7 with Table 4), the final regression R^2 values only accounted for an additional 4 to 5% of the variation in yield over that accounted for by each group of traits alone. For example, the R^2 value for the regression of yield on most visually assessable (Group A) traits was equal to .49. The addition of PB1 visual yield scores as an independent variable resulted in an R^2 value of .53.

Results of regressions of yield on combined selector scores with the three groupings of traits are also listed in Table 7. Four of the eighteen individual selector scores appeared in the results from the first regression analysis, resulting in an increase in R^2 of .10 (from .49 to .59) over that obtained from regressing yield on the Group A traits alone (see Table 4). Similarly, an

Table 7. Results from stepwise multiple regressions of yield on the twenty-two traits measured on all plots with the addition of individual selector scores as independent variables.

†Group A traits + selector PB1 scores as independent variables	Group A + Group B traits + selector PB1 scores as independent variables	Group A + Group B + Group C traits + selector PB1 scores as independent variables
Yield =	Yield =	Yield =
852.93	-600.39	461.72
2.62 spk/m	3.11 spk/m	-3.24 lodg
59.62 spk 1	22.30 1000K	8.75 plt ht
-4.37 lodg	285.80 k/spklt	-43.27 bas st
-64.81 awn	-3.97 lodg	3266.08 HI
10.05 plt ht	11.20 plt ht	-8.28 head
-78.59 bas st	-86.60 bas st	1.68 byld
-21.36 ped	-25.34 ped	-22.17 ped
-127.32 PB1	-135.99 PB1	-80.25 PB1
R^2 = .53	R^2 = .61	R^2 = .74

Group A traits + all individual selector scores as independent variables	Group A + Group B traits + all individual selector scores as independent variables	Group A + Group B + Group C traits + all individual selector scores as independent variables
Yield =	Yield =	Yield =
3737.37	1618.75	2149.65
1.33 spk/m	2.15 spk/m	2.19 spk/m
-4.25 lodg	17.62 1000K	-2.58 lodg
7.65 plt ht	304.13 k/spklt	2410.94 HI
-66.37 bas st	-3.79 lodg	-11.31 head
63.07 spk lax	7.57 plt ht	2.12 byld
-9.24 mat	-81.08 bas st	-19.43 ped
-26.57 ped	-9.76 head	-65.34 GS5
-112.20 SW4	-27.03 ped	-95.66 GS3
-83.77 PB1	-58.19 GS5	80.04 GS4
-102.23 GS3	-95.42 PB1	R^2 = .75
72.18 GS4	-94.17 GS3	
R^2 = .59	92.79 GS4	
	R^2 = .67	

†See Tables 2 and 4 for explanations of trait groupings.

increase of .11 in R^2 (from .56 to .67) occurred when all individual selector scores were combined with both Group A and Group B traits as independent variables. Table 7 also shows that when all 22 traits and all individual selector scores were combined as independent variables, the final R^2 value from stepwise multiple regression anslysis was .75, an increase of .5 over that obtained by regression of yield on the 22 traits alone. Results of combining selector group average visual yield scores instead of individual selector average scores with the three groupings of traits were similar to results cited above, and are presented in Appendix Table 3.

The regression and correlation results presented thus far have provided information regarding the overall relationship between plot grain yield and scoring. It has been demonstrated that traits that are readily assessable visually accounted for approximately 50% of the variation in plot yield. Individual selector scoring, in contrast, accounted for much less plot yield variation (from 0 to 31%). Combining all individual selector scores as independent variables in a regression analysis accounted for 43% of the variation in plot yield. However, most plant breeding programs for yield are not concerned with general measures of selector success in selecting for yield, such as the information provided by a significant correlation coefficient between a score and grain yield or a moderately predictive regression equation. Of specific interest is the fate of those lines which are the highest yielding and may eventually be released as new varieties. Therefore, it would be useful to focus in this investigation on the scoring of the highest yielding plots.

Distribution of Scores by Selector within the 1 to 5 Yield Scale

The distribution of visual yield scores for both trials by individual selector presented in Table 8 provides a clear picture of individual and group differences in the use of the 1 to 5 yield scale. Individual selector use of the scoring system varied greatly. Selector GS5 scored 26.0 plots (17.3%) per trial in the '1' category, whereas SW2 only scored 1.5 plots (1.0%) per trial as '1'. Selector GS3 scored 72.0 plots (48%) as a '2' per trial, whereas SW4 placed 118.0 plots (78.7%) per trial in the '3' score category.

Considering the selector group averages, it is evident that the plant breeders (PB) were able to use the scoring scale most effectively to separate plots into distinct yield classes. The PB placed 11.8% of the plots in the '1' category, versus 6.0% and 3.5% for the GS and SW, respectively. Similar results were seen at the low end of the yield scale, where the PB (scoring 11.7% of the plots as a '5') were less hesitant to place plots in the lowest yield score category (the percent of '5's' for the GS and SW were 3.9% and 3.2%, respectively). However, when the two highest yield categories, '1' and '2', were combined, a similarity between PB and GS scoring was apparent. Overall, the PB gave scores of '1' or '2'

Table 8. Frequency distribution of visual yield scores given to 150 plots by individual selector averaged over two trials.

	Frequency distribution of visual yield scores 1 to 5[†]				
	1	2	3	4	5
Selector					
PB1	10.5	37.5	54.0	35.0	13.0
PB2	25.0	19.5	71.0	12.5	22.0
PB mean	17.8	28.5	62.5	23.8	17.5
%	11.8	19.0	41.7	15.8	11.7
GS1	2.5	58.0	68.5	15.5	5.5
GS2	3.5	22.5	90.5	31.0	2.5
GS3	14.5	25.0	66.5	32.0	12.0
GS4	13.5	27.0	69.0	27.5	13.0
GS5	26.0	53.5	53.0	17.0	0.5
GS6	4.0	59.0	64.5	13.5	9.0
GS7	5.5	72.0	52.5	19.5	0.5
GS8	3.0	30.0	91.5	21.5	4.0
GS mean	9.1	43.4	69.5	22.2	5.9
%	6.0	28.9	46.3	14.8	3.9
SW1	2.5	27.0	85.0	32.5	3.0
SW2	1.5	9.5	107.5	29.5	2.0
SW3	4.0	17.5	77.0	41.0	10.5
SW4	6.5	17.0	118.0	8.5	0.0
SW5	13.5	29.5	76.5	25.5	5.0
SW6	3.0	13.5	101.5	29.0	3.0
SW7	5.5	25.0	74.5	31.5	13.5
SW8	6.0	50.5	63.0	29.0	1.5
SW mean	5.3	23.7	87.9	28.3	4.8
%	3.5	15.8	58.6	18.9	3.2

[†]The scoring scale ranged from 1 to 5, with '1' denoting the highest yielding plots by visual selection, '5' the lowest yielding.

to 30.8% of the plots, compared to an average of 34.9% for the GS. The SW were not as discriminating, only assigning a '1' or '2' to 19.4% of the plots. When scores at the low end of the scale were similarly combined, the PB were noted to have assigned a '4' or '5' to 27.5% of the plots, versus 18.7% for the GS and 22.1% for the SW.

In summary, the PB were approximately equally discriminating in assigning large numbers of plots to both the high and low yielding score classes. The GS assigned only a small number of plots to the highest visual yield score category, but assigned '2' values to the extent that their two highest score categories contained approximately the same number of plots on the average as the PB. Neither the GS nor the SW assigned as many plots as the PB to the lowest score categories, '4' or '5'. The distribution of SW visual yield scores was most notable by the high percentage within the middle category, '3': 58.6% of all plots.

Average Selector Visual Yield Scores of the Highest Yielding Plots

Averages of all visual yield scores given by each selector to the highest yielding 45, 30, 20, and 10 plots in both trials are presented in Table 9. The PB demonstrated by having the lowest average scores, that they assigned more high yielding plots 'correctly' to score categories '1' or '2'. The GS were second, followed by the SW, in effectively assigning high ranking plots in yield to the highest score categories. It was especially interesting to note that the average scores given to the top 45,

Table 9. Mean of all visual yield scores over two trials assigned to highest yielding 45, 30, 20, and 10 plots by each selector.

	Mean visual yield score[†]			
Selector	Highest 45	Highest 30	Highest 20	Highest 10
PB1	2.31	2.35	2.35	2.20
PB2	2.15	2.23	2.30	1.55
PB mean	2.23	2.29	2.33	1.88
GS1	2.50	2.50	2.63	2.30
GS2	2.90	2.85	2.85	2.65
GS3	2.39	2.37	2.35	1.85
GS4	3.09	3.15	3.08	2.70
GS5	2.20	2.30	2.23	2.05
GS6	2.24	2.30	2.35	1.90
GS7	2.36	2.30	2.30	2.10
GS8	2.69	2.72	2.75	2.50
GS mean	2.55	2.55	2.57	2.26
SW1	2.81	2.76	2.78	2.50
SW2	3.13	3.12	3.13	3.00
SW3	2.93	2.83	2.88	2.60
SW4	2.62	2.63	2.58	2.30
SW5	2.45	2.55	2.60	2.45
SW6	2.87	2.83	2.85	2.60
SW7	2.90	2.90	2.88	2.80
SW8	2.52	2.53	2.58	2.45
SW mean	2.78	2.77	2.79	2.59

[†]The scoring scale ranged from 1 to 5, with '1' representing the highest yielding plots by visual selection, '5' the lowest yielding. Therefore, low scores indicate effective selection of high yielding plots.

30, and 20 plots were almost identical within each group. These average scores might instead have been expected to decrease somewhat as progressively higher ranked plots were considered. However, no drop in average score occurred until the highest 10 plots in yield were considered, when a considerable dropoff in average score for each group indicated that these plots were more readily discriminated as high yielding.

Distribution of Visual Yield Scores by Selector for the Highest Yielding Plots

Appendix Tables 4 through 7 further described the scoring of the highest yielding 45, 30, 20, and 10 plots, respectively, by tabulating the number of plots placed in each of the five score categories by each selector, averaged over two trials. Again considerable variation in individual scoring was evident. From Appendix Table 5, describing the scoring of the highest yielding 30 plots, selector GS7 was observed to have 'correctly' scored 21.5 plots (71.7%) as a '1' or '2', while GS2 'correctly' scored only 7 plots (23.3%). Selector SW2 scored only 1.5 (5.0%) of the top 30 plots as a '1' or '2', while SW8 led the SW group with 14.5 (48.3%) in the '1' or '2' categories.

Despite this individual scoring variability, it is clear from examining Table 10 that the PB were consistently able to score a higher percentage of each actual high yield category (Top 45, 30, 20, and 10 plots) 'correctly' in score categories '1' or '2' than other selector groups. For example, considering the top 30 plots

Table 10. Frequency distribution of visual yield scores among the highest yielding 45, 30, 20, and 10 plots by selector group averaged over two trials.

	% plots scored '1' or '2'[†]				% plots scored '3'				% plots scored '4' or '5'			
	PB	GS	SW	BGS	PB	GS	SW	BGS	PB	GS	SW	BGS
	Selector group											
Highest yielding												
45 plots	57.8	48.7	30.6	61.7	36.7	39.8	54.2	29.4	5.6	11.3	15.2	8.9
30 plots	54.2	48.3	29.0	60.8	39.2	39.6	57.3	28.3	6.7	12.0	13.8	10.8
20 plots	56.3	48.7	28.8	60.0	38.8	38.8	56.6	28.8	5.0	12.6	14.7	11.3
10 plots	65.0	62.6	38.2	77.5	35.0	30.6	51.9	17.5	0.0	6.9	10.1	5.0

[†]The scoring scale ranged from 1 to 5, with '1' denoting the highest yielding plots by visual selection, '5' the lowest yielding. High percentages of plots scored '1' or '2' indicate effective selection.

in yield, the PB 'correctly' scored 54.2% as a '1' or '2' versus 48.3% for the GS and 29.0% for the SW. However, results in Table 10 reveal that the two best graduate student selectors (BGS) consistently placed a higher percentage of plots in visual yield score categories '1' or '2' than even the PB. This does not necessarily suggest a greater ability to recognize the highest yielding plots, but might rather imply that a different selection intensity was practiced. This was indeed the case. Selectors GS3 and GS6 (the two BGS) scored 34.2% of the plots as '1' or '2' versus 30.8% for the PB (from Table 8).

Evaluating Selector Ability to Identify High Yielding Plots

If a definitive statement is to be made about a selector's ability to identify high yielding plots, it is essential that his individual use of the visual yield scoring categories (selection intensity) be considered. Results in Table 11 indicate the ability of each individual selector to place the highest yielding 45, 30, 20, and 10 plots in score categories '1' or '2' with a frequency surpassing random selection. In this analysis, the total number of plots scored '1' or '2' (selection intensity) is taken into consideration for each selector. Thus, selector GS7 placed 30.5 plots of the highest yielding 45 in score categories '1' or '2'. Yet this was not significantly different from random expectation at the indicated probability level, since he averaged 77.5 scores of '1' or '2' (51.7%) per trial. In contrast, selector SW6 only

Table 11. Selectors' ability to score the highest yielding 45, 30, 20, and 10 plots in visual yield score categories '1' or '2' at better than random expectation.

Selector	Total number of scores of '1' or '2' per 150 plots/trial	Number of scores of '1' or '2' per highest yielding plots/trial			
		Highest yielding 45 plots	Highest yielding 30 plots	Highest yielding 20 plots	Highest yielding 10 plots
PB1	48.0	26.5**	16.5*	11.0*	5.5
PB2	44.5	25.5**	17.0**	11.5**	7.5**
GS1	60.5	25.5*	17.5	10.0	6.0
GS2	26.0	9.5	7.0	4.5	4.0
GS3	39.5	32.0**	16.0**	11.0**	7.5**
GS4	40.5	14.0	8.5	6.5	4.0
GS5	79.5	26.5	16.0	12.5	7.0
GS6	63.0	33.5**	20.5*	13.0	8.5*
GS7	77.5	30.5	21.5	14.0	8.0
GS8	33.0	14.0	9.0	6.5	5.0
SW1	29.5	16.5*	10.5	6.5	5.5*
SW2	11.0	3.0	1.5	0.5	0.5
SW3	21.5	11.5	9.0*	5.0	3.0
SW4	23.5	13.5*	8.5	6.5	5.0*
SW5	43.0	19.5*	11.5	7.5	4.5
SW6	16.5	10.0*	6.5	5.0	4.0*
SW7	30.5	13.0	7.5	5.5	2.5
SW8	56.5	23.0	14.5	9.5	5.5

*,**Significantly greater than if selection were random at .05, .01 levels of significance, respectively. Scores '1' and '2' indicated the highest yielding plots by visual selection. Significance denotes effective selection.

scored 10.0 of the highest yielding 45 plots as '1' or '2', but as he only averaged 16.5 scores of '1' or '2' per trial, this was a significant number at the 5% level of probability.

From the results of Table 11, it is reasonable to conclude that individual selectors demonstrated rather limited ability to discriminate the highest yielding plots. Only the two PB, GS3, and GS6 consistently scored more plots 'correctly' as '1' or '2' than would be expected if selection were at random (and PB1 even 'missed' at choosing a significant proportion of the 10 highest yield plots; GS6 'missed' at choosing the highest 20). Five of the eight graduate student selectors (GS) were not able to significantly choose more high yielding plots than random expectation in any category. The SW selectors were also inconsistent in selecting high yielding plots. However, four of eight SW were successful at choosing more of the top 45 plots than random expectation, and three of eight SW were similarly successful with the 10 highest yielding plots.

These negative results are somewhat deceiving in forming conclusions about selectors' ability to differentiate high yielding plots. In fact, with the exception of SW2, every selector among the highest yielding 45, 30, 20, and 10 plots was observed to score a greater number of plots as '1' or '2' than random expectation, but simply not with the success level necessary to demonstrate significance at the probability levels indicated. But the fact that no selector, other than SW2, placed less plots in the '1' or '2' category than random expectation as determined by individual selection intensity demonstrated some ability in each selector (other than SW2) to discriminate plots for high yield.

Mean Selector Visual Yield Scores of the Lowest Yielding Plots

In addition to identifying the highest yielding plots, it is also of interest in a plant breeding program to be able to identify experimental material which yields poorly, so it may be eliminated and not contribute to program inefficiency in the use of time and land. Table 12 lists the mean visual yield scores given to the lowest yielding 45, 30, 20, and 10 plots. The pattern of scoring was similar to that of the highest yielding plots. Once again, the PB made most successful use of the yield scale, as indicated by their consistently higher mean visual yield scores (more scores of '4' or '5' given). Again, the mean scores within each selector group showed little variation when one examines the lowest yielding 45 plots and proceeds downward until the lowest yielding 10 plots were scored. At this point for the PB and GS, a considerable rise in the mean visual yield score occurred, indicating greater success in 'correctly' placing the lowest yielding 10 plots in the lowest score categories.

Distribution of Scores by Selector for the Lowest Yielding Plots

Individual selector scoring of the lowest yielding plots, as presented in Appendix Tables 8 through 11, indicate the number of plots placed in each of the five visual yield score categories

Table 12. Mean of visual yield scores over two trials assigned to the lowest yielding 45, 30, 20, and 10 plots by each selector.

Selector	Mean visual yield score for lowest yielding plots†			
	Lowest 45	Lowest 30	Lowest 20	Lowest 10
PB1	3.66	3.71	3.75	4.25
PB2	3.62	3.77	3.78	4.35
PB mean	3.64	3.74	3.77	4.30
GS1	3.03	3.06	3.10	3.25
GS2	3.33	3.32	3.28	3.25
GS3	3.57	3.60	3.55	3.95
GS4	3.11	3.13	3.10	3.25
GS5	2.89	2.95	3.15	3.55
GS6	3.20	3.26	3.26	3.95
GS7	2.79	2.73	2.78	3.00
GS8	3.28	3.32	3.23	3.50
GS mean	3.15	3.17	3.18	3.46
SW1	3.28	3.34	3.33	3.40
SW2	3.31	3.27	3.18	3.30
SW3	3.51	3.56	3.35	3.40
SW4	3.08	3.11	3.10	3.20
SW5	3.10	3.10	3.05	3.35
SW6	3.27	3.23	3.28	3.40
SW7	3.44	3.47	3.23	3.25
SW8	3.14	3.15	3.05	3.20
SW mean	3.27	3.28	3.20	3.31

†The scoring scale ranged from 1 to 5, with '1' representing the highest yielding plots by visual selection, '5' the lowest yielding. Therefore, high score values indicate effective selection.

averaged over two trials. Again there was considerable variation for scoring within groups. Results in Appendix Table 9 show that selector GS7 scored 16.7% of the lowest yielding 30 plots as a '4' or '5', while GS3 placed 51.7% of the plots in the two lowest score categories. Similarly, selector SW4 scored only 11.7% of the lowest 30 plots as a '4' or '5', whereas SW3 led the SW group with 48.3% 'correctly' scored as either a '4' or '5'.

The percentage of the lowest yielding plots placed in each score category by selector group, as shown in Table 13, demonstrates that the PB selectors were consistently able to score a higher percentage of low yielding plots in score classes '4' or '5' than the other selector groups. Examining the scores given to the bottom 30 plots, the PB 'correctly' scored 58.4% as a '4' or '5' versus 33.0% for the GS and 33.1% for the SW. The two best graduate student selectors (BSG), GS3 and GS6, were not as successful as the PB in placing the lowest yielding plots in score categories '4' or '5', in contrast to their previously mentioned success in scoring high yielding plots 'correctly'.

Evaluating Selector Ability to Identify Low Yielding Plots

Table 14 (comparable to Table 11 for the highest yielding plots) reports the results of significance testing of whether individual selectors were able to place the lowest yielding 45, 30, 20, and 10 plots in score categories '4' or '5' at better than random expectation, as determined by individual selection

Table 13. Frequency distribution of visual yield scores among the lowest yielding 45, 30, 20, and 10 plots by selector group averaged over two trials.

Lowest yielding	% plots scored '1' or '2'†				% plots scored '3'				% plots scored '4' or '5'			
	PB	GS	SW	BGS	PB	GS	SW	BGS	PB	GS	SW	BGS
	Selector group											
45 plots	7.8	17.8	8.6	11.1	43.9	52.5	60.0	51.7	48.4	29.8	31.4	37.2
30 plots	6.7	19.0	9.3	10.8	35.0	48.1	57.6	48.3	58.4	33.0	33.1	40.8
20 plots	10.1	17.5	11.3	15.0	30.0	51.3	60.6	43.8	60.0	31.3	28.2	41.3
10 plots	5.0	12.8	10.6	7.5	10.0	39.4	53.1	27.5	85.0	47.6	36.3	65.0

†The scoring scale ranged from 1 to 5, with '1' denoting the highest yielding plots by visual selection, '5' the lowest yielding. High percentages of plots scored '4' or '5' indicate effective selection.

Table 14. Selectors' ability to score the lowest yielding 45, 30, 20, and 10 plots in visual yield score categories '4' or '5' at better than random expectation.

Selector	Total number of scores of '4' or '5' per 150 plots/trial	Number of scores of '4' or '5' per lowest yielding plots/trial			
		Lowest yielding 45 plots	Lowest yielding 30 plots	Lowest yielding 20 plots	Lowest yielding 10 plots
PB1	48.0	23.0**	18.5**	12.5**	8.5*
PB2	34.5	20.5**	16.5**	11.5**	8.5*
GS1	21.0	10.0	7.5	5.5	4.0
GS2	33.5	16.0	11.0	5.5	3.0
GS3	44.0	22.5**	15.5*	9.0	6.0
GS4	40.5	12.5	9.5	6.0	4.0
GS5	17.5	12.5**	10.0**	8.0**	6.0*
GS6	22.5	11.0	9.0	7.5*	7.0*
GS7	20.5	9.0	5.0	3.0	2.5
GS8	25.5	13.5*	11.5**	5.5	5.5
SW1	35.5	14.0	11.0	7.0	4.0
SW2	31.5	14.0	8.5	4.0	3.5
SW3	51.5	20.0	14.5	7.5	4.0
SW4	8.5	4.0	3.5	2.0	2.0
SW5	30.5	13.0	9.0	5.5	4.0
SW6	32.5	11.5	6.5	4.0	2.5
SW7	45.0	20.5*	15.0	7.0	4.0
SW8	30.5	16.0*	11.5*	8.0	5.0

*,**Significantly greater than if selection were random at .05, .01 levels of significance, respectively. Scores '4' and '5' indicated the lowest yielding plots by visual selection. Significance denotes effective selection.

intensities. Only PB1, PB2, and GS5 consistently scored more low yielding plots in score categories '4' or '5' than would be expected from random selection. Three of eight GS and six of eight SW were not able to identify as a '4' or '5' more low yielding plots than random expectation in any of the low yield categories (Table 14). Significance testing at the levels indicated obscures the fact that not one selector scored fewer lower yielding plots in categories '4' or '5' than would be expected at random for the lowest 45, 30, 20, or 10 plots. However, most selectors were not able to score enough plots greater than random expectation to show significance at the 5% level.

Contrasting Selector Recognition of Low versus High Yielding Plots

Selectors' abilities to place high yielding plots 'correctly' in score categories '1' or '2' and low yielding plots 'correctly' in categories '4' or '5' are contrasted in Tables 15 and 16. In Table 15, it is noted that all selectors except the SW scored more high yielding plots 'correctly' than low yielding plots. For example, the GS scored 48.7% of the highest yielding 45 plots as '1' or '2' but only placed 29.8% of the lowest yielding 45 plots in a '4' or '5' score category. The SW scored high and low yielding plots 'correctly' at approximately the same frequency, 30.7% versus 31.3%, respectively. Table 16 presents a similar picture for the highest and lowest yielding 20 plots. In this table, it can be seen that the PB showed slightly more success in scoring

Table 15. Comparison of the scoring of the highest and lowest yielding 45 plots averaged over two trials by selector group.

Selector group	Plot yield category	Number of plots in each visual yield score category†			Percentage of plots in each visual yield score category		
		1 and 2	3	4 and 5	1 and 2	3	4 and 5
PB	High 45	26.0	16.5	2.5	57.8	36.7	5.6
	Low 45	3.5	19.8	21.7	7.8	44.0	48.2
BGS	High 45	27.8	13.3	3.9	61.8	29.6	8.7
	Low 45	5.0	23.0	17.0	11.1	51.1	37.8
GS	High 45	21.9	17.9	5.2	48.7	39.8	11.6
	Low 45	8.0	23.6	13.4	17.8	52.4	29.8
SW	High 45	13.8	24.4	6.9	30.7	54.2	15.3
	Low 45	3.9	27.0	14.1	8.7	60.0	31.3

†The scoring scale ranged from 1 to 5, with '1' representing the highest yielding plots by visual selection, '5' the lowest yielding. A high percentage of high yielding plots scored '1' or '2' denotes effective selection for high yield. A high percentage of low yielding plots scored '4' or '5' indicates effective selection for low yield.

Table 16. Comparison of the scoring of the highest and lowest yielding 20 plots averaged over two trials by selector group.

Selector group	Plot yield category	Number of plots in each visual yield score category†			Percentage of plots in each visual yield score category		
		1 and 2	3	4 and 5	1 and 2	3	4 and 5
PB	High 20	11.3	7.8	0.9	56.5	39.0	4.5
	Low 20	2.1	6.0	12.0	10.5	30.0	60.0
BGS	High 20	12.0	5.8	2.2	60.0	29.0	11.0
	Low 20	3.0	8.8	8.2	15.0	44.0	41.0
GS	High 20	9.8	7.8	2.4	49.0	39.0	12.0
	Low 20	3.5	10.3	6.2	17.5	51.5	31.0
SW	High 20	5.7	11.3	3.0	28.5	56.5	15.0
	Low 20	2.2	12.1	5.7	11.0	60.5	28.5

†The scoring scale ranged from 1 to 5, with '1' representing the highest yielding plots by visual selection, '5' the lowest yielding. A high percentage of high yielding plots scored '1' or '2' denotes effective selection for high yield. A high percentage of low yielding plots scored '4' or '5' indicates effective selection for low yield.

the lowest plots 'correctly', 60.0% in categories '4' and '5' versus 56.5% for categories '1' and '2'.

Selecting High Yielding versus Eliminating Low Yielding Plots

In plant breeding programs with a primary emphasis on yield, it is essential that the experimental material with the highest yield potential not be eliminated at any stage of the program. However, the need to preserve the best material must be balanced by the necessity to progressively eliminate large numbers of progeny as homozygosity increases, for reasons of limited time, land, expense, and manageable numbers for evaluation. A graphical comparison of the number of the highest yielding 20 plots that were "selected" (scored '1' or '2') by each selector, averaged over two trials, is presented in Figure 1. Also depicted is the number of plots scored '1' or '2' by each selector that were in fact in the lower 50% of all plots in yield. Therefore, the black bars of Figure 1 indicate the number of low yielding plots that would have to be carried forward in the program, along with high yielding plots.

Selectors PB1 and PB2 are seen to have "selected" (scored '1' or '2') 11.0 and 11.5, respectively, of the highest yielding 20 plots per trial, whereas GS5, GS6, and GS7 selected 12.5, 13.0, and 14.0 plots, respectively. However, the "price to be paid" in lower yielding plots also selected were 11.5 and 9.0 for PB1 and PB2 compared to 35.0, 17.0, and 31.5 for GS5, GS6, and GS7, respectively. Thus, the one to three additional high yielding plots selected by the three GS selectors beyond those selected by the

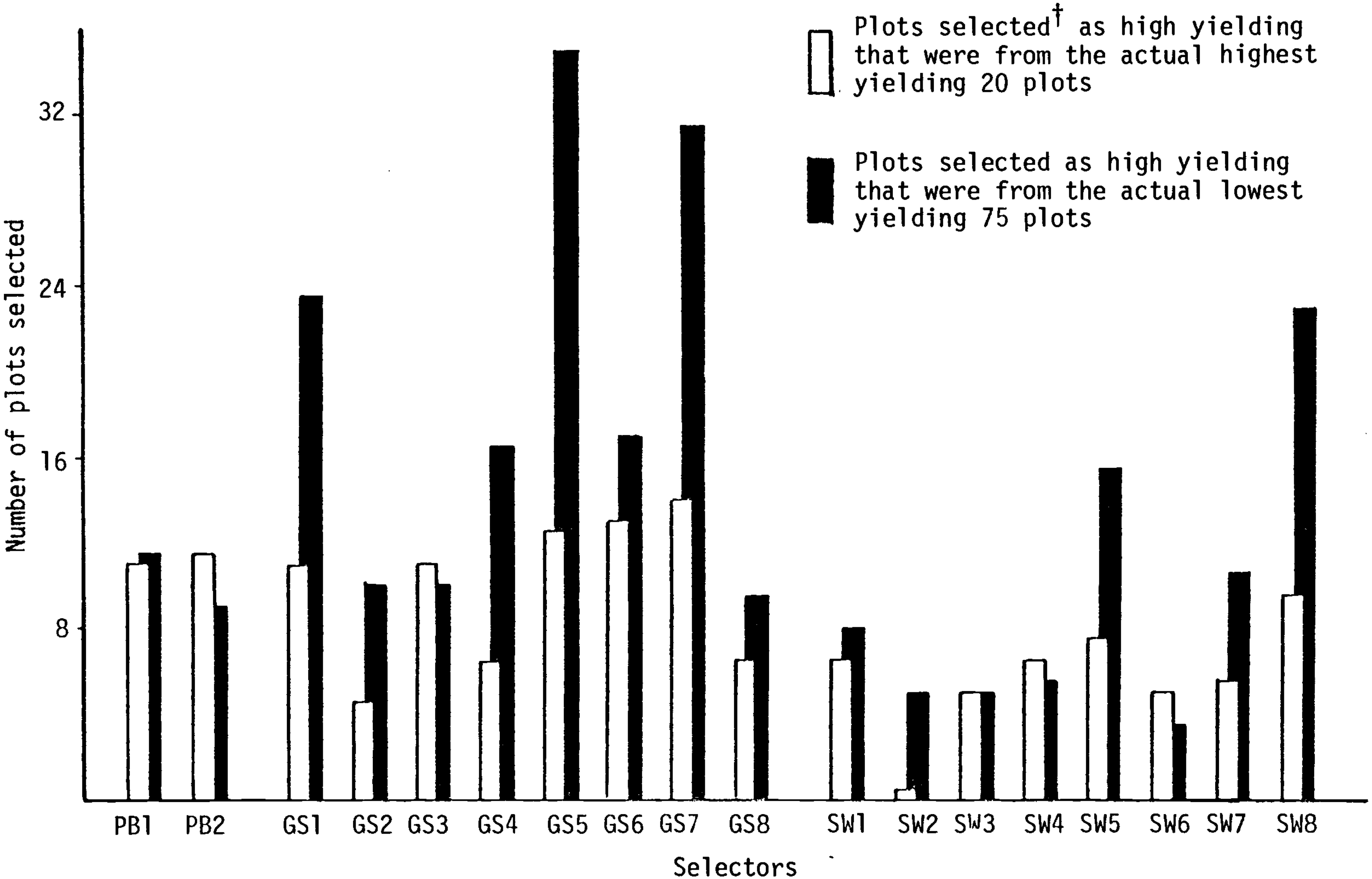

Figure 1. Comparison of the number of highest yielding twenty plots with the number of lowest yielding seventy-five plots scored '1' or '2' on the visual yield scale by each selector averaged over two trials of selection.

†A plot was considered "selected" if scored '1' or '2' on the visual yield scale of 1 to 5.

two PB would result in as many as 200% more low yielding plots than the PB selected being kept in the program.

Further examination of Figure 1 suggests an overall pattern of selection efficiency for each selector group. The two PB selectors on the average selected 11.25 of the highest yielding 20 plots and 'incorrectly' chose 10.25 low yielding plots per trial. Selector GS3, one of the two BGS, exhibited a very similar pattern of selection efficiency, averaging 11.0 'correct' and 10.0 'incorrect' choices per trial. Selector GS6 (the other BGS) averaged 13.0 'correct' selections per trial, and 17.0 low yielding choices. The remaining GS can be put into two groups, those who chose a high percentage of the top 20 plots but also chose many low yielding plots, and those GS who chose a small number of both high and low yielding plots. As examples, GS5 averaged 12.5 'correct' and 35 low yielding selections per trial, while GS2 averaged only 4.5 high selections and 10 low yielding selections. The previously noted reluctance of the SW to score plots as '1' or '2' resulted in a more consistent pattern of low numbers of the highest yielding 20 plots chosen but also low numbers of low yielding plots selected as well. One notable exception to this generalization was SW8, who averaged 9.5 'correct' selections per trial, but then also averaged 23 low yielding ones.

In summary, the overall patterns of selector efficiency in scoring the highest yielding 20 plots were (1) relatively high numbers of plots from the highest yielding 20 selected and relatively low numbers of misscores (PB1, PB2, GS3, and GS6); (2) relatively high percentage of the highest yielding 20 plots chosen but also high numbers of misscores (GS1, GS5, GS7, and SW8); and (3) relatively low to moderate number of the highest yielding 20 plots selected and low to moderate number of misscores (all remaining selectors).

Selection of Highest Yielding Plots by the Four "Best" Selectors

A typical plant breeding program would not make unrestricted use of a large number of inexperienced selectors, as in this investigation. It would, therefore, be of interest to consider the number of highest yielding 20 plots selected (scored '1' or '2') by the two PB and the two best GS (GS3 and GS6), which would more closely approximate a plant breeding situation of both experienced and moderately experienced individuals participating jointly in the selection process. The number of plots from the highest yielding 20 chosen in Trial 1 by either or both PB was 14. If the two BGS are included, 17 of the highest yielding 20 plots were chosen by at least one of the four selectors. Considering Trial 2, the results were similar. Either or both of the PB chose 16 of the highest 20 plots, and GS3 and GS6 added an additional plot to again total 17 of the highest yielding 20 plots chosen by one or more of the four selectors. However, these results were for examining the trials separately. It is a common plant breeding practice to select within the same nursery more than once in a season. And so, if both trials are considered, either one or both PB selected 16 of the highest yielding 20 plots at least once. When the two best GS (BGS) are included as selectors, 19 of the highest yielding 20 plots were selected at least once by one of the four selectors.

Thus, a complementarity in selectors' assessments of what constitutes a high yielding plot is apparent. This is also evident if instead of individual plots, the scoring of the highest yielding 20 breeding lines from the total of 50 entries (averaged over three replications) are considered, as presented in Table 17. A line scored '1' or '2' in any replication was considered "selected." Selector PB1 is seen to have not selected 2 of the highest yielding 10 lines in any replication in Trial 1, and missed 8 of the highest 20. Similarly, PB2 did not select 2 of the 10 highest yielding lines in any replication in Trial 1, nor did he select 6 of the highest 20. However, if the selections of the best graduate student selectors (BGS) are also considered, all 10 of the highest yielding 10 lines were selected in at least one replication in Trial 1, as were 18 of the highest yielding 20 lines. Considering both trials and all four selectors, only a single breeding line (line 18) of the top 20 was not selected at least once.

Regression Equations as Predictors of the Highest Yielding Plots

It is of interest to utilize the results of the stepwise

Table 17. Selection of the twenty highest yielding breeding lines by the four best selectors.

Breeding line number	Yield† ranking	Number of times selected‡							
		Trial 1				Trial 2			
		PB1	PB2	GS3	GS6	PB1	PB2	GS3	GS6
20	1	3	3	2	3	3	3	2	3
9	2	1	2	3	3	2	2	2	3
14	3	0	0	1	2	1	0	0	3
41	4	0	3	2	3	0	3	1	3
29	5	3	2	2	3	3	1	1	3
50	6	1	0	0	1	0	2	2	2
46	7	2	3	0	2	1	3	2	2
48	8	3	2	1	2	2	3	3	3
28	9	3	2	1	3	3	0	1	2
8	10	1	1	1	3	0	1	0	2
38	11	0	0	1	3	0	0	0	3
34	12	0	0	0	0	0	0	2	0
47	13	0	1	0	0	0	1	0	0
43	14	3	1	0	1	1	1	1	0
22	15	3	3	3	3	3	3	3	3
18	16	0	0	0	0	0	0	0	0
13	17	3	3	1	2	0	2	0	2
42	18	0	1	2	1	0	2	1	1
26	19	0	0	1	1	1	1	0	0
16	20	3	3	2	2	3	3	1	3

†Yield rankings were determined from the mean plot yield of three replications.

‡Visual yield scores '1' and '2' denoted the highest yielding plots by visual selection. A line was 'selected' if scored '1' or '2' in any replication.

multiple regressions to predict the highest yielding 20 plots and breeding lines, and compare the results to those cited above for the four best selectors. The predictive equation resulting from the regression of yield on visually assessable (Group A) traits alone (Table 4) was able to predict 17 of the highest yielding 20 plots and 18 of the highest 20 breeding lines (averaged over three replications). Adding individual or selector group scores to the regressions as independent variables (Table 7) gave virtually identical results. Importantly, considerably fewer plots from the lower 50% of all plots were concurrently "selected" by any of the predictive equations (from 6 to 8), in contrast to the large number of poor selections noted in Figure 1 for individual selectors.

Association of Selected Traits and Consistency of Visual Scoring for Yield

Correlations Among Selector Visual Yield Scores

The results in Table 18 present the correlations among the visual yield scores of all selectors averaged over two trials. In a similar study with fewer agronomic traits and three trained observers, Kwon and Torrie (1964) noted that the "correlations between the visual score of an observer with phenotypic (actual) yield were in all instances less than those between the visual scores of two observers." Referring to Table 5, which lists the correlations of scores with yield, this same relationship was noted among the four "best" observers, PB1, PB2, GS3, and GS6. For example, the correlation coefficient between the scores of PB1

Table 18. Correlation coefficients among the scores of eighteen selectors averaged over two trials of selection.

	PB2	GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
PB1	.73	.59	.43	.68	.25	.40	.77	.37	.65	.45	.40	.51	.39	.46	.47	.30	.61
PB2		.48	.40	.70	.32	.62	.71	.37	.62	.49	.25	.43	.46	.30	.30	.42	.55
GS1			.38	.58	.26	.28	.61	.44	.60	.43	.34	.47	.30	.20	.24	.21	.51
GS2				.40	.54	.14	.30	.37	.60	.62	.55	.73	.58	.36	.35	.42	.50
GS3					.34	.54	.61	.35	.62	.49	.30	.37	.41	.29	.30	.34	.54
GS4						.39	.27	.32	.56	.60	.58	.50	.51	.28	.30	.39	.32
GS5							.52	.26	.47	.37	.12	.14	.39	.08	.11	.27	.31
GS6								.40	.65	.41	.28	.42	.37	.45	.42	.32	.53
GS7									.39	.49	.34	.50	.31	.38	.45	.28	.17
GS8										.60	.54	.62	.56	.41	.41	.43	.56
SW1											.49	.70	.67	.42	.47	.50	.43
SW2												.59	.40	.41	.42	.28	.38
SW3													.61	.48	.47	.44	.49
SW4														.41	.44	.31	.44
SW5															.66	.26	.37
SW6																.28	.33
SW7																	.27

Correlation coefficients of .16 and .21 are required for significance at the .05 and .01 levels, respectively. N = 150.

and yield was -.56 (recall that the sign is negative because a low score indicates high yield) while the correlations of PB1's scores with PB2, GS3, and GS6 were .73, .68, and .77, respectively, all higher in absolute value than -.56. In fact, the less efficient selectors (all selectors other than the two PB and the two BGS) also had consistently higher correlations with the best selectors (the two PB and the BGS) than with yield itself. For example, less efficient selector SW8 demonstrated correlations of .61, .55, .54, and .53 with PB1, PB2, GS3, and GS6, respectively, but only showed an 'r' value of -.33 between his scores and yield. However, generally the scores of the best selectors were correlated more highly with yield than with the scores of the less efficient selectors. For example, PB2 showed a lower correlation than .52 (absolute value of the correlation between PB2's scores and yield) with 11 of the 14 less efficient selectors.

The high correlations among selector group visual yield scores, as presented in Table 19, further indicated that there was similarity in what each group, on the average, "saw" as yield. Every correlation coefficient listed is higher than that between the respective group and yield itself (Table 5).

Consistency of Selector Scoring from Replication to Replication

Having considered the correlations among selector visual yield scores, which are indicators of overall similarities of scoring among selectors, it would be of interest to examine the consistency

Table 19. Correlation coefficients among the selector group scores averaged over two trials of selection.

	GS	SW	BGS
PB	.79	.64	.85
GS		.76	.87
SW			.61

All correlation coefficients are significant at the .01 level. N = 150.

of selectors' scoring from replication to replication and from day to day (trial to trial). Table 20 examines the correlations among scores given to the same breeding lines from replication to replication (rep to rep). The PB were generally more consistent than either the SW or the GS in scoring the same line similarly from rep to rep, as evidenced by the average correlation coefficient of the PB being consistently larger than that of the GS, who in turn had consistently larger 'r' values than the SW. However, selectors GS4, GS5, GS6, SW3, and SW4 were notable in demonstrating correlation coefficients of a magnitude consistently in the same range (approximately .60) as the PB. Many individual selectors showed particularly high single correlation coefficients. For example, GS6 in Trial 2 demonstrated a correlation coefficient of .82 in scoring the same lines in rep 2 and rep 3.

At the bottom of Table 20 are listed the correlation coefficients of the actual yield of the same breeding line from replication to replication (rep to rep). It is of interest to compare these rep to rep yield correlations of the same line with the various selector rep to rep score correlations of the same lines. Considering the correlation coefficient (.37) between the yield of the same lines in rep 1 and rep 2, every single correlation coefficient of PB and GS scoring between rep 1 and rep 2 was higher in value, except for two instances (GS3, Trial 1, and GS7, Trial 2). This would suggest that the PB and the GS were biased positively and/or negatively for certain breeding lines or plant types, and

Table 20. Correlation coefficients between selector visual yield scores given to the same breeding line from replication to replication.

	Correlation coefficients for visual yield scores between replications					
	rep 1-rep 2		rep 1-rep 3		rep 2-rep 3	
Selector	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
PB1	.61	.73	.74	.77	.70	.65
PB2	.54	.66	.75	.76	.70	.74
PB mean	.58	.70	.75	.77	.70	.70
GS1	.56	.56	.62	.58	.56	.57
GS2	.48	.53	.38	.52	.49	.49
GS3	.57	.33	.49	.65	.39	.34
GS4	.64	.65	.59	.70	.46	.71
GS5	.56	.64	.65	.62	.51	.74
GS6	.53	.71	.76	.70	.65	.82
GS7	.32	.82	.51	.66	.44	.73
GS8	.47	.55	.56	.66	.46	.54
GS mean	.52	.60	.57	.64	.50	.62
SW1	.41	.50	.62	.45	.62	.22
SW2	.37	.39	.33	.33	.33	.16
SW3	.66	.48	.64	.49	.73	.61
SW4	.57	.58	.64	.65	.61	.59
SW5	.41	.31	.46	.29	.50	.42
SW6	.51	.17	.40	.30	.34	.27
SW7	.26	.14	.26	.13	.39	.34
SW8	.15	.27	.37	.50	.03	.35
SW mean	.42	.36	.47	.41	.43	.37

†Correlation coefficients of .27 and .35 are required for significance at the .05 and .01 levels, respectively (N = 150). The correlation coefficients for actual plot yield between replications (N = 50) were:

	r
rep 1-rep 2	.37
rep 1-rep 3	.66
rep 2-rep 3	.47

scored these lines more similarly than rep to rep yield correlations indicate was warranted. This same evidence for specific plant type or line bias was evident in the rep 2-rep 3 score correlations, where only four correlations among the PB and the GS (out of 20) were less than the rep 2-rep 3 yield correlation (.47). However, the rep 1-rep 3 score correlations did not as strongly support this line of reasoning. The rep 1-rep 3 line yield correlation coefficient was the highest (.66), and the PB rep to rep score correlations again surpassed that figure in both trials. However, only 5 of the 16 rep 1-rep 3 GS score correlations were greater than or equal to .66.

As for the SW, individuals within this group demonstrated these same patterns of higher rep to rep score correlations than rep to rep yield correlations. This was evident in 9 of 16 rep 1-rep 2 correlations, and 6 of 16 rep 2-rep 3 correlations. However, not a single SW rep 1-rep 3 score correlation surpasses the rep 1-rep 3 line yield correlation of .66.

Consistency of Selector Scoring from Trial to Trial

An examination of selector consistency in scoring should also include correlations between scoring of the same plot in different trials (days), as is described in Table 21. The correlation coefficients in this table are indices of reliability of scoring, whether a selector can be expected to judge the same plot with the same score in each trial. Again, the PB had the highest correlation coefficients of .78 and .83. But significantly, the BGS

Table 21. Correlation coefficients between visual yield scores given to each plot in Trial 1 and Trial 2 for each selector.

Trial 1-Trial 2 visual yield score correlation coefficients					
	r		r		r
PB1	.78	GS1	.66	SW1	.62
PB2	.83	GS2	.61	SW2	.39
PB mean	.81	GS3	.71	SW3	.65
		GS4	.66	SW4	.69
		GS5	.68	SW5	.56
		GS6	.78	SW6	.68
		GS7	.51	SW7	.36
		GS8	.71	SW8	.49
		GS mean	.67	SW mean	.55

All correlation coefficients are significant at the .01 level.
(N = 150)

(GS3 and GS6) also had high 'r' values of .71 and .78, respectively, as did GS8 (.71). The GS group, with an average "reliability" coefficient of .67, surpassed that of the SW selectors (.55).

Correlations Between Selector Visual Yield Scores and Traits

The high intercorrelation among selectors' scores previously noted, suggests that selectors were using similar visual cues in scoring plots for yield. The relatively consistent scoring of the same experimental line or variety from replication to replication, despite actual yield inconsistencies, emphasizes selectors' preferences for certain plant types. It is, therefore, of interest to consider ways of examining the contributions of different visual traits to selectors' decisions in scoring. One approach is the use of a table of correlation coefficients (r) between the average visual yield score for each selector or selector group and the measured traits (Table 22). It is interesting to note that for the PB, the correlation coefficient between scoring and yield was greater than the correlation coefficient between scoring and any single trait. Since the intent of the scoring system was to differentiate plots for yield and not select for any other trait, this was an expected result. However, only one other selector, GS3, demonstrated this same result. For all other selectors, there were usually several correlations between scoring and traits which surpassed in absolute value the correlation between scoring and grain yield.

Table 22. Correlation coefficients between individual selector visual yield scores and twenty traits and between selector group visual yield scores and twenty traits averaged over two trials of selection.

Selector	YLD	spk/m	K/spk	1000K	spklt/ spk	K/spk	spk l	spk w	lodg	plt ht	crown	bas st	unif	spk lax	HI	mat	head	byld	ped	flg l	flg w
YLD		.06	.19	.26	.14	.17	.14	.41	-.23	.12	.04	-.18	.06	.26	.30	.23	.09	.61	-.25	.03	.18
PB1	-.56	.08	-.28	-.03	-.38	-.09	-.01	-.52	.22	.01	.02	-.08	-.13	-.20	-.27	-.51	-.40	-.28	.32	.17	-.41
PB2	-.52	.04	-.19	-.17	-.28	-.05	-.16	-.43	.05	-.20	-.11	-.06	-.12	-.26	-.13	-.47	-.42	-.37	.15	.25	-.31
GS1	-.30	.02	-.16	.01	-.35	.06	.00	-.26	-.03	-.05	-.01	.03	-.18	.03	-.13	-.44	-.42	-.19	.18	.10	-.45
GS2	-.30	.32	-.41	-.24	-.40	-.26	-.56	-.52	.00	.15	-.07	.24	.05	-.32	-.38	-.29	-.06	-.07	.24	.01	-.36
GS3	-.53	-.11	-.10	-.17	-.25	.07	-.09	-.32	.05	-.19	-.08	-.04	-.15	-.10	-.06	-.41	-.40	-.44	.10	.13	-.36
GS4	-.04	.22	-.46	-.01	-.33	-.39	-.47	-.30	.09	.22	-.31	.13	.17	-.33	-.26	-.32	-.05	.06	.12	.11	-.22
GS5	-.34	-.16	.03	-.07	.04	.03	-.07	-.15	.00	-.27	-.34	-.11	-.13	-.17	.04	-.28	-.23	-.33	-.11	.19	-.09
GS6	-.49	.13	-.13	-.09	-.26	.02	.13	-.34	.27	-.05	-.15	-.10	-.12	-.10	-.26	-.58	-.48	-.20	.27	.25	-.44
GS7	-.28	.06	-.37	-.01	-.39	-.18	-.27	-.23	.28	.39	-.47	.10	.17	-.35	-.53	-.65	-.45	.03	.43	.18	-.50
GS8	-.38	.22	-.30	-.11	-.35	-.13	-.27	-.42	.12	.01	-.20	.05	-.09	-.17	-.27	-.45	-.31	-.16	.18	.20	-.35
SW1	-.32	.16	-.44	-.15	-.40	-.30	-.53	-.50	.06	.26	-.31	.17	.10	-.33	-.36	-.43	-.13	-.08	.28	.12	-.40
SW2	-.13	.21	-.43	.03	-.40	-.26	-.38	-.42	.10	.30	-.17	.21	.09	-.18	-.31	-.36	-.16	.03	.27	-.02	-.35
SW3	-.33	.30	-.52	-.10	-.50	-.34	-.53	-.57	.12	.33	-.23	.23	.14	-.38	-.50	-.48	-.20	.00	.40	.11	-.46
SW4	-.38	.11	-.27	-.21	-.14	-.29	-.55	-.50	.03	.12	-.37	.30	-.03	-.39	-.33	-.25	-.15	-.18	.16	-.04	-.23
SW5	-.32	.32	-.40	-.06	-.37	-.28	-.22	-.44	.55	.45	-.19	.08	.04	-.17	-.49	-.47	-.25	.14	.44	.14	-.41
SW6	-.34	.25	-.31	-.08	-.30	-.18	-.25	-.43	.65	.41	-.25	.11	.04	-.13	-.41	-.48	-.31	.04	.45	.09	-.49
SW7	-.27	.23	-.27	-.26	-.27	-.19	-.40	-.26	.03	-.08	-.13	.09	.12	-.32	-.11	-.27	-.09	-.17	.09	.03	-.22
SW8	-.33	.12	-.18	-.07	0.23	0.08	-.16	-.39	.04	-.03	-.01	-.01	-.33	.00	-.11	-.32	-.26	-.10	.17	.01	-.34
PBA	-.58	.06	-.25	-.11	-.35	-.07	-.10	-.51	.14	-.11	-.11	-.08	-.13	-.25	-.21	-.53	-.44	-.35	.24	.23	-.38
GSA	-.46	.11	-.33	-.12	-.39	-.13	-.27	-.44	.13	.02	-.29	.05	-.05	-.26	-.30	-.59	-.42	-.24	.23	.21	-.48
SWA	-.43	.31	-.49	-.16	-.46	-.33	-.52	-.61	.29	.30	-.28	.19	.03	-.33	-.46	-.54	-.25	-.07	.40	.09	-.51
BGSA	-.57	.01	-.13	-.14	-.28	.05	.02	-.37	.17	-.13	-.13	-.07	-.15	-.11	-.17	-.55	-.49	-.37	.20	.21	-.44

Correlation coefficients of .16 and .21 required for significance at the .05 and .01 levels, respectively. N = 150.

An examination of correlation coefficients between scoring and traits provided information about trait patterns that may be important to the selector in discriminating plots for grain yield. If all correlations between scoring and traits of a significant magnitude (such as .30 or greater) are considered, the different selector groups can be compared and contrasted. From Table 22, all groups (from selector group average visual yield scores) displayed significant scoring-trait 'r' values greater than .30 for physiological maturity, spike width, and flag leaf width. All groups except the SW showed similar high correlations for heading date, and all but the BGS did likewise for spikelets per spike. Further examination showed more distinct patterns among the groups. The PB showed significant trait-scoring correlations of this magnitude for higher biological yield. The GS demonstrates significant correlations for kernels per spike and harvest index. Uniquely among the selector groups, the SW had large and significant correlation coefficients for several spike characteristics. In addition to spikelets per spike mentioned above, the SW showed correlations above .30 with kernels per spike, kernels per spikelet, spike length, and spike laxity. The SW were also unique in showing significant negative correlations between perceived high yield (low scores) and spikes per meter, staking, plant height, and peduncle length. The BGS group demonstrated virtually an identical pattern of scoring-trait 'r' values of magnitude greater than .30 as the PB, suggesting that both groups emphasized similar visual traits in the scoring process.

An examination of individual selector visual yield score correlations with traits (Table 22) confirmed the results from selector group averages. For example, five of eight SW, only two GS and neither PB showed correlations with spike length greater in absolute value than .30. This supports results reported above that the SW selector group scoring was more strongly associated with spike characteristics than other groups. Allowing for individual variation within groups, there were no serious departures from the overall patterns noted above for selector groups.

In studying similar comparisons among scores and traits, Kwon and Torrie (1964) investigated not only the magnitude of the 'r' values between scoring and a particular trait. They also examined the magnitude of the difference between this 'score-trait r value' and the 'r' value between actual grain yield and that same trait. They suggested that if the difference between the score-trait 'r' value and the yield-trait 'r' value were large, a bias was implied on the part of the selector, since the visual trait was not being used in a way appropriate to the trait's actual relationship with yield. When this approach was used with the data of Table 22, differences greater than .30 between the score-trait 'r' and the yield-trait 'r' were found for all selector group average scores with regard to physiological maturity, and all groups but the SW for heading date. This points to maturity and heading date as possible sources of bias for selectors. By this same process of looking for large differences between the scoring-trait and yield-trait correlation coefficients, all selector groups were similarly "biased" for wide flag leaves and against long flag leaves. The SW by this approach showed "biases" for most spike characteristics, which was not true for any other group with the exception of PB and GS "biases" for spikelets per spike. The SW were also the only group to show large differences between the scoring-trait and yield-trait correlation coefficients for plant height. In summary, this "bias" approach is intuitively interesting and implies patterns of relationship between scoring and traits somewhat different from that implied by the magnitude of correlation coefficients alone. However, either approach can only suggest relationships with further analysis must confirm or refute. Correlation coefficients do not imply causations, nor with many trait intercorrelations is it possible to distinguish which visual traits may be related to the scoring process and which others may be significantly related to scoring by virtue of correlation with some other unknown factor.

Traits Associated with Plots Ranked Highest in Yield by Selectors

In this study, visual scores given to each plot by all selectors within a group were averaged over two trials to form the basis of selector group scores for the PB, GS, SW, and BGS. To construct Table 23, these group scores were then ranked from 1 to 150, and the highest ranked 45, 30, 20, and 10 plots by the ranking of each group were compared for grain yield and all 22 measured traits. Table 23 provides additional information about patterns of traits related to selector group scoring, much in agreement with the

Table 23. Comparisons of means of grain yield and 22 traits for the highest ranked 45, 30, 20, and 10 plots by selector group average visual yield score with similar values for the actual highest yielding plots at harvest.

Highest yielding and highest ranked plots	Yld	spk/m	K/spk	1000K	spklt/spk	K/spklt	spk l	spk w	stak†	lodg	awn†	plt ht
Actual high 45	2368.04**	192.00	52.01	48.15*	19.07	2.72	8.50	1.54**	.44	6.73**	.58**	119.76
PB high 45	2233.62**	187.86	52.17	47.82*	19.29	2.69	8.72	1.56**	.50	8.27	.69*	120.14
GS high 45	2177.88**	181.54	53.94*	47.98*	19.64**	2.74	9.11	1.55**	.37	7.23	.91	117.09
SW high 45	2157.64**	172.38**	56.89**	47.17	20.04**	2.84**	9.28**	1.59**	.19**	5.05**	.81	113.00**
BGS high 45	2230.11**	185.40	50.95	48.43	19.32	2.63	8.63	1.52	.50	8.66	.76	121.58
Actual high 30	2437.00**	186.93	52.76	47.71	10.05	2.77	8.61	1.55*	.43	7.87	.57**	118.07
PB high 30	2245.75**	191.59	51.79	47.82	19.16	2.69	8.83	1.58**	.50	9.66	.72	118.84
GS high 30	2255.43**	180.13	55.54**	47.88	19.87**	2.79*	9.44**	1.59**	.33	5.27**	.90	116.57
SW high 30	2144.69*	172.13**	58.52**	46.71	20.27**	2.89**	9.49**	1.62**	.19**	5.41**	.81	111.66**
BGS high 30	2263.68**	187.19	50.43	49.15**	19.11	2.63	8.63	1.54*	.50	8.06	.76	120.26
Actual high 20	2507.1**	191.15	52.19	48.34	18.72	2.77	8.76	1.56*	.45	9.10	.65	117.55
PB high 20	2263.71**	192.17	51.27	48.55	19.13	2.67	8.84	1.59**	.60	10.83	.70	118.58
GS high 20	2301.16**	185.26	52.87	48.99*	19.28	2.75	9.51**	1.60**	.40	4.58**	.95*	115.21
SW high 20	2270.00**	178.16	56.76**	47.83	19.95*	2.84**	9.81**	1.70**	.20*	5.60*	.75	110.58**
BGS high 20	2367.47**	188.79	50.15	50.44**	18.84	2.66	8.87	1.59**	.50	8.79	.75	118.16
Actual high 10	2612.90**	194.80	52.61	49.26	19.04	2.78	9.18**	1.58	.50	8.90	.70	116.40
PB high 10	2418.38**	189.00	56.81**	49.84**	19.50	2.91**	9.93**	1.76**	.40	4.87**	.60	110.13
GS high 10	2327.56**	186.33	51.78	50.03*	18.80	2.75	9.94*	1.66*	.60	6.44*	1.00**	117.78
SW high 10	2381.22**	186.44	54.04	49.31*	19.24	2.80	10.17**	1.74**	.20	4.11**	.80	109.00**
BGS high 10	2490.00**	193.00	53.39	49.42*	19.57	2.74	9.44*	1.64*	.40	2.67**	.80	116.22
Grand means (150 plots)	1992.57	187.07	50.34	46.41	18.77	2.68	8.40	1.47	.46	11.67	.82	118.17

(Continued on next page)

Table 23 (continued)

Highest yielding and highest ranked plots	Crown	bas st	unif	spk lax	HI	mat	head	byld	ped	flg l	flg w
Actual high 45	1.62	1.64	3.04	2.73	.381	185.60*	144.31	835.67**	18.13**	21.84	1.83
PB high 45	1.62	1.78	3.10	2.90**	.378	186.57**	145.74**	809.07**	18.40**	21.29	1.87
GS high 45	1.84*	1.67	3.00	2.86**	.382*	187.05**	145.02*	789.35*	18.61*	21.63	1.95**
SW high 45	1.88*	1.62	2.79	2.95**	.391**	188.19**	144.86*	761.05	17.55**	21.73	1.98**
BGS high 45	1.66	1.66	3.16	2.63	.373	186.58**	145.63**	817.66**	18.77	21.69	1.93**
Actual high 30	1.57	1.43**	2.97	2.87	.388**	185.63*	143.70	833.13**	17.88*	22.58	1.85
PB high 30	1.63	1.78	3.22	2.94**	.381	187.09**	146.06**	810.91**	18.28*	21.23*	1.88
GS high 30	2.00*	1.47**	3.07	2.93**	.383*	188.30**	145.57**	804.13**	18.15**	21.43	1.99**
SW high 30	1.91*	1.56*	2.84	2.88*	.392**	188.31**	144.97	756.66	17.29**	21.65	1.99**
BGS high 30	1.71	1.71	3.19	2.68	.377	186.90**	145.61**	826.52**	18.28*	21.56	1.96*
Actual high 20	1.55	1.25**	2.95	3.10*	.393**	186.25*	143.40	843.40**	17.67*	22.95	1.91
PB high 20	1.58	1.83	3.33*	2.88*	.383	187.46**	147.04**	818.89**	18.15*	21.29	1.89
GS high 20	2.16**	1.32**	3.16*	2.89	.384	188.89**	146.21**	819.32**	17.84**	21.05*	1.98**
SW high 20	2.05*	1.47*	3.05	3.00**	.396**	189.58**	146.00**	784.47	16.43**	21.69	2.08**
BGS high 20	1.79	1.74	3.26	2.84	.384	187.84**	145.63**	830.11**	17.33*	20.91	1.99*
Actual high 10	1.70	1.20**	2.60	3.50**	.400*	188.50**	144.90	858.70**	17.14	22.54	2.06
PB high 10	1.88	1.75	3.38	2.88	.405*	188.38*	146.63*	844.00**	15.99*	21.50	2.16*
GS high 10	2.11**	1.44**	3.00	2.89	.388*	188.56**	145.89	833.11**	17.74*	21.08	1.95
SW high 10	2.33	1.56	3.22	3.00	.401*	190.33**	147.22*	812.89*	16.23**	21.93	2.16*
BGS high 10	2.00	1.56	3.00	3.00	.389	188.78**	145.44	849.89**	17.28	20.83*	2.01**
Grand means (150 plots)	1.56	1.79	2.90	2.51	.371	183.67	143.18	753.18	19.77	22.11	1.89

*, **Significantly different from random sample of same size at .05 and .01 levels, respectively.

†Values listed for staking and awnedness represent proportions (.00 to 1.00) of plots staked or awned, not means.

correlation patterns cited above. In considering the spike characteristic of the actual highest yielding plots, none were consistently different from those of a random sample of plots from the population, with the exception of spike width, which also was prominently significant in the highest ranked plots of all groups. The SW selectors in particular, however, appear to have significantly chosen plots having the spike characteristics of increased spike length, kernels per spikelet, number of spikelets, and kernels per spike.

The highest scored plots of the SW selectors were consistently the lowest in number of spikes per meter of any selector group. Rather than implying an SW preference for few spikes per meter, this result is more likely a consequence of the negative correlations between spikes per meter and other spike characteristics, such as spike length, emphasized by the SW selector group. The GS also appear to have chosen plots as high yielding with the spike characteristics of increased spike length, spikelets per spike, and kernels per spike, but not with the same intensity (i.e. trait means were less frequently significant) as the SW. The PB showed no significantly different means for spike characteristics other than spike width until the highest yielding 10 plots were considered, at which point mean kernels per spike, kernels per spikelet, and spike length were all significantly increased over a random sample of plots. Only the SW's and GS's highest ranked plots consistently had mean spike lengths averaging more than 9 centimeters.

Turning to other traits, although the proportion of staked plots among the actual highest yielding plots was always non-significant in Table 23, the SW consistently chose more unstaked plots than was expected at random. The data for the GS also suggests this tendency, although not enough to demonstrate statistical significance. The GS and the SW chose plots significantly less lodged than random, whereas the actual highest yielding plots were only significantly different from random for the highest yielding 45 plots. In contrast, the PB and BGS only chose plots significantly less lodged than random when considering the 10 highest ranked ones.

Because of the relatively good yield performance of awnless lines in this investigation, the highest yielding plots show significantly more awnless types than a random sample from the population. The GS, however, demonstrated a preference for awned types. In fact, of the top 10 ranked plots of the GS, none were awnless. It should also be noted that other selector groups showed tendencies to select more awned types, as the proportion of awned plots selected as high yielding was consistently higher than the proportion of awned plots among the actual highest yielding plots.

In proceeding from the actual 45 highest yielding plots to the highest yielding 10 plots in Table 23, there is a gradual decrease in plant height, although no means are significantly different from a random sample of plots from the populations. However, the plots chosen by the SW were significantly shorter than random samples in all instances. Although the other selector groups generally showed a decline in plant height as the highest scored plots were approached, the data was not as striking as the SW data nor were the mean heights significantly different from random.

The SW and GS selectors also exhibited significance for plant types with more open crowns, although this characteristic was non-significant in all instances of the actual highest yielding plots. In contrast, the actual highest yielding plots did show significantly lower mean basal sterility scores than a random sample in three instances of Table 23, and yet only the GS in three instances and the SW in two instances showed significantly lower mean basal sterility than random. Rather than implying that GS and SW selectors were more conscious of basal sterility in selection, this result is more likely an artifact of the negative correlation of basal sterility with spike length (Table 3) and other spike characters favored by the SW and GS selector groups. Spike laxity was shown to be significant in the actual highest yielding 10 and 20 plots, and also appeared as a significant trait at least twice for all groups except the BGS. Physiological maturity was noted to be the trait most highly and consistently correlated with all selector scores (Table 22). In Table 23, a tendency was evident to score plots as higher yielding that were later maturing than the actual highest yielding plots. This supports correlation results that that selectors overemphasized late maturity as an indicator of high yield. Considering the four yield classes (highest ranked 45, 30, 20, and 10 plots), the PB in four instances and the other selector groups in three of four instances, all showed heading date means significantly later than random samples of plots, whereas the heading date means for the actual highest yielding plots were non-significant in all instances. Therefore, late heading date (as it was by correlation analysis) was also implicated as a "bias" in selector scoring for high yield.

The results for biological yield revealed that all groups other than the SW significantly chose plots with mean biological yield higher than random. It is likely that the SW tendency to have chosen plots with significantly shorter mean plant heights was a principal factor in the nonsignificance shown by the SW in regard to biological yield. The mean peduncle lengths of all groups and the actual highest yielding plots were significantly less than random samples in all but four instances. Mean flag leaf width increases gradually but nonsignificantly in the highest yielding plots as one proceeds from the highest yielding 45 to highest 10 plots. The PB followed this pattern closely, exhibiting a mean flag leaf width significantly different from random only for the ten highest ranked plots However, all other selector groups showed significantly greater mean flag leaf widths than random in every instance, the lone exception being the GS highest 10 plots. Similar to correlation analysis, these results implicate wider flag leaves as a bias in yield selection. Flag leaf width was strongly correlated with physiological maturity and heading date (Table 3), suggesting that the implied bias may, in fact, result from selector preference for later plant types.

In Section I, it was concluded that although selectors demonstrated a limited ability on an individual basis to discriminate the highest yielding plots, the results were somewhat deceiving because all selectors (except SW2) were able to place more plots than random expectation in the highest visual yield score categories, but simply not at the required proficiency to show significance at the stated probability levels. When the average of all scores within a selector group were utilized to determine the highest yielding plots (as in Table 23), the highest ranked 45, 30, 20, and 10 plots of every selector group showed significantly higher mean yield than a random sample in every instance. Yet, on an individual selector basis (Table 24), the mean yield of plots scored '1' or '2' by two GS and four SW selectors were not significantly higher than random samples of the same size. However, no mean yield of any selector was lower than the overall mean yield of all 150 plots, suggesting some ability of all selectors to select higher yielding plots than random selection would achieve.

Turning again to an examination of trait association with individual selector scoring, Table 24 lists the means of all traits for those plots scored '1' or '2' by each individual selector in Trial 2. Mean physiological maturity and mean spike width are significantly greater than a random sample of plots for 15 of 18 selectors, emphasizing the strong association of these traits with

Table 24. Mean grain yield and means of twenty-two traits for plots scored '1' or '2' by individual selectors in trial 2.

Selector	Trait: YLD	spk/m	K/spk	1000K	spklt/spk	K/spklt	spk l	spk w	stak†	lodg	awn†	plt ht
PB1	2180.35**	187.20	51.91	47.08	19.40*	2.67	8.33	1.56**	.47	8.67	.63*	118.10
PB2	2218.91**	186.89	52.46	47.79	19.08	2.74	8.93	1.55**	.51	11.18	.82	120.49
GS1	2088.91*	186.46	51.37	46.50	19.31*	2.67	8.56	1.52*	.48	13.08	.68*	119.27
GS2	2150.38*	176.24	55.20**	48.01	19.84*	2.78	9.85**	1.64**	.52	9.77	.81	113.81*
GS3	2195.32**	192.54	52.69	47.52	19.26	2.72	8.93*	1.52	.54	14.39	.88	122.32*
GS4	2043.88	175.55*	55.51**	46.32	19.40	2.86**	9.07**	1.53*	.20**	6.13*	1.00**	111.58**
GS5	2071.61*	193.32	49.80	46.53	18.58	2.67	8.43	1.48	.49	10.97	.93**	120.78
GS6	2174.77**	183.00	50.23	48.27**	18.96	2.65	8.36	1.52*	.41	6.67**	.66*	119.02
GS7	2078.66*	189.28	53.05**	45.99	19.25*	2.75*	8.68*	1.51*	.24**	5.67**	.80	113.81**
GS8	2078.45	174.97*	53.99*	47.66	19.57*	2.75	9.18**	1.54	.35	5.84**	.97**	115.19
SW1	2187.38**	186.69	54.58*	47.51	19.54	2.78	9.45**	1.61**	.38	12.79	.86	114.38*
SW2	2101.20	172.00	59.03*	48.12	20.18	2.92*	9.93**	1.68**	.20	8.00	.80	109.10**
SW3	2233.94**	175.94	58.04**	47.24	20.06**	2.89**	9.78**	1.68**	.29	8.53	.71	110.88**
SW4	2251.32**	179.32	54.50*	48.60	19.04	2.87**	10.07**	1.63**	.41	10.05	.95*	116.41
SW5	2035.05	173.67**	56.07**	46.45	19.87**	2.82**	8.83*	1.56*	.19**	3.12**	.74	111.16**
SW6	2244.78**	181.17	55.70**	47.44	19.51*	2.85*	9.57**	1.64**	.11**	2.22	.83	110.33**
SW7	2019.28	183.72	51.45	46.81	19.15	2.68	8.61	1.45	.44	15.89	.83	125.11*
SW8	2073.67	178.70	52.15	47.10	19.21	2.73	8.79	1.55**	.41	11.41	.74	117.41
Grand means (150 plots)	1992.57	187.07	50.34	46.41	18.77	2.68	8.40	1.47	.46	11.78	.82	118.17

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Table 24 (continued)

Selector	Crown	bas st	unif	spk lax	HI	mat	head	byld	ped	flg l	flg w
PB1	1.43	1.88	3.12	2.65	.379	186.49**	145.63**	786.43**	18.23**	21.74	1.89*
PB2	1.67	1.69	3.16	2.98**	.377	186.04**	144.78**	802.49**	19.38	21.55	1.84
GS1	1.56	1.74	3.11	2.47	.374	185.79**	144.77*	776.68	19.33	21.90	1.89**
GS2	1.67	1.48*	2.86	2.86**	.394**	186.86*	144.91	772.62	17.60**	22.18	1.98*
GS3	1.63	1.73	2.98	2.93**	.371	185.10	144.07	816.42**	19.72	22.09	1.86
GS4	1.95**	1.75	2.75	2.90**	.390**	186.98**	143.55	728.45	18.13**	21.60	1.91**
GS5	1.79*	1.83	2.99	2.62	.368	184.66	143.82	785.84**	20.43	21.82	1.79
GS6	1.69	1.87	3.00	2.67	.380*	186.25**	145.10**	782.43*	18.75	21.77	1.89**
GS7	1.92**	1.71	2.66*	2.89**	.387**	186.80**	144.94**	752.94	18.51**	21.50	1.88**
GS8	1.90*	1.58	3.03	2.58	.383*	186.97**	144.94	753.42	18.91	21.88	1.95**
SW1	1.96*	1.59	2.79	2.83*	.384*	187.24**	144.10	783.97	18.21*	21.69	1.93*
SW2	2.00	1.80	3.30	2.40	.400*	187.90*	146.30*	769.10	17.20*	22.31	1.95
SW3	1.94*	1.65	2.88	2.94*	.399**	188.12**	145.12	778.88	16.72**	22.19	2.01*
SW4	2.32**	1.27**	2.91	3.27**	.391**	187.18**	143.59	782.64	17.99**	22.26	1.89
SW5	1.70	1.74	2.79	2.76	.391**	186.72**	144.42	727.02	17.80**	21.90	1.92**
SW6	2.06**	1.39*	2.83	3.11**	.396**	188.94**	145.56	782.06	16.69**	21.85	2.02**
SW7	1.61	2.00	2.72	2.88	.356	185.67	144.00	784.94	20.20	21.97	1.91*
SW8	1.61	1.72	3.24**	2.59	.376	186.04**	144.63	759.74	18.66	22.15	1.90*
Grand means (150 plots)	1.56	1.79	2.90	2.51	.371	183.67	143.18	753.18	19.77	22.11	1.78

*,** Significantly different from random sample of the same size at .05 and .01 levels, respectively.

†Values for awnedness and staking represent proportions of plots staked or awned, not means.

selector scoring for high yield. As suggested by other results, spike characteristics figured prominently in the plots selected as highest yielding by the SW, with six of eight SW selectors showing significant means for kernels per spike and spike length. Mean kernels per spikelet score was higher than a random sample of plots for five of eight SW. In contrast, neither PB nor four GS showed significantly greater mean scores for kernels per spike, and neither PB and only one GS showed significantly greater kernels per spikelet means. For the trait spike length, five GS selector scores demonstrated significantly greater means than random.

Plant height was shown to be related to SW selection for high yield, with six of eight SW scores showing mean plant heights significantly lower than random samples of plots. Of the four GS whose selected plots showed significance for mean plant height, one was for higher plant height than random. Significantly lower lodging means than random were noted for four GS, one SW, and neither PB. Both PB selected as a '1' or '2' plots that were significantly later heading, but only three GS and no SW exhibited this tendency. Wider flag leaves were seen significantly in six GS, six SW, and one PB, which was consistent with results reported for correlation analysis. Shorter peduncle lengths were significant in the results of six SW, but only two GS and one PB.

Traits Associated with Plots Ranked Lowest in Yield by Selectors

The lowest ranked 45, 30, 20, and 10 plots of each selector group are examined in Table 25. Turning first to spike characteristics, it can be seen that significant in the lowest scored plots of all selector groups were reduced spikelets per spike and spike widths. In contrast, narrower spike width, but not fewer spikelets per spike, appeared to be significant traits in the actual lowest yielding plots. All groups except the BGS consistently chose more awned types than would be expected at random, which is consistent with the fact that there were more awned types among the actual lowest ranked plots than random samples from the population of the same size. In the actual highest yielding plots reported in Table 23, mean maturity dates were significantly later than random, and selector groups also selected later maturing plots as high yielding. Conversely, all selector groups, as shown in Table 25, significantly chose earlier heading and earlier maturing types as low yielding. However, these two traits were not shown to be significantly different from random samples from the population for the actual lowest yielding plots. Thus, selector overemphasis of heading and maturity dates as indicators of yield is further supported by these results. Similarly, mean flag leaf width was not shown to be significantly different from random for the actual lowest yielding plots in Table 25, but all of the lowest yielding plots of all selector groups had mean flag leaf widths significantly less than random.

The results stated above for the lowest ranked lines according to selector group can be confirmed in Appendix Table 12 for

Table 25. Comparisons of means of grain yield and 22 traits for the lowest ranked 45, 30, 20, and 10 plots by selector group average visual yield score with similar values for the actual lowest yielding plots at harvest.

Lowest yielding and lowest ranked plots	Yld	spk/m	K/spk	1000K	spklt/spk	K/spklt	spk l	spk w	stak†	lodg	awn†	plt ht
Actual low 45	1618.51**	185.67	47.78	45.08	18.24	2.62	8.05*	1.39**	.40	16.02	.93**	113.87
PB low 45	1759.41**	194.46	47.26*	45.71	17.61**	2.67	8.28	1.38**	.50	15.57	1.00**	115.00
GS low 45	1816.44**	190.16	46.39**	45.82	17.63**	2.65	8.09	1.41**	.51	11.38	.91*	116.93
SW low 45	1842.79**	206.91**	43.66**	45.45	17.20**	2.53**	7.70**	1.38**	.64*	20.19*	.93**	121.67
BGS low 45	1784.61**	182.98	49.38	45.95	18.23	2.70	8.55	1.41**	.45	11.88	1.00**	113.82**
Actual low 30	1558.74**	189.42	47.55	44.75	18.21	2.59	8.01	1.37**	.34	16.00	.93*	111.90*
PB low 30	1739.93**	192.00	46.06**	46.91	17.16**	2.67	8.46	1.38**	.60	17.57	1.00**	114.90
GS low 30	1785.19**	195.65	45.37**	45.99	17.29**	2.62	8.06	1.39**	.55	13.32	.97**	117.74
SW low 30	1881.29	207.50**	43.52**	45.90	17.14**	2.54**	7.78*	1.38**	.68*	20.11	.89	121.96
BGS low 30	1761.93**	187.07	47.67	46.47	17.65**	2.69	8.56	1.39**	.60	14.10	1.00**	114.13*
Actual low 20	1496.00**	182.00	48.24	45.75	18.70	2.56	8.37	1.38*	.35	21.05	.90	113.05
PB low 20	1708.89**	190.37	45.34**	48.17*	17.39**	2.59	8.83	1.37**	.65	18.32	1.00**	114.42*
GS low 20	1738.33**	189.38	45.35*	46.62	17.18**	2.63	8.29	1.38**	.65	17.29	.95*	118.52
SW low 20	1861.33	208.95**	43.48**	45.99	16.87**	2.58*	7.90	1.38**	.70*	24.67*	.90	121.91
BGS low 20	1773.57**	185.48	47.68	47.44	17.55**	2.70	8.77	1.41	.60	13.83	1.00**	115.35
Actual low 10	1416.60**	176.60	45.92	47.49	17.77	2.57	8.72	1.37	.40	23.60	1.00**	112.70
PB low 10	1730.50*	201.80	42.56**	48.98*	16.54**	2.57	8.95	1.32**	.70	19.80	1.00**	115.60
GS low 10	1736.20*	201.30	42.20**	48.37	16.33**	2.58	8.83	1.32**	.80*	20.80	1.00**	118.30
SW low 10	1690.44**	207.33	41.52**	44.44	15.96**	2.60	7.40	1.32**	.70	19.78	1.00**	120.22
BGS low 10	1613.50**	195.25	44.85*	48.66	16.88**	2.65	9.19*	1.34*	.90**	31.75	1.00**	116.00
Grand means (150 plots)	1992.57	187.07	50.34	46.41	18.77	2.68	8.40	1.47	.46	11.67	.82	118.17

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Table 25 (continued)

Lowest yielding and lowest ranked plots	Crown	bas st	unif	spk lax	HI	mat	head	byld	ped	flg l	flg w
Actual low 45	1.51	1.93	2.78	2.22*	.363	182.87	143.24	676.09**	20.24	22.32	1.74
PB low 45	1.57	1.70	2.89	2.20**	.363	179.73**	140.59**	713.11*	20.57	23.13	1.62**
GS low 45	1.47	1.71	2.89	2.24	.359*	179.84**	140.42**	717.47*	20.61	22.79	1.61**
SW low 45	1.48	2.02	2.90	2.12**	.346**	180.07**	142.10	757.52	21.00*	22.06	1.59**
BGS low 45	1.57	1.69	2.73	2.39	.369	180.67**	140.51**	700.98**	19.93	22.53	1.66*
Actual low 30	1.54	1.94	2.97	2.16*	.361	183.48	144.03	665.65**	19.98	22.80	1.79
PB low 30	1.47	1.57	3.00	2.27	.360	177.57**	138.43**	708.60**	21.05*	23.88**	1.59**
GS low 30	1.52	1.81	2.97	2.13*	.350**	178.52**	139.97**	726.65	20.72	22.82	1.56**
SW low 30	1.39	1.93	3.11	1.96**	.342**	178.29**	140.75*	773.14	21.12	22.68	1.56**
BGS low 30	1.53	1.60	2.86	2.43	.362	178.90**	139.17**	701.17**	20.19	23.14	1.60**
Actual low 20	1.45	2.00	2.90	2.20	.356	182.75	143.60	656.25**	20.18	22.79	1.78
PB low 20	1.37	1.47	2.74	2.42	.355*	176.11**	137.63**	703.53*	20.42	23.74	1.56**
GS low 20	1.19**	1.67	2.81	2.10*	.346**	176.19**	137.95**	725.38	20.98	23.08	1.50**
SW low 20	1.33	2.00	3.24	1.90**	.345**	177.24**	140.19*	772.00	21.56*	23.23	1.49**
BGS low 20	1.35	1.43*	2.78	2.52	.358	177.13**	137.35**	716.13*	20.39	23.09	1.56**
Actual low 10	1.40	2.00	2.80	2.20	.346	179.00	140.10	638.90**	20.76	24.01	1.72
PB low 10	1.10**	1.60	2.70	2.40	.341*	173.70**	136.10**	738.40	21.24*	24.71*	1.47**
GS low 10	1.00**	1.60	2.70	2.20	.337**	172.70**	135.60**	746.90	21.79*	23.82	1.42**
SW low 10	1.22	2.00	3.22	1.78	.327**	174.89**	138.22**	734.67	23.42*	23.72	1.49**
BGS low 10	1.13**	1.50	2.63	2.63	.346*	172.88**	135.13**	719.50	22.39**	24.32	1.43**
Grand means (150 plots)	1.56	1.79	2.90	2.51	.371	183.67	143.18	753.18	19.77	22.11	1.78

*, **Significantly different than random sample of same size at .05 and .01 levels, respectively.

†The values for awnedness and staking represent proportions of plots staked or awned, not means.

individual selectors' plots scored '4' or '5' in Trial 2. However, two traits in particular showed a different relationship to individual selector scoring than plots selected by group average implied. From group rankings, the significant of spike length among the lowest ranked plots was not prominent. However, in Appendix Table 12, there were five GS and four SW whose choices of plots showed mean spike lengths significantly different from random samples of plots. The four SW were selecting shorter spike lengths as lower yielding, while two of the five GS actually exhibited longer mean spike lengths than random in their selected low yielding plots. Heading date was the other trait significantly associated with lower yielding plots that could be interpreted differently when examining individually selected plots rather than those ranked by group average. Although results reported in Table 25 demonstrated that the lowest yielding plots chosen by the average of all SW scores were consistently earlier heading than random, only one individual SW was shown in Appendix Table 12 to have scored as '4' or '5' plots with a mean heading date significantly earlier than a random sample of plots.

Regressions of Selector Visual Yield Scores on Traits

The results discussed thus far do not furnish information concerning the total amount of variation in scoring associated with the use of traits as independent variables. This was accomplished by the use of stepwise multiple regression analysis. Results of the regressions of each of the average selector group scores on Group A traits (those that were judged most visually assessable) together with the corresponding coefficients of multiple determination (R^2) are presented in Table 26. The 'R^2' values measure the proportionate reduction of total variation in scoring associated with the use of the specified set of traits as independent variables in each regression. In addition to the 'R^2' values in Table 26 are the coefficients of simple determination (r^2) obtained from regression of the same scores on yield itself as the sole independent variable. It can be seen in every instance that much more reduction of the variation in selector group scoring was associated with the use of traits to describe scoring (R^2) than when yield alone accounted for variation in scoring (r^2). For example, 18% ($r^2 = .18$) of the total variation of SW scoring was associated with the use of yield as the sole independent variable, while 63% ($R^2 = .63$) of the variation in SW scoring was associated with the use of the visual traits of Group A as independent variables.

Table 27 lists the results from the stepwise multinle regressions of each individual selector's scores on the same most visually assessable (Group A) traits as was reported for group scores in Table 26. 'R^2' and 'r^2' values are also listed as explained above. The greater proportion of reduction of variation in scoring attributable to 'R^2' versus 'r^2' values was even more striking when regressions of individual selector scores were examined. The 'r^2' values obtained from regressions of individual GS scores on yield

Table 26. Results from stepwise multiple regression of selector group visual yield scores averaged over two trials on visually assessable (Group A) traits.

PBA =	GSA =	SWA =
27.626	17.307	11.498
-2.270 spk w	-1.117 spk w	-.146 spk l
- .006 lodg	- .082 stak	-.846 spk w
- .031 plt ht	- .172 awn	.004 lodg
.262 crown	- .013 plt ht	-.076 unif
- .279 unif	- .058 mat	-.032 mat
- .277 spk lax	- .372 flg w	
- .096 mat		
.050 flg l		
†R^2 = .67	R^2 = .57	R^2 = .63
‡r^2 = .34	r^2 = .21	r^2 = .18

BGSA =
21.172
.104 spk l
-1.673 spk w
- .028 plt ht
- .068 mat
- .513 flg w
R^2 = .55
r^2 = .32

†R^2 = coefficient of multiple determination for regression shown.

‡r^2 = coefficient of determination for simple linear regression of selector group visual yield score on actual plot yield. Computed for comparison with R^2.

Table 27. Results from stepwise multiple regression of individual selector visual yield scores averaged over two trials on visually assessable (Group A) traits.

PB1 = 25.735 .149 spk l -2.837 spk w -.145 stak .011 lodg -.015 plt ht .277 crown -.208 unif -.239 spk lax -.095 mat †R^2 = .63 ‡r^2 = .31	PB2 = 29.316 -2.314 spk w -.044 plt ht -.269 unif -.297 spk lax .097 mat -.069 flg l R^2 = .60 r^2 = .27	GS1 = 13.616 -.126 stak .164 awn -.012 plt ht -.044 mat -.833 flg w R^2 = .38 r^2 = .09	GS2 = 10.845 .003 spk/m -.214 spk l -.694 spk w -.193 stak -.026 mat -.443 flg w R^2 = .52 r^2 = .09	GS3 = 21.547 -.006 spk/m -1.657 spk w -.034 plt ht -.050 mat -.952 flg w R^2 = .44 r^2 = .28	GS4 = 14.906 .005 spk/m -1.379 spk w -.755 awn -.126 spk lax -.055 mat R^2 = .57 r^2 = .00
GS5 = 18.698 .150 spk l -1.514 spk w -.510 awn -.038 plt ht -.260 crown -.185 unif -.164 spk lax -.054 mat .033 flg l R^2 = .57 r^2 = .12	GS6 = 21.904 .184 spk l -1.946 spk w .008 lodg -.025 plt ht -.081 mat R^2 = .57 r^2 = .24	GS7 = 11.916 -.169 crown -.162 spk lax -.043 mat -.479 flg w R^2 = .52 r^2 = .08	GS8 = 14.809 .004 spk/m -1.463 spk w -.166 awn -.013 plt ht -.134 unif -.050 mat .038 flg l R^2 = .43 r^2 = .14	SW1 = 13.122 -.210 spk l -.803 spk w -.039 mat R^2 = .46 r^2 = .10	SW2 = 9.225 -1.073 spk w -.145 awn -.095 bas st -.025 mat R^2 = .33 r^2 = .02
SW3 = 13.263 -.268 spk l -.912 spk w .160 awn -.031 mat -.479 flg w R^2 = .56 r^2 = .11	SW4 = 5.767 -.111 spk l -.850 spk w -.168 crown .098 bas st -.127 unif -.107 spk lax R^2 = .49 r^2 = .14	SW5 = 7.343 -1.561 spk w .016 lodg .137 awn .013 plt ht -.021 mat R^2 = .53 r^2 = .10	SW6 = 5.648 -.060 spk l -.903 spk w -.017 lodg -.514 flg w R^2 = .62 r^2 = .12	SW7 = 14.190 .003 spk/m -.170 spk l -.018 plt ht -.148 spk lax -.042 mat R^2 = .33 r = .07	SW8 = 11.708 -1.516 spk w -.282 unif -.319 mat R^2 = .34 r^2 = .11

†R^2 = coefficient of multiple determination for regression shown.

‡r^2 = coefficient of determination for simple linear regression of selector yield score on actual plot grain yield. Computed for comparison with R^2.

ranged from .00 to .28 with a mean of .13, while comparable figures for the SW were a range from .02 to 14 and a mean of .10. In contrast, the 'R^2' values obtained by the regression of individual GS scores on Group A traits accounted on the average for 51% of the variation in GS scoring (range of .38 to .59) while 'R^2' values for the SW ranged from .33 to .62 and accounted on the average for 46% of the variation in SW scoring. In summary, these results imply that in the process of selection for grain yield, selectors were utilizing groups of visual traits presumed to be related to yield. These groups of visual characters accounted for a much larger proportion of the variation in scoring than could be accounted for by grain yield itself, despite the fact that selectors were selecting only for grain yield and no other plot characteristic.

In comparing regression coefficients with reference to the independent variables present in the regression analysis results, it must be remembered that "one cannot interpret any one set of regression coefficients as reflecting the effects of different independent variables." (Neter and Wasserman, 1974). A particular regression coefficient reflects not an inherent particular effect but rather a partial effect in accordance with other independent variables present in the model. However, it is possible to note some general characteristics of the regression analyses which support results previously presented. As Ledent and Moss (1979) noted, stepwise regression selects the variable most closely related to the dependent variable, and then the variable which accounts for the greatest part of the remaining variation in the dependent variable. Each "step" provides some indication of the ranking, or relative importance of variables according to the order in which they are chosen to account for variation in the dependent variable.

In examining the regressions of individual visual yield scores on the most visually assessable (Group A) traits, the first variable entering the model was the one most highly correlated with the selector score. For PB1 and four of eight GS, the first variable entering the stepwise multiple regression was physiological maturity date (Appendix Table 13). The prominence of maturity in selector scoring was further emphasized by the fact that it was the second variable entering for PB2, GS4, and four SW selectors. Scoring by the SW group, as has been previously noted, was more noticeably correlated with spike characteristics than were other selector groups. For six SW, the first trait to enter the stepwise multiple regression was spike length or width, and for the remaining two, the first trait was lodging. It is striking to note that the first three traits to enter the regressions of the selector group scores of the PB and GS were identical: maturity, spike width, and plant height. The same three traits were also the first to enter for the best graduate student selectors (BGS), but in a slightly altered order: maturity, plant height, and spike width. For the SW selector group, the first three traits to enter the stepwise regressions were (in order) spike width, maturity, and spike length. In contrast, the first three visual traits to enter the regression of yield on visual (Group A) traits were spike width, awnedness, and lodging.

Considering all traits that were significant in the regression analyses of all individual selectors (Table 27), the traits appearing most often were maturity (16 of 18 selectors) and spike width (15 selectors). Plant height (both PB, four GS, two SW) and spike length (one PB, three GS, five SW) were the next most frequent traits in the regression results. Awnedness appeared in the regression results of four GS and three SW, but did not appear as a significant trait in the regression of either PB. It has been previously noted that the awnless types in this investigation were high yielding relative to the mean performance of all lines. This is also reflected by the negative value of the regression coefficient for awnedness in the regression of grain yield on visual (Group A) traits (Table 4). However, the regression coefficients of awnedness for selectors GS4, GS5, GS8, and SW2 (Table 27) indicated a positive relationship between selection for high yield and awnedness, further emphasizing the previously noted preference or bias for awned types demonstrated by certain selectors.

The addition of less visually assessable traits (Group B and Group C) to the regressions of individual and selector group visual yield scores on Group A traits did not enhance significantly the reduction of total variation in scoring as represented by the coefficient of multiple determination, 'R^2'. For both PB, 'R^2' values increased by 5.0% each and for the GS, 'R^2' values increased by an average of 3.6% when all measured traits were included as independent variables. For the SW, the average increase in 'R^2' values was only 1.5% Because of the lack of appreciable increase in 'R^2' when all traits were included in the regression model and because of the inherent difficulty of interpreting the association with visual yield scores of traits not readily discernible visually, stepwise multiple regressions of scores on these traits will not be discussed, but are presented in Appendix Tables 14 through 17.

Trait Association in the Most Frequently Misscored Plots

A final approach to the examination of traits associated with the process of visual scoring for yield is to focus specifically on those plots which were misscored. Table 28 lists the standardized traits of those low yielding plots which were most often misscored as being in the highest yielding 25% of all plots. Each trait variate shown was 'standardized' by subtracting it from the overall trait mean and dividing by the corresponding standard deviation. The actual yield rankings of the misscored plots among all 150 plots of the experiment, and their rankings by virtue of the average visual yield scores of the PB, GS, and SW selector groups, are listed in the last four columns of Table 28.

What trait characteristics do these low yielding plots have in common that may furnish clues to selector mistakes in scoring? The standardized traits demonstrate a number of consistencies with data already presented. The low yielding plots misscored as high yielding

Table 28. Standardized traits,† ranking by actual grain yield and ranking by selector group visual yield scores averaged over two selection trials of the five low yielding plots most frequently misscored as high yielding.

Plot number	Standardized traits											
	YLD	spk/m	K/spk	1000K	spklt/spk	K/spklt	spk l	spk w	lodg	plt ht	crown	bas st
1	-1.46	-1.95	1.42	-.16	2.32	.07	.77	-.72	-.44	-.66	.56	1.53
22	-.01	-.48	.43	1.37	-.28	.94	1.47	1.44	.42	-.34	1.84	.27
80	-.13	-1.69	1.33	-.96	1.48	.60	.54	-.33	-.59	-.17	-.72	-.99
96	-.41	-.75	1.26	-2.71	.26	1.63	2.01	1.77	1.95	-.74	.56	-.99
116	-.42	-.78	.33	-.25	.75	-.15	2.09	2.68	-.59	-.50	1.84	-.99

Plot number	Standardized traits									Rank scale‡: 1-150			
	unif	spk lax	HI	mat	head	byld	ped	flg l	flg w	YLDRNK	PB	GS	SW
1	-.96	-.55	.63	.56	1.10	-2.03	-.98	-.34	.57	141	118	34	23
22	.11	.52	.85	1.22	.72	.04	-1.11	.00	1.07	77	6	3	4
80	.11	.52	.50	.56	1.10	-1.00	-.33	.16	.60	84	19	22	30
96	.11	1.59	.85	1.22	-.79	-.98	-.67	.97	1.14	94	64	25	18
116	.11	.52	-.43	1.22	1.67	-.45	.03	.63	-.30	97	16	16	7

†Each trait variate was subtacted from the corresponding overall trait mean and divided by its standard deviation.

‡The 150 plots of the experiment were ranked by actual grain yield at harvest (YLDRNK), and by the mean of all visual yield scores within each selector group (PB, GS, SW).

were all shorter, later in maturity, had longer spikes and more kernels per spike than the mean of the population (Table 28). Four of the five plots showed more spikelets per spike and kernels per spikelet than the population mean. These are factors which might contribute to high yield and would support a selector decision to score the plot accordingly. However, results in Table 28 also demonstrated that all five plots had considerably fewer number of spikes per meter than the population mean, a trait which is discernible visually and would contribute to low yield. In addition, four of five plots had a lower 1000 kernel weight than the population mean, which would lead to low yield, but is difficult to assess visually. Four of the misscored plots also had wider flag leaves and later heading dates than the population mean.

Results of both regression and correlation analyses, and examinations of trait means of visually selected plots showed that certain patterns of traits were consistently associated with selector scoring. Selectors chose later maturing and wider flag-leafed plant types as high yielding to a degree inconsistent with the actual relationship of these traits to yield. Similar associations or "biases" were noted for entries having long spikes, later heading dates, and shorter height. The plot entries listed in Table 28 were characterized by many of these suggested "biases." Therefore, it is not surprising that they were incorrectly scored as high yielding

The eight high yielding plots most frequently misscored as low yielding are listed in Table 29. It is noteworthy that seven of the eight plots were taller than the population mean, had longer, narrower flag leaves, and less spikelets per spike. In addition, six of the selected plots were earlier heading and five plots were earlier maturing than the respective population means. All of these traits have been suggested as possible "bias" factors contributing more to a lower visual score than the actual relationship of the trait with yield would infer. It is also notable that six of the selected plots showed higher than average 1000 kernel weight, a trait important to yield not readily discernible visually.

Plot 118 (Table 29) is worthy of individual consideration as the most often misscored of 150 plots. Although it was the twelfth highest yielding plot overall, it was ranked 148th, 146th, and 133rd by the PB, GS, and SW selector group average yield scores, respectively. As reported above, selectors had consistently scored as lower yielding, plots that were earlier maturing, earlier heading and with narrower flag leaves, the standardized traits of which for plot 118 were -2.12, -1.55, and -1.40, respectively. The prominent expression of these "bias" factors possibly obscured traits for plot 118, which selectors would recognize as contributing to high yield: a high 1000 kernel weight and high number of spikes per meter.

Table 29. Standardized traits,† ranking by actual grain yield, and ranking by selector group visual yield scores averaged over two selection trials of the eight high yielding plots most frequently misscored as low yielding.

Plot number	Standardized traits											
	YLD	spk/m	K/spk	1000K	spklt/spk	K/spklt	spk l	spk w	lodg	plt ht	crown	bas st
64	1.59	-.81	1.11	.57	-.04	1.76	.31	1.05	-.34	-.66	.56	-.99
82	.85	1.65	-1.30	-.55	-1.60	-.62	-1.16	-.98	-.34	1.19	-.72	.27
100	1.63	1.41	.28	-1.33	-.09	.51	.15	-.85	-.59	.79	.56	-.99
108	.91	-.36	-.63	.23	-.28	-.71	-1.16	-.72	-.34	1.11	-.72	1.53
118	1.34	.72	-1.00	1.58	-.97	-.72	1.08	.26	-.09	.15	-.72	-.99
134	1.53	.27	.90	.82	1.29	.19	1.78	1.31	1.95	1.27	-.72	-.99
76	1.33	1.47	-.62	.02	-1.56	.57	-1.01	.00	2.96	1.19	-.72	.27
103	.95	-.96	.65	.80	-.53	1.60	1.24	.20	.93	.06	-.72	-.99

Plot number	Standardized traits									Rank scale‡: 1-150			
	unif	spk lax	HI	mat	head	byld	ped	flg l	flg w	YLDRNK	PB	GS	SW
64	-2.02	1.59	2.08	.56	-.03	.44	-1.61	1.69	-.10	7	80	100	72
82	.11	-1.62	-1.47	-1.95	-1.17	1.95	1.37	.91	-1.27	31	98	134	125
100	-2.02	1.59	-.24	.39	.91	1.47	1.50	.28	-1.26	6	64	74	111
108	1.17	-1.62	-.22	-.61	.72	.13	-.41	-2.22	-.86	27	99	131	137
118	1.17	-.55	.06	-2.12	-1.55	.99	-.10	.91	-1.40	12	148	146	133
134	-2.02	1.59	-.27	.05	-.60	1.22	1.08	.28	.40	8	80	75	98
76	1.17	-.55	-.49	-1.45	-1.17	1.53	1.99	1.03	-1.93	13	49	90	112
103	.11	-.55	.28	-1.62	-2.11	.44	1.18	1.63	-1.20	23	125	100	120

†Each trait variate was subtracted from the corresponding overall trait mean and divided by its standard deviation.

‡The 150 plots of the experiment were ranked from 1 to 150 by actual grain yield at harvest (YLDRNK), and by the mean of all visual yield scores within each selector group (PB, GS, SW).

DISCUSSION

In large breeding programs for self-pollinated crops, it is necessary to reduce the number of selections made from early generation populations to a size facilitating intensive evaluation. In programs involving the pedigree method, much of this reduction is accomplished through visual evaluation. Visual selection has been shown to be effective for more simply inherited plant characteristics such as height, maturity, and certain disease resistance patterns. However, a primary task of the plant breeder is, and will continue, to be the creation of higher yielding genotypes. The literature reviewed in this investigation has demonstrated that the effectiveness of visual selection for yield has ranged from worse than random selection (Mann, 1975) to moderately successful (Salmon and Larter, 1978).

Selection for yield in the generations preceding yield trials is the plant breeder's dilemna. Reliable predictive selection criteria could hasten evaluation of new breeding lines. However, quantitative characters such as yield are difficult to evaluate, particularly because of high levels of heterozygosity in early generations and the involvement of large numbers of major and minor genes. The effectiveness of visual evaluation for yield in those generations preceding intensive yield testing depends on the plant breeder's ability to distinguish differences among genotypes and the persistence of those genotypes in later generations. Many earlier studies reporting failure of visual selection did not effectively test selectors' abilities to select high yielding lines and individual plants, since yield measurements were often not taken the same year as selection. By instead measuring the yield of lines derived from, for example, visually selected individual F_2 plants, these studies were really testing the proposition that perceived yield differences in spaced planted populations persist in advanced generations (solid-seeded if carried through to yield trials). Even if selectors in an F_2 nursery are able to visually select the highest yielding plants (Boyce et al., 1947; McGinnis and Shebeski, 1973), those differences are unlikely to persist due to the confounding effects of dominant and epistatic gene action, and the inability to measure genotype by environment interactions. Also, yield differences among genotypes are influenced by spacing/competitive effects.

With these considerations in mind, a breeding program utilizing the pedigree method must grow large enough early generation populations to have a reasonable chance of obtaining the desired segregates from a cross. If one assumes that the heterozygotes in the earliest generations are not reliable guides to the yield of lines which may be derived from them, selection should be more effective as homozygosity increases. Therefore, selection for yield itself is often formally delayed as many as five or six generations. Yet within all generations in the pedigree method, the breeder is at least indirectly selecting for yield by selecting for certain simply inherited traits (such as disease resistance or height), and by a largely subjective process of choosing plants of "overall agronomic worth." As Frey (1962) has pointed out, this involves a number of biases against effective selection for yield, since some of the plant characteristics comprising a selector's unique mental picture of "overall agronomic worth" may be positively, negatively, or insignificantly associated with actual high yield potential.

As homozygosity increases in the F_4 generation and beyond, the plant breeder may bypass certain families and select within others because of subjective, biased selection criteria. It is in those generations (F_5, F_6) immediately preceding the first preliminary yield trials that the results of this study are most applicable. The presence of greater homozygosity diminishes the confounding effects of heterozygosis noted above. Yield differences are more likely to persist in subsequent generations. Frey's (1962) investigation confirmed that yield improvement prior to yield trials was relatively effective by visual selection among F_5 oat progeny rows but ineffective among F_2 individual plants. However, if selectors within F_4 or F_5 progeny rows are using inappropriate visual cues in yield discrimination, it is likely that certain lines with high yield potential would not be selected for yield trial testing because of subjectively inferior phenotypic appearances.

This investigation, although employing cultivars and experimental lines from more advanced generations, provided significant information regarding the ability of different selector groups to discriminate high and low yielding plots, and investigated the association of various traits with the process of visual selection.

Effectiveness of Visual Selection for Yield

The results for visual selector effectiveness reviewed here definitely fall more toward the moderately successful end of the spectrum of earlier investigations. The two plant breeders (PB) appear to have made the most successful use of the 1 to 5 yield scale to discriminate among the 150 plots constituting the experiment. They were shown to have more evenly distributed their scores among the five score classes. In contrast, the graduate student selectors (GS) were notably reluctant to place plots in the lowest yield categories. The most inexperienced selectors, the summer workers (SW), placed a relatively fewer number of plots than the PB in both the high and low score categories.

Among the three main selector groups (PB, GS, and SW), the PB were shown to have the largest correlation coefficients between scores and yield. In addition, by chi-square analysis, the PB demonstrated the most consistent ability among selector groups to discriminate more high and low yielding plots than random selection. These results are in contrast to those of Townley-Smith et al. (1973) and Mann (1975), who found no differences in the visual discrimination abilities of experienced and inexperienced selectors, but are in agreement with those results obtained by Salmon and

Larter (1978). Hanson (1964) asserted that plant breeding experience and familiarity with the material were critical to success in visual selection. However, although less familiar with the breeding material, the best graduate student selectors (BGS) of this study, GS3 and GS6, were similar to the PB in their ability to distinguish the highest yielding plots. Although the GS as a group were generally more successful than the SW in selecting for yield, it is noteworthy that GS4's scoring had the lowest correlation with yield of any selector, and the best individual SW selectors were able to select for yield as effectively or better than the worst GS selectors.

It was noted earlier that the fate of the highest yielding plots was of critical concern to the breeding program, since it is among these plots that future high yielding cultivars would be expected to emerge. In considering the scoring of the highest yielding plots, it was also noted that the correlation of visual yield scores between selectors was generally higher than the correlation between scores and yield itself. This is in agreement with Kwon and Torrie (1964), who noted that this implies selectors are "seeing" similar plot characteristics as high yielding. The results of this investigation showed that, although similar, selectors' choices were complementary. Four of the highest 20 plots were not picked by either PB in two trials. However, only a single plot was missed if the two best graduate students' (BGS) scores were also considered.

Of the 20 highest yielding plots, 17 were identified when using the regression of grain yield on visually assessable traits alone or in combination with individual selector scores (using the same selection intensity as the PB and BGS). Importantly, the number of plots in the lower half of the population concurrently selected was fewer than the number chosen by any of the four best selectors. Therefore, use of such a statistical selection index reduced the amount of unproductive material that would have to be carried forward in a regular breeding program. This would provide a more efficient use of time, land, labor, and capital. With the advent of widespread computer usage in agriculture, it is not unreasonable to assume that selectors could soon efficiently use statistical indices in the field in lieu of simple "select" or "reject" procedures now employed. Several years' data would have to be accumulated to test the validity of such an approach, as there is no reason to believe that a statistical index made up of scored visual traits from a single year's data would be a reliable predictor for the following year. Atkins (1964) supported this point of view, noting that the prominent role of environmental influences on the expression of selection criteria made it difficult to attain marked permanent progress with specific, set criteria.

Considering the 20 highest yielding breeding lines from the total of 50 entries (averaged over three replications), the benefits of utilizing more than one selector were obvious. Similar to the data for the highest yielding individual plots, only a single line among the highest 20 lines was not chosen in any replication in either trial by one of the four best selectors. This complementarity of selectors' choices among the high yielding plots is a definite asset to a breeding program, compensating in part for any one individual selector's personal bias.

Atkins (1964) has argued that environmental influences on the selection criteria and on yield itself may have a lesser impact in relation to the expression of low yield than they do for high yield. He noted support for this rationale to be common in selection for simply inherited traits, such as dwarfness and chlorophyll deficiencies, which are readily removed from segregating populations. He offered this argument as an explanation for his results and previous investigations (Hanson et al., 1962) that showed selectors to be more effective in discriminating low yielding than high yielding breeding lines. The results of this investigation do not support that contention. The two PB and GS5 were the only selectors to significantly and consistently identify more low yielding plots 'correctly' than would be expected if selection were random. Selectors generally were equally or more adept at selecting high yielding than low yielding plots. Selectors' inability to more effectively select low yielding plots may be partially explained by the relatively high performance of all plots in this investigation. The mean yield per plot was equivalent to 76.8 quintals per hectare (114.3 bushels per acre); the lowest yielding five plots averaged 51.3 quintals per hectare (76.4 bushels per acre).

Association of Selected Traits with Visual Scoring for Yield

It has been noted that the most common selection index used by selectors is a "mental picture" derived from experience (Frey, 1962). Frey emphasized that many of the plant characteristics that comprise the selector's "mental picture" may, in fact, be totally unrelated to yield potential. This has serious consequences with regard to the difficult task of finding those rare transgressive segregates with high yield potential in a pedigree program. If selectors are consciously or unconsciously selecting for a number of plant characteristics which are detrimental in their relation to yield expression or ignoring potentially high yielding plant types because of biases for or against certain visual traits, the already low probability of identifying an improved genotype becomes lower still.

By correlation analysis, plot yield in this investigation was shown to be significantly and positively associated with kernels per spike, kernels per spikelet, 1000 kernel weight, spike width, spike laxity, harvest index, physiological maturity, biological yield and flag leaf width. Plot yield was significantly and negatively correlated with lodging, basal sterility and peduncle length. Considering all the above factors, and others not measured (such as color), the selector's task in discriminating high yielding plots is an admittedly difficult one. He or she is being asked to "see" and to integrate various yield components which are exceedingly difficult to estimate visually, without being unduly biased by a large number of other visual characteristics.

If a bias is defined as the association of a trait with visual scoring for grain yield in a manner inconsistent with the trait's actual relationship with yield, two distinct types of visual biases were suggested by this investigation. The first is the association of a trait in a manner opposite in direction to the trait's statistically derived relationship to yield. For example, due to the relatively high grain yield of several awnless breeding lines in this study, yield was positively associated with the awnless condition. Yet, GS4 favored awned types, to the extent that awnedness was the first variable to enter in the stepwise regression of his visual yield scores on traits. In Trial 2, he scored not a single awnless type among his highest selections. This apparent bias for awned tvpes may partially explain why GS4's scores had the lowest correlation with yield of any selector. The second type of bias was the association of a trait in the same direction as the trait's statistically derived relationship with yield, but with a marked overemphasis on that trait when scoring for yield. For example, yield was positively correlated with spike length ($r = .14$), whereas the absolute value of the correlation coefficients between GS2's and SW4's scores and spike length were .56 and .55, respectively. This overemphasis on spike length suggests that SW4 and GS2 were relying too much on a single character, and were not utilizing other traits that might improve their ability to effectively discriminate plots for yield. The vast majority of suggested biases were of this second type.

Results presented in this investigation suggest a pattern of biases for and against certain traits which demonstrates both commonalities and distinctions among the selector groups' "mental pictures" of high and low yielding plots. In scoring for high yield, biases for later heading and maturing types operated across all selector groups. Although the actual highest ranked plots were significantly later maturing than the population mean, all groups selected plots even later maturing than the actual highest yielding plots. Mean heading dates for the actual highest yielding plots were not significantly different from random samples from the experimental population in any of the high yield categories (highest yielding 45, 30, 20 and 10 plots). That these two biases were the most general ones across all selector groups is understandable. Later plant types, some of which still retained small areas of green tissue at the time of selection, arguably demonstrated a more vigorous and productive appearance. This is supported by previous investigators (McKenzie and Lambert, 1961; Hanson et al., 1962; Kwon and Torrie, 1964; Stuthman and Steidl, 1976; Wilcox and Schabaugh, 1980), who reported that later maturing plant types appeared to selectors as phenotypically superior.

In selecting for high yield, the plant breeders (PB) were clearly distinguished from the other selector groups by their relative lack of biases for or against certain traits. In contrast, all other groups, the summer workers (SW) in particular, demonstrated a number of biases in selecting for high yield. The SW were most notable by their preference for spike characteristics such as longer spikes with more spikelets and kernels per spike. The GS showed some of these same tendencies to overemphasize spike characteristics, but to a lesser degree. Several SW and GS selectors were not able to appropriately consider the lodging and staking of plots, generally overemphasizing their negative relation to yield. The GS were uniquely more biased for awned types than the other selector groups, whereas the SW particularly overemphasized shorter types as high yielding. All groups except the PB seemed to overemphasize wide flag leaves, which may simply be an artifact of the relatively high positive correlations among flag leaf width, maturity and heading dates.

The results of this investigation for low yield selection were generally consistent with results reported above for high yield selection. If a selector group preferentially chose plots with long-spiked plants as high yielding, the same group generally chose plots containing short spikes as low yielding. In the actual lowest yielding plots, mean values for maturity dates, heading dates, spikelets per spike and flag leaf widths were not significantly different from the population mean. However, selector groups consistently chose as lower yielding, plots that were significantly earlier in maturity, earlier heading, with fewer spikelets and narrower flag leaves.

Past investigators studying the relationship of traits to visual selection generally included few traits in their studies.

Besides the results noted above for maturity, McKenzie and Lambert (1961) and Wilcox and Schabaugh (1980) found plant height to be a significant bias factor among selectors. Hanson et al. (1962) and Kwon and Torrie (1964) reported lodging and plant height to influence selectors' concept of yield to a degree inappropriate to the traits' actual relationship with yield.

Multiple regressions of visual yield scores on traits generally confirmed the results cited above for the association of traits with the scoring process. Physiological maturity, spike width and plant height explained more of the variation in selector group scoring than other traits, with spike length being uniquely prominent among the SW. On the average, more significant traits appeared in the regressions of the PB than the other selector groups, which suggests a broader consideration of many plot characteristics in decision making. This is in particular contrast to regressions involving SW scores as dependent variables, half of which contained but three or four significant traits. The PB were also notable by their consistent scoring of the same plot on different days and of similar plant types (lines) on the same day in different replications. Consideration of a number of visual characteristics and consistency of scoring would both contribute to selector success in discriminating yield differences among plots.

Improvement in visual selection for yield may result if selectors become aware of their individual biases with regard to certain plant characteristics. A bias for later plant types seemed to be prevalent across all selector groups in selection for high yield. This would suggest that in a program of pedigree selection, at least one preliminary visual selection should be conducted within a nursery so that high yielding earlier types are not overlooked. The earlier breeding lines in this investigation appeared to have been overlooked by selectors because they were well past their optimal phenotypic appearance. The training of inexperienced selectors should emphasize the myraid possibilities of variations in the phenotypic expression of yield components and other traits, many different combinations of which may lead to actual high yield potential. High yield can be equally achieved by many small spikes as well as fewer large ones, awnless types as well as awned, and where environmental constraints are not limiting, late maturing types as well as earlier ones. Wilson (1981) asserted that "there can be no universal ideotype in plant breeding, but rather many biological models." It is possible to avoid the noted tendency, for example, of certain inexperienced selectors in this investigation to "see" only later, shorter plant types with large spikes as high yielding.

The implications from this investigation for the improvement of selector success in visual selection are significant. Both Allard (1960) and Briggs and Knowles (1967) have stressed the necessity of breeder awareness of physiological and morphological characteristics of the crop which make it successful in the environments in which it is to be grown. Plant breeding is indeed a numbers game, and if visual characteristics of the crop are utilized appropriately, they can be an aid in more effectively identifying those infrequent valuable types which will become the cultivars of the future.

SUMMARY AND CONCLUSIONS

An experimental population consisting of 150 plots representing 50 diverse wheat genotypes was visually rated for grain yield using a five-point scale by two experienced plant breeder selectors, eight novice graduate student selectors, and eight inexperienced summer student workers. The effectiveness of visual selection for grain yield was examined for both individual selectors and selector groups.

Twenty-two agronomic traits were measured on each plot to evaluate trait association with the process of scoring plots for yield.

This investigation was conducted during the 1981-82 growing season at Hyslop Agronomy Farm, located eleven kilometers northeast of Corvallis, Oregon.

The following conclusions were drawn, based on the results of this investigation:

1. On the average, the two plant breeder selectors were more successful in discriminating high yielding plots than either the graduate student or summer student worker selector groups. However, the best two graduate student selectors were similar to the plant breeders in their ability to distinguish high yielding plots.

2. The graduate student selectors as a group were generally more successful than the summer workers in identifying a higher percentage of high yielding plots. However, there was considerable overlap in the ability of the more effective summer worker selectors

and the less effective graduate student selectors.

3. In discriminating low yielding plots, the plant breeder selectors were more successful than the other selector groups. Unlike the results of selection for high yield, the two best graduate student selectors were not as effective at selecting low yielding plots as the two plant breeders. The graduate student selectors were marginally more effective than the summer workers in discriminating the lowest yielding plots.

4. Considered individually, the most effective selectors failed to select a number of the highest yielding plots. However, when selections of the four most effective selectors were combined, only one of the highest yielding twenty plots was not selected. This complementarity of selectors' choices regarding what constitutes high yield potential is a definite asset to a breeding program, compensating in part for any one individual selector's personal bias for or against certain plant types.

5. In order to select a high percentage of the best plots or breeding lines, there was a tradeoff in more low yielding plots or lines concurrently selected.

6. A statistical index combining selector scores and easily evaluated visual traits was efficient in selecting many high yielding plots and few low yielding plots. However, large environmental effects on the expression of selection criteria frequently noted in the literature do not support the use of set visual selection criteria from year to year.

7. Unlike several previous investigations, selectors were generally equally or more adept at selecting high yielding than low yielding plots.

8. Regression analysis showed that traits assessable visually accounted for more variation in selector scoring than could be accounted for by plot grain yield itself. Similarly, more variation in plot grain yield was accounted for by visual traits than individual or combined selector scores.

9. Consistency of scoring of the same plots from day to day (trial to trial) and of the same entry (breeding line) in different replications on the same day was more characteristic of the most effective selectors.

10. Several traits were found to be associated with selector scoring for yield in a manner inconsistent with the traits' actual relationship with plot yield. Although such statistical associations do not imply cause and effect relationships, for ease of explication such selector "misuses" of visual cues were referred to as "biases" on the part of the individual selectors or selector groups:

a. Later heading and maturing plant types with wide flag leaves were the biases most common to all selector groups when selecting for high yield, as were earlier maturing and heading types with narrower flag leaves when selecting for low yield. That later plant types are often seen as phenotypically superior in yield has been noted by previous investigators. This suggests that pedigree programs include at least one visual selection date early enough to avoid bypassing early, high yielding genotypes which at a later date might appear phenotypically inferior to selectors.

b. The plant breeder selectors were notable for their relative lack of biases for or against certain traits in comparison to other selector groups.

c. Summer worker selectors in particular demonstrated a number of biases for spike characteristics, tending to select as high yielding shorter plant types with long spikes having many spikelets and kernels per spike. Results suggested that the graduate student selectors were similarly biased for spike characteristics, but to a lesser degree.

d. Several graduate student and summer worker selectors were biased against lodged and staked plots, generally overemphasizing their negative relation to yield expression. Certain graduate student and summer worker selectors also were biased in favor of awned types.

e. Results suggested that all selector groups overemphasized reduced spikelets per spike when selecting the lowest yielding plots.

11. Consistent with the conclusions noted above for trait association with visual scoring for yield:

a The low yielding plots most frequently misscored as high yielding generally contained shorter, later heading and maturing types with wide flag leaves and prominent long spikes having many fertile spikelets, but low 1000 kernel weight and few spikes per meter.

b. The high yielding plots most frequently misscored as low yielding generally contained taller, earlier heading and maturing types with narrow, long flag leaves, few spikelets per spike, and high 1000 kernel weight.

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A P P E N D I C E S

Appendix Table 1. Varietal names, Oregon State University selection numbers, pedigrees, mean yield and means of selected traits averaged over three replications for the fifty breeding lines of the experiment.

Entry No.	Pedigree - OSU selection number/varietal name	Yld (gm/plot)	Yld (q/ha)	Yld rank	Kernel type	Awn	Plt ht (cm)	Spk l (cm)	Head date
1	68-1846/HYS//RDL/SU,F_1/3/CLLF S/1162-68/VH OWW76260 B-01H-5S-0P	1555.7	60.1	48	SR	+	109.7	9.5	149
2	OFN/4/YT54/3/N10B/LR//MFO/5/DJ/6/PCH/7/KAL/BB SUM 765858*-03H-1H-0H	1561.0	60.3	47	HW	+	138.7	7.7	144
3	7C/CNO//CAL/3/CNO S/PJ 62//GLL SWM 765854*-02P-1H-0P	2061.7	79.6	21	SR	+	122.3	10.0	132
4	BEZ/TOB//8156 SWCM 5092-7D-1P-1H-1P-0P	1545.3	59.6	49	HR	+	102.0	8.3	143
5	WRSWWN 10745318	1964.3	75.8	29	SW	+	110.7	7.5	149
6	Lewjain	1810.7	69.9	38	SW	+	108.7	7.9	153
7	ORE F1-158/FDL//BLLS SWM 742026*-10P-1H-1S-0S	2048.0	79.0	23	SW	+	131.3	9.0	136
8	MRS/CNDR SWM 754189*-02H-1P-2H-0P	2253.0	87.0	10	HW	-	135.0	6.9	147
9	ND/P101//BB/GLL SWM 754666*-03P-3P-2H-0P	2439.3	94.2	2	SW	+	121.3	8.4	144
10	Nugaines	1669.0	64.4	44	SW	+	103.3	6.9	149
11	CLFF/PCH//P101/VOGAF SWD 71452A-03H-2H-0P	1863.3	71.9	36	HR	+	116.3	9.0	145
12	KRF/CHA2 SWM 754075*-04P-1P-1P-0H	1696.7	65.5	43	SW	+	119.0	10.0	135
13	MRS/CZECH X OWW 74056*-3H-1H-3H-0S	2106.0	81.3	17	SR	-	128.3	7.2	143
14	SPN//AU/YMH OWW 72341-2-01-2H-0P	2410.7	93.0	3	SW	-	106.3	8.1	143
15	HN4/4/KT54A/N10B//KT54B/3/NAR/5/TZPP/PL//7C SWM 754308*-03P-1H-1P-0P	1756.0	67.8	40	HW	+	102.3	8.8	145
16	55-1744/7C//SU/RDL SWO 730902F-1H-1P-0P	2068.3	79.8	20	HR	+	115.0	11.6	152
17	ND/P101//AZT SWM 765591*-06H-1P-0P	1883.0	72.7	34	SW	+	101.7	7.9	141
18	RMN F12-71/SKA SWM 765614*-09P-1H-0S	2127.0	82.1	16	SW	+	119.0	9.9	135

(Continued on next page)

Appendix Table 1 (continued)

Entry No.	Pedigree - OSU selection number/varietal name	Yld (gm/plot)	Yld (q/ha)	Yld rank	Kernel type	Awn	Plt ht (cm)	Spk l (cm)	Head date
19	S64/2*SS/CNDR SWM 753987*-03H-4M-2H-OP	1610.3	62.2	45	SW	+	90.0	7.6	140
20	Maris Hobbit	2626.0	101.4	1	SR	-	97.7	9.3	149
21	PI/MZ//CNO/3/LFN/4/CNO/GLL SWM 777688*-1H-OP	1906.3	73.6	31	HR	+	113.0	9.5	135
22	ND/2*/P101//MCS, F1/3/TJB 801/1332 SW076112C-01P-2P-OP	2131.7	82.3	15	HW	+	112.7	10.3	147
23	MAYA S/3/SUT//SN64/KLRE SWM766018*-01P-1H-OH	1488.0	57.4	50	HR	+	112.0	8.6	134
24.	SN64/SS2//TRM, F1/3/TJB 788/1039 SW076212D-01P-1P-OH	1874.0	72.3	35	HW	+	108.7	8.1	140
25	NO/P101//KAL/BB SWM753995*-03P-1H-1P-OS	1978.3	76.4	27	HW	+	120.7	8.8	143
26	HIM/CNDR SWM 754660*-04H-3P-1H-OP	2076.7	80.2	19	HW	+	134.7	7.0	137
27	TEN/JUB*2//BNO/3/YR SWM 766290*-03P-1P-OS	1999.7	77.2	26	HR	-	107.7	7.3	150
28	YMH DWF	2285.3	88.2	9	SW	-	114.3	8.1	143
29	Yamhill	2314.0	89.3	5	SW	-	131.0	6.7	148
30	TJB 841/1543//YMH/MCD OWW 76098*-04P-1H-OP	2041.3	78.8	24	SW	+	116.0	9.1	148
31	HN 7/RMD//1523/DRC DWF, F1/3/CER OWW 76173D-01H-1H-OP	1833.3	70.8	37	SR	+	130.7	6.3	152
32	HIM/CNDR SWM 754660*-04H-3P-2H-OP	1914.7	73.9	30	SW	+	137.0	6.8	137
33	YMH/MCS SWM 754913*-04H-1P-3H-OP	2050.3	79.1	22	SW	+	135.3	7.7	142
34	LOM 23/CAN SWM 766263*-01P-1P-OP	2183.0	84.3	12	SR	+	136.0	10.2	140
35	TAST/ANZA SWM 75465*-06H-2P-2H-OP	1901.3	73.4	32	SR	+	130.0	6.3	139
36	H68-406/YMH OWW 70226-1E4-1H-OH	1976.3	76.3	28	SW	+	130.3	7.6	143
37	Druchamp	1712.0	66.1	42	SW	-	143.7	7.8	146

(Continued on next page)

Appendix Table 1 (continued)

Entry No.	Pedigree - OSU selection number/varietal name	Yld (gm/plot)	Yld (q/ha)	Yld rank	Kernel type	Awn	Plt ht (cm)	Spk l (cm)	Head date
38	TJB 368-268/YMH OWW 750263*-03P-1P-1H-0P	2203.0	85.0	11	SW	-	119.7	6.7	149
39	R37/GHL 1//PLO SWM 765886*-01H-1H-0P	1892.3	73.0	33	SR	+	122.7	6.7	141
40	ALBA/GNS//FN/SON 64 SWD7/1424B-11H-2H-3H-0P	2014.0	77.7	25	HR	+	112.0	8.9	143
41	Stephens	2338.3	90.3	4	SW	+	111.3	8.8	144
42	ND/WW//LEE/FN/N CH 2672-2C-3C-1C-10	2093.0	80.8	18	SR	+	132.3	9.1	143
43	CAR 193/WOPS SWM 765963*-10H-2H-0P	2177.7	84.1	14	HR	+	111.7	8.4	141
44	ANZA/SDY SWD 71164-03H-1P-3H-0P	1588.0	61.3	46	HR	+	120.0	8.8	138
45	HN4/4/KT54/A/N10B//KT54B/3/NAR/5/TZPP/PL//7C SWM 754308*-03P-3M-3H-0P	1724.0	66.5	41	SW	+	98.3	8.1	145
46	S148/BLLS SWM 742237*-02P-4P-1P-0P	2311.7	89.2	7	SW	+	109.3	10.0	139
47	SWM75-296,F1//ND/P101 SWo 76127A-01P-1P-0P	2178.7	84.1	13	HW	+	119.7	10.0	135
48	ND/VG9144//TRM SWM 754595*-03P-1H-1H-0H	2290.0	88.4	8	HW	+	128.3	10.0	149
49	AU/ERA SWH 72319-1H-2P-1H-0H	1784.0	68.9	39	HR	+	109.7	8.0	148
50	TJB 788-1039/HYS, F1//LKF OWW 76243C-01P-1H-0P	2312.0	89.2	6	HW	+	125.0	8.9	147

Key to symbols:

YLD = yield (gm/plot and q/ha)
SR = soft red
SW = soft white
HW = hard white
HR = hard red
\+ = awned
\- = awnless
plt ht = plant height (cm)
spk l = spike length (cm)
head date = heading date (days from January 1, 1982)

Appendix Table 2. Summary of meteorological data at Hyslop Agronomy Farm, Corvallis, Oregon (1981-82)

Month	Temperature (C°) Max.	Temperature (C°) Min.	Humidity (%) Max.	Humidity (%) Min.	Precipitation (mm)
September	25.1	8.5	98.4	38.8	78.5
October	16.6	4.9	99.0	60.5	140.2
November	12.4	4.3	99.0	71.0	170.9
December	9.3	2.8	99.0	79.5	355.1
January	6.1	0.4	99.0	82.7	183.1
February	9.6	1.6	93.6	61.3	180.8
March	12.4	2.0	99.0	53.2	89.9
April	14.3	2.4	96.8	46.1	116.1
May	20.1	5.9	98.4	37.0	12.5
June	23.5	10.6	97.6	44.7	38.4
July	25.4	10.8	98.0	38.7	10.9
August	27.2	10.8	97.5	34.1	7.1

Appendix Table 3. Results of stepwise multiple regressions of grain yield on the twenty-two traits measured on each plot with the addition of selector group visual yield scores as independent variables.

†Group A traits + selector group visual yield scores as independent variables	Group A + Group B traits + selector group visual yield scores as independent variables	Group A + Group B + Group C traits + selector group visual yield scores as independent variables
Yield =	Yield =	Yield =
4993.72	2420.16	975.00
2.62 spk/m	3.10 spk/m	-3.47 lodg
57.96 spk l	15.17 1000K	7.81 plt ht
-4.42 lodg	239.72 K/spklt	-39.91 bas st
-83.06 awn	-4.40 lodg	3087.93 HI
5.58 plt ht	-72.69 awn	-10.25 head
-72.75 bas st	8.36 plt ht	1.65 byld
-17.46 mat	-70.39 bas st	-22.65 ped
-27.28 ped	-14.46 head	-88.95 PBA
-85.27 PBA	-24.74 ped	
-139.69 BGSA	-77.29 PBA	R^2 = .74
	-114.29 BGSA	
R^2 = .59		
	R^2 = .66	

†See Tables 2 and 4 for explanations of trait groupings.

Appendix Table 4. Frequency distribution of visual yield scores averaged over two trials given to the highest yielding 45 plots by individual selectors.

Selector	Frequency distribution of visual yield scores 1 to 5				
	1	2	3	4	5
PB1	8.5	18.0	15.5	2.0	1.0
PB2	16.0	9.5	17.5	0.5	1.5
PB mean	12.3	13.8	16.5	1.3	1.3
%	27.2	30.6	36.7	2.8	2.8
GS1	1.5	24.0	16.5	1.5	1.5
GS2	1.5	8.0	29.5	5.5	0.5
GS3	11.5	10.5	17.5	5.0	0.5
GS4	5.5	8.5	15.0	8.5	7.5
GS5	11.0	15.5	17.0	1.5	0.0
GS6	4.0	29.5	9.0	1.5	1.0
GS7	3.0	27.5	10.0	4.5	0.0
GS8	2.0	12.0	29.0	2.0	0.0
GS mean	5.0	16.9	17.9	3.7	1.4
%	11.1	37.6	39.8	8.2	3.1
SW1	2.5	14.0	19.5	7.5	1.5
SW2	0.0	3.0	34.0	7.0	1.0
SW3	3.0	8.5	23.0	9.5	1.0
SW4	5.0	8.5	30.0	1.5	.0
SW5	9.0	10.5	21.0	3.5	1.0
SW6	2.5	7.5	28.5	6.5	0.0
SW7	3.0	10.0	22.5	7.5	2.0
SW8	4.5	18.5	16.5	5.0	0.5
SW mean	3.7	10.1	24.4	6.0	0.9
%	8.2	22.4	54.2	13.3	1.9

Appendix Table 5. Frequency distribution of visual yield scores averaged over two trials given to the highest yielding 30 plots by individual selectors.

Selector	Frequency distribution of visual yield scores 1 to 5				
	1	2	3	4	5
PB1	6.0	10.5	11.5	1.0	1.0
PB2	10.5	5.5	12.0	0.5	1.5
PB mean	8.3	8.0	11.8	.8	1.3
%	27.5	26.7	39.2	2.5	4.2
GS1	1.5	16.0	10.0	1.0	1.5
GS2	1.5	5.5	19.0	4.0	0.0
GS3	8.0	8.0	9.5	4.0	0.5
GS4	3.5	5.0	10.5	5.5	5.5
GS5	6.5	9.5	12.5	1.5	0.0
GS6	3.0	17.5	7.5	1.0	1.0
GS7	1.5	20.0	6.5	2.0	0.0
GS8	1.0	8.0	19.5	1.5	0.0
GS mean	3.3	11.2	11.9	2.6	1.1
%	11.0	37.3	39.6	8.5	3.5
SW1	2.0	8.5	15.0	3.5	1.0
SW2	0.0	1.5	23.5	5.0	0.0
SW3	2.5	6.5	15.0	5.5	0.5
SW4	3.5	5.0	20.5	1.0	0.0
SW5	6.0	5.5	15.0	3.0	0.5
SW6	2.0	4.5	20.0	3.5	0.0
SW7	1.5	6.0	17.5	4.0	1.0
SW8	4.0	10.5	11.0	4.5	0.0
SW mean	2.7	6.0	17.2	3.8	0.4
%	9.0	20.0	57.3	12.5	1.3

Appendix Table 6. Frequency distribution of visual yield scores averaged over two trials given to the highest yielding 20 plots by individual selectors.

Selector	Frequency distribution of visual yield scores 1 to 5: 1	2	3	4	5
PB1	4.0	7.0	8.0	0.0	1.0
PB2	7.5	4.0	7.5	0.0	1.0
PB mean	5.8	5.5	7.8	0.0	1.0
%	28.8	27.5	38.8	0.0	5.0
GS1	1.5	8.5	7.5	1.0	1.5
GS2	0.5	4.0	13.5	2.0	0.0
GS3	5.5	5.5	6.0	2.5	0.5
GS4	2.0	4.5	6.5	4.0	3.0
GS5	4.5	8.0	6.0	1.5	0.0
GS6	2.5	10.5	5.5	0.5	1.0
GS7	1.0	13.0	5.0	1.0	0.0
GS8	0.0	6.5	12.0	1.5	0.0
GS mean	2.2	7.6	7.8	1.8	0.8
%	10.9	37.8	38.8	8.8	3.8
SW1	1.5	5.0	10.5	2.5	0.5
SW2	0.0	0.5	16.5	3.0	0.0
SW3	1.5	3.5	11.5	3.0	0.5
SW4	2.5	4.0	13.0	0.5	0.0
SW5	4.5	3.0	9.0	3.0	0.5
SW6	1.0	4.0	12.0	3.0	0.0
SW7	1.0	4.5	11.0	3.0	0.5
SW8	2.5	7.0	7.0	3.5	0.0
SW mean	1.8	3.9	11.3	2.7	0.3
%	9.1	19.7	56.6	13.4	1.3

Appendix Table 7. Frequency distribution of visual yield scores averaged over two trials given to the highest yielding 10 plots by individual selectors.

Selector	Frequency distribution of visual yield scores 1 to 5				
	1	2	3	4	5
PB1	2.5	3.0	4.5	0.0	0.0
PB2	7.0	0.5	2.5	0.0	0.0
PB mean	4.8	1.8	3.5	0.0	0.0
%	47.5	17.5	35.0	0.0	0.0
GS1	1.5	4.5	3.5	0.5	0.0
GS2	0.5	3.5	5.0	1.0	0.0
GS3	4.5	3.0	2.0	0.5	0.0
GS4	1.5	2.5	4.0	1.5	0.5
GS5	3.5	3.5	1.5	1.5	0.0
GS6	2.5	6.0	1.5	0.0	0.0
GS7	1.0	7.0	2.0	0.0	0.0
GS8	0.0	5.0	5.0	0.0	0.0
GS mean	1.9	4.4	3.1	0.6	0.1
%	18.8	43.8	30.6	6.3	0.6
SW1	1.5	4.0	3.0	1.0	0.5
SW2	0.0	0.5	9.0	0.0	0.5
SW3	1.5	1.5	6.5	0.5	0.0
SW4	2.0	3.0	5.0	0.0	0.0
SW5	2.5	2.0	4.0	1.5	0.0
SW6	1.0	3.0	5.0	1.0	0.0
SW7	0.5	2.0	6.5	1.0	0.0
SW8	2.0	3.5	2.5	2.0	0.0
SW mean	1.4	2.4	5.2	0.9	0.1
%	13.8	24.4	51.9	8.8	1.3

Appendix Table 8. Frequency distribution of visual yield scores averaged over two trials given to the lowest yielding 45 plots by individual selectors.

	Frequency distribution of visual yield scores 1 to 5				
Selector	1	2	3	4	5
PB1	0.0	3.5	18.5	12.0	11.0
PB2	2.0	1.5	21.0	7.5	13.0
PB mean	1.0	2.5	19.8	9.8	12.0
%	2.2	5.6	43.9	21.7	26.7
GS1	0.5	9.0	25.5	8.5	1.5
GS2	0.0	2.5	26.5	14.5	1.5
GS3	1.0	2.0	19.5	15.0	7.5
GS4	2.0	5.5	25.0	10.5	2.0
GS5	3.5	11.0	18.0	12.0	0.5
GS6	0.0	7.0	27.0	6.0	5.0
GS7	1.5	15.5	19.0	9.0	0.0
GS8	0.0	3.0	28.5	11.5	2.0
GS mean	1.1	6.9	23.6	10.9	2.5
%	2.4	15.4	52.5	24.2	5.6
SW1	0.0	2.0	29.0	13.5	0.5
SW2	0.0	0.5	30.5	13.5	0.5
SW3	0.0	1.5	23.5	15.5	4.5
SW4	0.0	0.0	41.0	4.0	0.0
SW5	1.5	7.5	23.0	11.0	2.0
SW6	0.0	1.5	32.0	9.5	2.0
SW7	1.5	4.5	18.5	13.5	7.0
SW8	0.0	10.5	18.5	15.0	1.0
SW mean	0.4	3.5	27.0	11.9	2.2
%	0.8	7.8	60.0	26.5	4.9

Appendix Table 9. Frequency distribution of visual yield scores averaged over two trials given to the lowest yielding 30 plots by individual selectors.

Selector	Frequency distribution of visual yield scores 1 to 5				
	1	2	3	4	5
PB1	0.0	2.5	9.0	12.5	6.0
PB2	1.5	0.0	12.0	6.0	10.5
PB mean	0.8	1.3	10.5	9.3	8.3
%	2.5	4.2	35.0	30.8	27.6
GS1	0.0	6.5	16.0	6.5	1.0
GS2	0.0	2.5	16.5	9.5	1.5
GS3	0.5	1.5	12.5	10.0	5.5
GS4	1.5	4.5	14.5	7.5	2.0
GS5	3.0	6.0	11.0	9.5	0.5
GS6	0.0	4.5	16.5	5.5	3.5
GS7	1.5	10.5	13.0	5.0	0.0
GS8	0.0	3.0	15.5	10.0	1.5
GS mean	0.8	4.9	14.4	7.9	1.9
%	2.7	16.3	48.1	26.5	6.5
SW1	0.0	1.0	18.0	10.5	0.5
SW2	0.0	0.5	21.0	8.0	0.5
SW3	0.0	1.5	14.0	10.0	4.5
SW4	0.0	0.0	26.5	3.5	0.0
SW5	1.5	5.0	14.5	7.0	2.0
SW6	0.0	1.0	22.5	5.0	1.5
SW7	1.0	3.0	11.0	10.5	4.5
SW8	0.0	8.0	10.5	10.5	1.0
SW mean	0.3	2.5	17.3	8.1	1.8
%	1.0	8.3	57.6	27.1	6.0

Appendix Table 10. Frequency distribution of visual yield scores averaged over two trials given to the lowest yielding 20 plots by individual selectors.

Selector	Frequency distribution of visual yield scores 1 to 5				
	1	2	3	4	5
PB1	0.0	2.5	5.0	7.5	5.0
PB2	1.5	0.0	7.0	4.5	7.0
PB mean	0.8	1.3	6.0	6.0	6.0
%	3.8	6.3	30.0	30.0	30.0
GS1	0.0	4.0	10.5	5.0	0.5
GS2	0.0	1.5	13.0	4.0	1.5
GS3	0.5	1.0	9.5	5.0	4.0
GS4	1.0	3.5	9.5	4.5	1.5
GS5	1.5	2.0	8.5	8.0	0.0
GS6	0.0	4.5	8.0	4.0	3.5
GS7	1.0	5.5	10.5	3.0	0.0
GS8	0.0	2.0	12.5	4.5	1.0
GS mean	0.5	3.0	10.3	4.8	1.5
%	2.5	15.0	51.3	23.8	7.5
SW1	0.0	1.0	12.0	6.5	0.5
SW2	0.0	0.5	15.5	4.0	0.0
SW3	0.0	1.5	11.0	6.5	1.0
SW4	0.0	0.0	18.0	2.0	0.0
SW5	1.5	3.5	9.5	3.5	2.0
SW6	0.0	0.0	16.0	2.5	1.5
SW7	1.0	2.0	10.0	5.5	1.5
SW8	0.0	7.0	5.0	8.0	0.0
SW mean	0.3	1.9	12.1	4.8	0.8
%	1.6	9.7	60.6	24.1	4.1

Appendix Table 11. Frequency distribution of visual yield scores averaged over two trials given to the lowest yielding 10 plots by individual selectors.

Selector	Frequency distribution of visual yield scores 1 to 5				
	1	2	3	4	5
PB1	0.0	1.0	0.5	3.5	5.0
PB2	0.0	0.0	1.5	3.5	5.0
PB mean	0.0	0.5	1.0	3.5	5.0
%	0.0	5.0	10.0	35.0	50.0
GS1	0.0	2.0	4.0	3.5	0.5
GS2	0.0	1.5	5.5	2.0	1.0
GS3	0.0	0.5	3.5	2.0	4.0
GS4	1.0	0.5	4.5	3.0	1.0
GS5	0.0	0.5	3.5	6.0	0.0
GS6	0.0	1.0	2.0	3.5	3.5
GS7	0.5	1.5	5.5	2.5	0.0
GS8	0.0	1.5	3.0	4.5	1.0
GS mean	0.3	1.1	3.9	3.4	1.4
%	2.5	11.3	39.4	33.8	13.8
SW1	0.0	0.5	5.5	3.5	0.5
SW2	0.0	0.5	6.0	3.5	0.0
SW3	0.0	1.0	5.0	3.0	1.0
SW4	0.0	0.0	8.0	2.0	0.0
SW5	0.5	1.5	4.0	2.0	2.0
SW6	0.0	0.0	7.5	1.0	1.5
SW7	0.0	1.5	4.5	4.0	0.0
SW8	0.0	3.0	2.0	5.0	0.0
SW mean	0.1	1.0	5.3	3.0	0.6
%	0.6	10.0	53.1	30.0	6.3

Appendix Table 12. Mean grain yield and means of twenty-two traits for plots scored '4' or '5' by individual selector in trial 2.

Selector	Trait: YLD	spk/m	K/spk	1000K	spklt/spk	K/spklt	spk l	spk w	stak†	lodg	awn†	plt ht
PB1	1791.0**	191.48	47.84*	46.56	17.97**	2.65	8.49	1.39**	.46	14.58	.98**	116.23
PB2	1741.8**	188.57	47.64	46.83	17.46**	2.72	8.55	1.39**	.53	15.67	1.00**	112.37**
GS1	1856.72	190.83	46.21	47.58	17.04**	2.69	8.68	1.40	.61	8.78	1.00**	119.61
GS2	1848.00**	204.62**	44.66**	44.81**	17.47**	2.57*	7.60**	1.39**	.52	12.98	.83	120.48
GS3	1814.14**	181.52	48.59	46.06	18.23	2.66	8.34	1.39**	.45	10.86	.90	116.14
GS4	2022.92	193.92	45.72**	46.97	18.20	2.53**	7.78**	1.45	.51	11.90	.46**	120.72
GS5	1603.13**	171.13	50.13	47.13	18.34	2.73	8.97**	1.41	.44	12.25	1.00**	110.50**
GS6	1746.06**	190.18	45.84*	49.76**	17.20**	2.66	9.29**	1.38*	.76*	22.82	1.00**	116.12
GS7	1953.94	201.31*	42.28**	46.73	17.13**	2.53*	7.56*	1.40**	.88**	10.25	.69	130.19**
GS8	1745.94**	206.22**	44.81*	46.66	16.98**	2.63	8.32	1.35**	.61	16.56	.94*	116.94
SW1	1933.12	198.61	43.95**	45.93	17.22**	2.55**	7.65**	1.39**	.64*	12.45	.76	121.55
SW2	1914.42	203.31*	43.17**	46.12	17.35**	2.53**	7.50**	1.40**	.65	17.62	.77	126.12**
SW3	1925.13	194.64	45.22**	46.35	17.71**	2.57*	7.76**	1.41**	.64*	14.60	.81	123.74**
SW4	1908.78	196.56	44.03*	47.22	17.99	2.44*	7.71	1.40*	.56	6.00**	.78	121.56
SW5	1844.00**	205.13*	45.77**	44.89	17.78**	2.56*	8.03	1.42*	.73**	28.60**	.87	124.30**
SW6	1907.29	200.11*	47.58	47.09	18.06*	2.66	8.56	1.45	.93**	42.68**	.82	126.61**
SW7	1920.63	192.79	47.54*	45.53	18.29*	2.60	7.87**	1.44	.52	13.87	.76	118.67
SW8	1870.17*	188.69	49.47	46.70	18.57	2.66	8.56	1.42*	.37	9.29	.91	114.54*
Grand means (150 plots)	1992.57	187.07	50.34	46.41	18.77	2.68	8.40	1.47	.46	11.67	.82	118.17

(Continued on next page)

Appendix Table 12 (continued)

Selector	Crown	bas st	unif	spk lax	HI	mat	head	byld	ped	flg l	flg w
PB1	1.71	1.83	2.81	2.33	.366	180.54**	141.31*	714.50**	20.56	22.41	1.66**
PB2	1.50	1.53	2.93	2.33	.367	178.30**	138.77**	697.87**	20.43	23.79*	1.60**
GS1	1.50	1.67	2.83	2.22	.355	177.28**	137.72**	744.44	21.79**	23.60	1.55**
GS2	1.57	2.00	2.95	2.05**	.351**	181.50*	143.07	749.00	21.51*	22.25	1.63**
GS3	1.50	1.69	2.81	2.29	.365	181.12*	141.33*	709.33**	19.84	22.41	1.68*
GS4	1.28**	1.87	3.15	2.10*	.363	182.36	143.56	760.74	19.60	22.67	1.74
GS5	1.44	1.75	2.63	2.19	.364	179.00*	139.50*	661.56**	19.86	24.11*	1.71
GS6	1.24**	1.35*	2.82	2.47	.354*	174.35**	135.83**	724.82	21.43**	24.92**	1.52**
GS7	1.06**	1.88	3.44*	1.31**	.325**	176.25**	140.31*	804.31*	22.93*	22.80	1.52**
GS8	1.44	1.72	2.94	2.06	.346**	177.72**	139.72*	730.00	21.41	23.91*	1.57**
SW1	1.36	1.94	2.97	2.18	.356*	179.85**	141.85	763.52	21.25*	23.16	1.62**
SW2	1.27*	2.19*	3.27	1.96**	.341**	179.50**	142.12	778.69	22.38**	22.28	1.59**
SW3	1.28**	1.96	3.02	2.01**	.351**	180.68**	142.17	764.83	21.35*	22.52	1.64**
SW4	1.44	2.11	2.89	1.67**	.332**	181.67	144.11	740.00	18.03	20.38	1.66
SW5	1.43	1.93	2.73	2.36	.345**	181.60	142.33	772.20	20.78	23.24	1.64**
SW6	1.39	1.79	3.14	2.50	.353*	180.04**	140.71*	785.18	22.25**	22.87	1.61**
SW7	1.41	1.81	3.08	2.22*	.366	181.94*	142.98	739.22	20.31	22.24	1.72
SW8	1.54	1.54	2.31**	2.63	.369	181.89	141.89	722.20	19.73	21.83	1.68*
Grand means (150 plots)	1.56	1.79	2.90	2.51	.371	183.67	143.18	753.18	19.77	22.11	1.78

*,**Significantly different from random samples of the same size at .05 and .01 levels, respectively.

†Values for staking and awnedness represent proportions of each group staked or awned, not means.

Appendix Table 13. First five variables to enter stepwise multiple regressions of grain yield, individual selector scores, and group selector scores on Group A (most visually assessable) traits.

Yield =	PB1 =	PB2 =	GS1 =	GS2 =	GS3 =
1 spk w	1 spk w	1 mat	1 flg w	1 spk l	1 mat
2 awn	2 mat	2 plt ht	2 awn	2 flg w	2 plt ht
3 lodg	3 crown	3 spk w	3 plt ht	3 stak	3 spk w
4 plt ht	4 plt ht	4 flg l	4 mat	4 spk w	4 flg w
5 spk lax	5 spk l	5 spk lax	5 stak	5 mat	5 spk/m
GS4 =	GS5 =	GS6 =	GS7 =	GS8 =	SW1 =
1 awn	1 crown	1 mat	1 mat	1 mat	1 spk l
2 mat	2 plt ht	2 plt ht	2 spk lax	2 spk w	2 mat
3 spk w	3 mat	3 lodg	3 crown	3 plt ht	3 spk w
4 spk/m	4 awn	4 spk w	4 flg w	4 spk/m	4 flg w
5 spk lax	5 spk w	5 spk l	5 spk w	5 awn	5 awn
SW2 =	SW3 =	SW4 =	SW5 =	SW6 =	SW7 =
1 spk w	1 spk w	1 spk l	1 lodg	1 lodg	1 spk l
2 mat	2 mat	2 spk w	2 spk w	2 spk w	2 mat
3 awn	3 spk l	3 crown	3 mat	3 flg w	3 plt ht
4 bas st	4 flg w	4 unif	4 plt ht	4 spk l	4 spk lax
5 flg w	5 awn	5 spk lax	5 spk/m	5 mat	5 spk/m
SW8 =	PBA =	GSA =	SWA =	BGSA =	
1 spk w	1 mat	1 mat	1 spk w	1 mat	
2 unif	2 spk w	2 spk w	2 mat	2 plt ht	
3 mat	3 plt ht	3 plt ht	3 spk l	3 spk w	
4 plt ht	4 flg l	4 awn	4 flg w	4 flg w	
5 flg w	5 unif	5 flg w	5 lodg	5 spk l	

Appendix Table 14. Results from stepwise multiple regressions of selector group visual yield scores averaged over two trials on combined Group A and Group B traits.

PBA =	GSA =	SWA =	BGSA =
27.626	17.307	11.498	21.172
-2.270 spk w	-1.117 spk w	- .146 spk 1	.104 spk 1
.006 lodg	- .082 stak	- .846 spk w	-1.673 spk w
- .031 plt ht	- .172 awn	.004 lodg	- .028 plt ht
.262 crown	- .013 plt ht	- .076 unif	- .068 mat
- .279 unif	- .058 mat	- .031 mat	- .513 flg w
- .277 spk lax	- .372 flg w		
- .096 mat		R^2 = .63	R^2 = .55
.050 flg 1	R^2 = .57		
R^2 = .67			

Appendix Table 15. Results from stepwise multiple regressions of selector group visual yield scores averaged over two trials on all twenty-two measured traits.

PBA =	GSA =	SWA =	BGSA =
25.942	16.895	10.068	19.706
.007 spk/m	.005 spk/m	.005 spk/m	.004 spk/m
-1.736 spk w	- .492 spk w	- .110 spk 1	.118 spk 1
- .014 plt ht	- .083 stak	- .529 spk w	-1.194 spk w
.248 crown	- .185 awn	.009 plt ht	- .015 plt ht
- .165 bas ster	- .106 unif	- .065 unif	- .064 mat
- .239 unif	- .075 spk lax	- .032 mat	- .003 byld
- .257 spk lax	- .066 mat	- .002 byld	- .513 flg w
- .094 mat	- .002 byld		
- .003 byld		R^2 = .68	R^2 = .62
.046 flg 1	R^2 = .63		
R^2 = .71			

Appendix Table 16. Results from stepwise multiple regressions of individual selector visual yield scores averaged over two trials on combined Group A and Group B traits.

PB1 = 24.162 -.083 spklt/spk .214 spkl -2.747 spk w -.173 stak .010 lodg -.013 plt ht .194 crown -.221 unif -.262 spk lax -.081 mat R^2 = .64	PB2 = 29.316 -2.314 spk w -.044 plt ht -.269 unif -.297 spk lax -.097 mat .069 flg l R^2 = .60	GS1 = 10.413 -.066 spklt/spk -.118 stak -.006 lodg .162 awn -.034 head -.877 flg w R^2 = .39	GS2 = 10.845 .003 spk/m -.214 spk l -.694 spk w -.193 stak -.026 mat -.443 flg w R^2 = .52	GS3 = 21.548 -.006 spk/m -.657 spk w -.034 plt ht -.050 mat -.952 flg w R^2 = .44	GS4 = 19.710 -.042 K/spk -.042 1000K -.120 stak -.729 awn -.066 mat R^2 = .60
GS5 = 20.052 .095 spklt/spk -1.529 spk w -.456 awn -.039 plt ht -.186 crown -.134 unif -.069 mat .047 flg l R^2 = .56	GS6 = 23.212 -.016 K/spk -.033 1000K .253 spk l -1.584 spk w .006 lodg -.025 plt ht -.082 mat R^2 = .59	GS7 = 11.600 -.053 spklt/spk -.202 crown -.150 spk lax -.036 mat -.400 flg w R^2 = .54	GS8 = 14.809 .004 spk/m -1.463 spk w -.166 awn -.013 plt ht -.134 unif -.005 mat .038 flg l R^2 = .43	SW1 = 12.540 -.192 spk l -.690 spk w -.058 mat .026 head R^2 = .47	SW2 = 8.661 -.011 K/spk -.093 spk l -.023 mat R^2 = .28
SW3 = 12.576 -.243 spk l -.817 spk w .166 awn -.104 spk lax -.027 mat -.537 flg w R^2 = .57	SW4 = 5.770 .010 K/spk -.141 spk l -1.057 spk w -.169 crown .097 bas st -.116 unif -.103 spk lax R^2 = .51	SW5 = 8.034 .004 spk/m -1.470 spk w .015 lodg .010 plt ht -.028 mat R^2 = .53	SW6 = 5.648 -.060 spk l -.903 spk w .017 lodg -.514 flg w R^2 = .62	SW7 = 16.378 -.031 1000K -.179 spk l -.016 plt ht -.121 spk lax -.044 mat R^2 = .35	SW8 11.708 -1.515 spk w -.282 unif .032 mat R^2 = .34

Appendix Table 17. Results from stepwise multiple regressions, of individual selector visual yield scores† averaged over two trials on all twenty-two measured traits.

PB1 =
21.771
.006 spk/m
- .092 spklt/spk
.237 spk l
-2.355 spk w
.219 crown
- .162 bas st
- .191 unif
- .262 spk lax
- .070 mat
- .004 byld

R^2 = .68

PB2 =
27.119
.008 spk/m
-1.731 spk w
- .027 plt ht
- .243 unif
- .352 spk lax
- .056 mat
- .048 head
- .003 byld
.063 flg l

R^2 = .65

GS1 =
11.194
- .067 spklt/spk
- .007 lodg
.176 awn
- .025 mat
- .002 byld
- .779 flg w

R^2 = .41

GS2 =
10.926
- .249 spk l
- .215 stak
- .380 HI
- .018 mat
- .593 flg w

R^2 = .52

GS3 =
17.742
-1.300 spk w
- .014 plt ht
- .047 head
- .004 byld
- .999 flg w

R^2 = .50

GS4 =
19.710
- .042 K/spk
- .042 1000K
- .120 stak
- .729 awn
- .066 mat

R^2 = .60

GS5 =
20.624
.153 spk l
-1.586 spk w
- .570 awn
- .048 plt ht
- .276 crown
- .139 unif
-5.841 HI
- .049 mat
.038 flg l

R^2 = .58

GS6 =
23.800
.200 spk l
-1.680 spk w
.007 lodg
- .035 plt ht
-6.373 HI

R^2 = .60

GS7 =
11.367
- .003 spk/m
- .084 spklt/spk
.563 spk w
- .186 crown
- .153 spk lax
-5.830 HI
- .026 head
- .512 flg w

R^2 = .61

GS8 =
14.425
.009 spk/m
- .929 spk w
- .108 stak
- .194 awn
- .127 unif
- .056 mat
- .002 byld
.037 flg l

R^2 = .49

†The results for all summer workers (SW) selectors were identical to those reported in Appendix Table 16, therefore are not listed here.