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Selection Among and Within S_1 Lines of Maize on S_2 Line and Testcross Performance[1]

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Most maize (*Zea mays* L.) breeders practice visual selection among lines during inbreeding, but may not be certain of the effectiveness of such selection. Visual selection among and within 1,636 S_1 lines of maize derived from 'Lancaster Composite' was used to select 200 S_2 lines, and a random set of 200 S_2 lines also was developed. Yield trials of the 400 S_2 lines in three environments and their testcrosses to (B73 × B84) in four environments were conducted to determine whether visual selection was effective in choosing high-yielding and agronomically desirable lines with superior combining ability.

Grain yield of the visually selected S_1 lines (3.11 Mg ha^{-1}) was significantly ($P<0.05$) greater than that of the unselected lines (2.94 Mg ha^{-1}), but there was no difference in testcross means. Visually selected S_1 lines had slightly greater mean grain moisture and slightly less mean stalk lodging than unselected lines in individual environments. Testcrosses of visually selected lines had greater grain moisture and less stalk lodging than testcrosses of unselected lines in individual environments. Estimates of genetic variance, heritability, and gain from selection were not consistently affected by visual selection. Many superior S_2 lines and testcrosses were unselected lines, showing that visual selection failed to identify many desirable genotypes. Our results suggest that visual selection should not be used to attempt to select the most superior genotypes, but should emphasize discarding of undesirable genotypes before yield testing.

INDEX DESCRIPTORS: *Zea mays* L., Corn, Corn Breeding, Breeding methods, Recurrent selection.

Maize (*Zea mays* L.) breeders utilizing recurrent selection for population improvement or early testing for hybrid development typically grow large numbers of progenies in yield trials. Because such trials are expensive, any selection that can identify desirable genotypes to include for evaluation, or eliminate undesirable ones from further consideration, is beneficial. Intrapopulation recurrent selection schemes based on the yield testing of S_2 progenies per se, or testcrosses of S_1 lines, permit use of visual selection among S_0 plants and among and within S_1 lines before yield trials are conducted. Evaluation of testcrosses of S_2 or more highly inbred lines permits further visual selection. Often, the breeder is not certain of the effectiveness of such selection.

Studies on effectiveness of visual selection have been conducted in both self-pollinated and cross-pollinated crops. Most reports for self-pollinated crops have emphasized yield rather than agronomic traits. Studies of visual selection for yield among F_2 plants of self-pollinated crops generally have shown that the technique either had no effect or was more useful for discarding unproductive genotypes than for selecting productive ones (Frey, 1962; Atkins, 1964; Knott, 1972; DePauw and Shebeski, 1973; Nass, 1983). Similar results were found for visual selecton for yield among F_3 or more highly inbred lines (McKenzie and Lambert, 1961; Hanson et al., 1962; Kwon and Torrie, 1964; Briggs and Shebeski, 1970; Stuthman and Steidl, 1976). Plants with desirable phenotypes that were visually selected as high-yielding were taller and later-maturing than unselected plants in several studies (McKenzie and Lambert, 1961; Wilcox and Schapaugh, 1980; Nass, 1983).

Visual selection experiments with maize have examined the effects of such selection, usually through several generations, on combining ability of lines rather than on line performance. Visual selection for desirable plant and ear types among and within maize lines had no effect on inbred combining ability for yield in some studies (Sprague and Miller, 1952; Wellhausen and Wortman, 1954; Brown, 1967) and a positive effect in others (Singleton and Nelson, 1945; Osler et al, 1958; Russell and Teich, 1967; El-Lakany and Russell, 1971; Russell and Machado, 1978). Some evidence indicates that use of higher plant densities may improve the efficacy of visual selection for inbred performance and combining ability (Russell and Teich, 1967; El-Lakany and Russell, 1971; Russell and Machado, 1978).

Objectives of this study were to investigate: 1) if visual selection among and within S_1 lines of maize derived from a genetically broad base population would be successful in choosing high-yielding and agronomically superior lines and 2) whether testcrosses of visually selected S_1 lines were superior to testcrosses of unselected S_1 lines. Effects of visual selection on heritability of traits, genetic variance, and predicted gain from selection among progenies also were presented.

MATERIALS AND METHODS

The maize population used in this study was 'Lancaster Composite', a genetically broad-base population synthesized between 1977 and 1980 at Iowa State University from inbred lines and populations of 'Lancaster Surecrop' origin. No previous selection had been conducted in Lancaster Composite at the time this study was initiated. S_1 progenies were obtained by self-pollination of unselected S_0 plants in Florida during winter 1979-1980, and the 1,636 S_1 progenies produced were evaluated in summer 1980 in a breeding nursery and a corn borer screening nursery, both near Ames, Iowa. One-row plots with one replication were used at each location. Plots contained 25 and 13 plants in the breeding and corn borer screening nurseries, respectively. At the corn borer nursery, the S_1 progenies were infested with two European corn borer egg masses (*Ostrinia nubilalis* Hübner) four times the last 10 days of June. Ratings on a 1 to 9 scale (1 = resistant and 9 = susceptible) were made about 3 weeks after infestation. Progenies susceptible (ratings 7 to 9) to first-generation corn borer leaf feeding were discarded before flowering in the breeding nursery and plants within remaining S_1 progenies were self-pollinated to produce S_2 progenies. Progenies in the corn borer nursery were inoculated with *Helminthosporium turcicum* Pass. on 11 August and rated for relative lesion number and size on 16 September. Pollinated plants were inoculated in mid-August in the second elongated internode with a stalk rot spore suspension containing *Diplodia maydis, Gibberella zeae, Fusarium moniliforme,* and *Collectotrichum graminicola* (Ces.) Wils. Based on the disease ratings, susceptible progenies were discarded at harvest.

Two sets of S_2 progenies were chosen at harvest in 1980. For one set, selection was based on maturity (date of pollination), seed set, ear size, resistance to stalk rot and leaf blight organisms on a scale of 0.5 to 5

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(0.5 = resistant and 5 = susceptible), and overall general appearance (vigor, stand, plant health) of progenies and plants within progenies. Two hundred S_1 progenies were selected, and the ear from the best plant within each selected S_1 progeny was saved to obtain 200 S_2 progenies. After completion of visual selection, 200 ears (S_2 seed) were saved by harvesting one self-pollinated ear from an unselected plant within approximately every eighth S_1 nursery row. Although no intentional selection was practiced, one necessary restriction was that each ear saved had adequate seed for replicated testing in four environments. Because of the manner in which the unselected 200-ear sample was taken, 31 of the unselected and visually selected S_2 lines were taken from common S_1 progenies.

In 1981, seed of the 400 S_2 progenies were planted in isolation for testcrossing to B84 × B73, a tester of 'Iowa Stiff Stalk Synthetic' origin. The S_2 lines were detasseled, and, at harvest, seed from approximately 13 plants of each line was bulked within lines to provide testcross seed. Because seed from each S_2 line was bulked, the crosses were genetically equivalent to S_1 plant × tester crosses.

The 400 S_2 lines were evaluated in yield trials at three Iowa locations (Ames, Ankeny, and Martinsburg) in 1981. An additional experiment was grown at the Ames corn borer screening nursery for collection of vertical root-pulling data. The 400 testcrosses were evaluated at these three locations in 1982 and 1983, but the Ankeny and Martinsburg locations were destroyed by windstorm and drought, respectively, in 1983. The experimental design at each location in all years was a split plot, with whole plots arranged in an incomplete block design with two replications. The 400 entries (S_2 lines in 1981 and testcrosses in 1982 and 1983) were divided into 10 sets of 40 entries each. Within each set, 20 visual and 20 unselected entries were included. Main plots in the split-plot design were selection types (visual or unselected) because the 20 entries of a selection type within a set were planted as a block. Subplots were individual entries nested within selection types. Selection types were randomized within each replication within each set, and entries were randomized within selection types.

Machine-planted, two-row plots 5.5 m long spaced 76 cm were used for each entry in the yield trials. Each entry in the root-pulling experiments was planted in a single-row plot 3.05 m long with 76 cm between plots. Root-pull plots were hand-planted in 1981 and 1982 and machine-planted in 1983. Plants in the hand-planted plots were spaced 25.4 cm within the row. All yield trial plots were machine-harvested, with no gleaning for dropped ears.

Data collected on all plots in each experiment included: 1) plants per plot (stand, thousands ha^{-1}), 2) plants per plot leaning 30° or more from the vertical (root lodging), 3) plants per plot broken below the ear (stalk lodging), 4) dropped ears per plot, 5) percentage grain moisture at harvest, and 6) shelled grain yield in Mg ha^{-1} (Mg $ha^{-1} \times 16 = bu\ A^{-1}$) converted to 15.5% grain moisture. Dropped-ear data were not taken at Ames in 1983. Root and stalk lodging and dropped ears were expressed as percentages of counted stands. Vertical root-pull resistance was measured each year in all plots in the corn borer screening nursery approximately 3 weeks after the beginning of anthesis, in the same manner as that reported by Kevern and Hallauer (1983).

An analysis of variance was computed for each trait for each set, pooled over sets for each environment, and combined across environments. Data were available from three environments for all S_2 traits except root-pull resistance, for which data were gathered in only one environment. Data from four environments were available for all testcross traits except dropped ears (three environments) and verticle root-pull resistance (two environments). Analyses of variance were performed using plot means for grain moisture and root pull and plot totals for the other traits. In all analyses in which they appeared, environments, sets, replications, and entries within selection types were considered random effects, and selection types were considered fixed effects. Entry sums of squares (380 df) and environment × entry sums of squares (760 and 1140 df for S_2 and testcross experiments, respectively) were partitioned into sums of squares for visually selected and unselected entries (190 df each) and their interactions with environments. Genotype (σ^2_G) and gentotype × environment (σ^2_{GE}) variance component estimates for each group were calculated by equating observed mean squares with their expected values. Variance component estimates from the visually selected and unselected entries were considered significantly different if the range of estimates, plus or minus twice their standard errors, did not overlap.

Heritability estimates on an entry mean basis were calculated as $\hat{\sigma}^2_G / (\hat{\sigma}^2_e / re + \hat{\sigma}^2_{GE} / e + \hat{\sigma}^2_G)$, where $\hat{\sigma}^2$ is an estimate of experimental error and r and e are number of replications and environments, respectively. Estimates of genetic gain per year for direct selection for a trait, and correlated responses in other traits, were calculated for both the visually selected and unselected groups of S_2 progenies and testcrosses as $\Delta G = kc\sigma^2{}_G h^2$ and $\Delta G = kc\sigma_{G2} r_{G12} h_1$, respectively. Predicted gains (or selection among S_2 lines) were based on a 3-year selection cycle, progeny evaluation using two replications in each of three environments, 12.5% selection intensity ($k = 1.65$), and recombination of S_2 seed. Gains from selection among testcrosses were predicted by assuming progeny evaluation using two replications in each of four environments, recombination of S_1 seed, and other variables the same as for the S_2 lines.

The 50 best S_2 lines of the 400 total entries were selected for single-trait superiority for grain yield, grain moisture, stalk lodging, and vertical root-pull resistance by using entry means calculated across all environments. A Smith-Hazel (Hazel and Lush, 1942) index using entry means for five traits (grain yield, grain moisture, stalk lodging, root lodging, and root-pull resistance) also was used to make selection among S_2 lines and their S_1 testcrosses. Estimated gains for each trait from each Smith-Hazel index were calculated as: $\Delta G = kbG/(b'Pb)^{1/2}$, where b is the vector of index weights, G is the genetic variance-covariance matrix, and P is the phenotypic variance-covariance matrix. The economic weights (a values) chosen for grain yield, grain moisture, root and stalk lodging, and root pull were 1.0, −1.0, −0.5, −0.5, and 0.25, respectively.

RESULTS

S_2 Line Selection Type Means

Significant differences ($P < 0.05$) between means of the visually selected and unselected groups of S_2 lines from the combined analysis were detected only for grain yield and stand (Table 1). Visual selection successfully chose a group of lines with mean grain yield (0.17 Mg ha^{-1}) and stand (2.6%) greater than that of the unselected lines. Environment × selection type interaction mean squares were not significant for all traits (data not shown), showing that selection type means changed little relative to one another across environments.

Examination of selection type means in individual environments revealed a significant difference for grain yield only at Martinsburg. Although differences between selection type means at Ames and Ankeny were not significant, the visually selected group had greater grain yield than the unselected group in all environments, indicating a consistent trend for the slight improvement of grain yield via visual selection (Table 1). No significant differences existed between selection type means for grain moisture in any environment, but the visually selected group tended to have slightly greater moisture in each environment. A trend toward improved stalk-lodging resistance for the visually selected group was established in each environment, ranging from 0.7% less at Ames to 5.1% less at Martinsburg, but differences were not signficiant. No significant differences between selection type means were observed for root lodging, dropped ears, or root pulling resistance. Stand percentage of the visually selected group was significantly greater than that of the unselected group in two of

Table 1. Means of S_2 line and S_1 line testcross selection types combined over all environments.

Progeny evaluation	Selection type[a]	Yield	Grain moisture	Stalk lodging	Root lodging	Dropped ears	Stand	Root pull
		Mg ha^{-1}		---%	---	---		kg
S_2 lines	VS	3.11 ± 0.03*	25.0 ± 0.09	15.5 ± 0.49	2.3 ± 0.15	0.6 ± 0.05	81.0 ± 0.28*	119 ± 0.7[b]
	RS	2.94 ± 0.02	24.3 ± 0.08	17.9 ± 0.18	2.4 ± 0.18	0.6 ± 0.05	78.4 ± 0.27	118 ± 0.6[b]
S_1 testcross	VS	8.10 ± 0.03	23.2 ± 0.05	18.8 ± 0.33	6.3 ± 0.22	0.5 ± 0.04	84.9 ± 0.22	158 ± 0.8[c]
	RS	8.10 ± 0.03	22.9 ± 0.05	20.7 ± 0.35	6.5 ± 0.22	0.5 ± 0.04	86.9 ± 0.18	159 ± 0.8[c]

*Selection type means differed at 0.05 probability level.

[a] VS refers to visually selected and RS to unselected entries.

[b] Root-pull data taken only at Ames in 1981.

[c] Root-pull data taken at Ames in 1982 and 1983.

three environments.

S_2 Line Testcross Selection Type Means

Testcross selection type means did not differ significantly for any trait in the combined analyses (Table 1). The environment × selection type interaction in the combined analyses was not significant for any trait (data not shown). Mean grain yield of the two groups of testcrosses, averaged over all environments, was identical. No consistent trend for yield of selection types was indicated by data from individual environments. For several other traits, trends noted in S_2 selection type means also were present in the testcross selection type means. Mean grain moisture of testcrosses of unselected lines was slightly less than that of testcrosses of visually selected lines in all environments. Mean stalk lodging of testcrosses of visually selected lines was significantly less than that of testcrosses of unselected lines at Ames in 1983, but the differences were not significant in the other environments. Selection type means for root lodging were not different, but the unselected group had 1.3% less root lodging than the visually selected group at Martinsburg (1982). Selection type means did not differ significantly in any environment for either percentage of dropped ears or root-pulling resistance, and no trend was evident for either trait. Testcrosses of visually selected lines had a smaller mean stand percentage than testcrosses of unselected lines in all environments, and in two environments (Ames 1982 and Martinsburg 1982), the differences were significant. These results are the reverse of those observed in the S_2 data.

Estimates of Genetic Variance and Gain From Selection

Genetic variance and heritability estimates calculated from the combined analyses of variance for both S_2 lines and testcrosses are presented in Table 2. Significant genetic variability was present for all the traits in the S_2 lines except for dropped ears in the unselected group. All genotype × environment interaction components for the S_2 lines also were significant but generally were smaller than their corresponding genetic variance components. The genotype × environment interaction was largest for stalk lodging and dropped ears and of least relative importance for grain yield. Genetic and genotype × environment variance component estimates for the visually

Table 2. Estimates of components of variance and heritabilities for S_2 lines and S_1 line testcross selection types calculated from combined analysis of variance.

		S_2 estimates				Testcross estimates			
Trait	Selection type[a]	$\hat{\sigma}^2_G$	$\hat{\sigma}^2_{GE}$	$\hat{\sigma}^2$	h^{2b}	$\hat{\sigma}^2_G$	$\hat{\sigma}^2_{GE}$	$\hat{\sigma}^2$	h^{2b}
Yield (Mg ha^{-1})[c]	VS	84.0 ± 9.9	17.0 ± 3.0	44.2	0.87	31.8 ± 5.5	35.9 ± 5.3	96.3	0.60
	RS	83.7 ± 9.9	16.2 ± 2.9		0.87	24.4 ± 4.6	28.2 ± 4.8		0.56
Grain moisture (%)	VS	4.3 ± 0.6	2.3 ± 0.3	4.6	0.74	1.4 ± 0.2	0.7 ± 0.1	2.5	0.75
	RS	4.0 ± 0.6	1.9 ± 0.3		0.74	1.5 ± 0.2	0.5 ± 0.1		0.78
Stalk lodging (%)	VS	115.0 ± 17.0	97.0 ± 10.5	91.7	0.71	25.4 ± 5.0	36.9 ± 5.5	100.5	0.54
	RS	138.4 ± 20.3	122.3 ± 12.3		0.71	33.1 ± 6.1	49.2 ± 6.2		0.57
Root Lodging (%)	VS	23.2 ± 2.9	5.9 ± 1.1	17.1	0.83	17.2 ± 2.8	10.0 ± 2.5	56.8	0.64
	RS	12.2 ± 2.0	11.5 ± 1.5		0.65	15.9 ± 2.7	12.3 ± 2.6		0.61
Dropped ears (%)[d]	VS	41.8 ± 9.5	26.5 ± 10.9	219.0	0.48	63.9 ± 9.7	1.2 ± 7.3	173.4	0.69
	RS	15.1 ± 7.8	45.4 ± 12.1		---[e]	5.5 ± 4.5	10.8 ± 7.9		---[e]
Stand (%)	VS	45.5 ± 6.3	13.9 ± 3.6	65.1	0.75	31.8 ± 4.3	20.1 ± 2.4	38.6	0.76
	RS	111.3 ± 12.9	12.5 ± 3.5		0.88	14.1 ± 2.1	6.4 ± 1.7		0.69
Root pull (kg)	VS	255.4 ± 50.2	---[f]	349.3	0.57	137.2 ± 29.7	57.3 ± 32.4	388.0	0.52
	RS	349.4 ± 53.7	---[f]		0.69	122.3 ± 29.3	70.5 ± 33.5		0.48

[a] S refers to visually selected and RS to unselected entries.

[b] h^2 is the heritability calculated on entry means as $\hat{\sigma}^2_G / (\hat{\sigma}^2_e / re + \hat{\sigma}^2_{GE} / e + \hat{\sigma}^2_G)$,

[c] Mg ha^{-1} × 10^2 for yield components of variance.

[d] % × 10^2 for dropped ears components of variance.

[e] Genetic variance was not considered significant; therefore, h^2 was not calculated.

[f] S_2 root-pull data taken in one environment only.

selected S_2 lines were not significantly different from their corresponding estimates from the unselected lines for grain yield, grain moisture, and stalk lodging. Genetic variance component estimates from the two selection types also were not significantly different for S_2 line root-pulling resistance. Estimates of genetic and genotype × environment variance components for root lodging among visually selected S_2 lines were significantly greater and smaller, respectively, than the estimates among the unselected lines. The genetic variance component estimate for stand percentage from the unselected lines was more than twice as large as that from the visually selected lines. As would be expected, given the similarity of variance component estimates from the two selection types, heritability estimates for the visually and unselected S_2 lines were similar for all traits.

Genetic variance component estimates from the testcrosses were usually smaller than those from the S_2 lines because the variation due to additive effects among S_2 lines was expected to be greater than among S_1 testcrosses. Differences in estimates from the two progeny types are confounded with a year effect, however, because lines and testcrosses were grown in different years. Significant genetic variability existed for all testcross traits with the exception of dropped ears in the unselected group. All estimates of genotype × environment interaction variance were significant, with the exception of the estimates for dropped ears in both selection types and the estimate root-pulling resistance in the visually selected group. Genotype × environment interaction variance components for both grain yield and stalk lodging were large and exceeded their respective estimates of genetic variances for both traits and both selection types. For all traits except percentage of stand and dropped ears, estimates of variance from the two selection types were similar and not significantly different. Heritability values were smaller than those estimated from the S_2 lines for most traits and ranged from 0.48 for vertical root-pulling resistance in the unselected group to 0.78 for grain moisture in the visually selected group. Estimated heritabilities for each trait were similar for each selection type, with neither selection type consistently showing greater heritabilities.

Predicted genetic gains and correlated responses from single-trait selection, and predicted gain from Smith-Hazel index selection, are shown in Table 3. For each trait, gains predicted for selection among visually selected or unselected S_2 lines were similar, with neither group of entries consistently showing greater predicted gains. Similar results were obtained for selection among testcrosses of either selection type. Predicted correlated responses were variable between the selection types. Of the 20 correlated responses predicted for S_2 selection, 11 were more advantageous to the breeder in the visually selected group, seven were better in the unselected group, and two were equivalent. Of 20 correlated responses predicted for testcross selection, nine and eight were more favorable in the visually selected and unselected groups, respectively, and three were identical in both groups. Predicted gains from Smith-Hazel index selection did not show a consistent advantage for either selection type, whether consid-

Table 3. Predicted direct gains and correlated responses for single-trait and Smith-Hazel (SH) (Hazel and Lush, 1942) index selection among S_2 lines and S_1 line testcrosses.

Selected trait	Selection type[a]	Yield	Grain moisture	Stalk lodging	Root lodging	Root pull
		Mg ha^{-1}	----------------	%----------------		kg
S_2 progeny						
Yield	VS	0.47	0.2	0.1	0.4	3.1
	RS	0.47	0.3	−0.4	0.0	3.2
Grain moisture	VS	−0.08	−1.0	2.0	−0.6	−3.8
	RS	−0.13	−1.0	2.5	−0.3	−6.5
Stalk lodging	VS	0.00	0.4	−5.0	0.1	1.6
	RS	0.03	0.4	−5.5	0.1	1.5
Root lodging	VS	−0.08	−0.3	0.3	−2.4	5.0
	RS	0.00	−0.2	0.5	−1.5	5.1
Root pull	VS	0.17	0.5	−1.2	−1.5	7.9
	RS	0.16	0.8	−1.0	−1.1	9.5
All traits in SH index	VS	0.40	0.3	−2.1	−0.6	6.3
	RS	0.41	0.6	−2.7	−0.5	6.3
		Mg ha^{-1}	----------------	%----------------		kg
Testcross progeny						
Yield	VS	0.48	0.3	−1.6	0.2	1.2
	RS	0.41	0.7	−1.8	0.4	2.6
Grain moisture	VS	−0.16	−1.1	1.9	−1.2	−0.7
	RS	−0.32	−1.2	1.5	−1.2	−1.3
Stalk lodging	VS	0.17	0.4	−4.1	−0.1	−1.5
	RS	0.16	0.3	−4.8	−0.4	0.5
Root lodging	VS	−0.03	−0.3	−0.1	−3.7	5.8
	RS	−0.05	−0.3	−0.7	−3.4	5.7
Root pull	VS	0.06	0.1	0.7	−2.1	10.7
	RS	0.12	0.1	−0.3	−2.1	9.8
All in SH index	VS	0.41	0.2	−2.4	−1.6	3.8
	RS	0.33	0.6	−3.6	−1.5	5.8

[a] VS refers to visually selected and RS to randomly selected entries.

Table 4. Number of visually selected entries present out of a total of 50 superior entries selected for the indicated trait.

Progeny type	Yield	Grain moisture	Stalk lodging	Root pull	Smith-Hazel index
S_2	28	17	26	28	29
Testcross	28	20	24	23	23

eration was for the S_2 lines or testcrosses for all traits.

Only slightly more than half of the 50 entries selected for superiority for S_2 grain yield, stalk lodging, root pull, and in the S_2 Smith-Hazel selection index were visual selections (Table 4). Unselected lines outnumbered visually selected lines 33 to 17, or nearly two to one, in the 50 S_2 lines with lowest grain moisture. Testcrosses of unselected lines slightly outnumbered testcrosses of visually selected lines in the 50 testcrosses superior for all traits except grain yield (Table 4).

DISCUSSION

The primary purpose of visual selection in recurrent selection or early testing schemes is to avoid using expensive yield trial resources to test undesirable gentoypes. Presumably, genotypes selected for yield testing are superior for some trait or traits to a random sample of genotypes from the population. In this study, the trend for average superiority for grain yield of the visually selected S_1 lines over the unselected lines was surprising. Visual evaluation of yield potential usually has been unsucessful for improvement of line yield, and some selection for ear size and seed set was done when choosing the unselected lines because of the need for adequate seed for yield trials. Improving grain yield of inbred lines per se is not usually considered an objective of visual selection, but if small gains can be accomplished while selecting against undesirable agronomic types, this is obviously desirable.

The trend (nonsignificant in this study) for visual selection to choose lines and plants with slightly later maturity, indicated by the slightly greater mean grain moisture of the visually selected group of S_1 lines, agrees with findings of other investigators that visual selection may result in selection of later-maturing genotypes (McKenzie and Lambert, 1961; Wilcox and Schapaugh, 1980; Nass, 1983). The relationshp between visual selection and later maturity in maize may be related to the later-maturing genotypes staying green and healthier-appearing in comparison with earlier genotypes and, thus, being phenotypically more attractive to selection. Maize breeders, however, should try to avoid selection of later-maturing plants and lines.

Although the trend of S_1 selection type means indicated some success in visual selection against stalk-lodging susceptibility, the lack of a greater difference between the two groups of lines was disappointing. One of the objectives of many breeders using visual selection among and within S_1 lines is to eliminate genotypes susceptible to stalk lodging. Because the set of unselected lines was developed without selection of stalk quality, selection pressure for improved stalk-rot resitance and, consequently, stalk lodging resistance would be expected to be greater for the visually selected lines. Stalk-rot and stalk-lodging variability were present to allow selection opportunities, and an adequate number of lines and plants were screened to allow selection intensities stringent enough to provide for progress had desirable genotypes been correctly identified. Either some of the plants selected as disease-free were escapes, or the spread of infection resulting from the artificial inoculation technique was not well correlated with field resistance to stalk rot and stalk lodging. Although visual evaluation of stalk-rot resistance by this technique did have a desirable impact on S_2 line stalk-lodging resistance, addition of other techniques to accentuate stalk-quality differences among genotypes may be desirable. These techniques could include planting S_1 lines more densely and harvesting them later in the season to allow more natural stalk lodging before selection. In this study, S_1 lines were planted at a moderate density (54.9 M ha^{-1}) in the breeding nursery and harvested in late September.

Lack of success of visual selection for reducing root lodging of S_2 lines was less surprising than for stalk lodging. Selection for root-lodging resistance was based on natural root lodging. Expression of root lodging in a breeding nursery is often sporadic and may reflect environmental differences rather than genotypic differences. This, along with poor expression of root lodging in the breeding nursery when selections were made, probably accounts for the lack of success of visual selection for improvement of root-lodging resistance. Additionally, occurrence of root lodging in the S_2 yield trials was never large enough to allow evaluation of differences between selection types. The most plausible explanation for improvement of mean stand percentage of the visually selected S_2 lines is that visual selection for large, well-filled ears and desirable plants resulted in selection pressure for disease-free seed from healthy maternal genotypes.

Selection among and within S_1 lines had little effect on line testcross performance for most traits. The single-cross tester used may have masked small grain yield differences between testcross selection types that were more evident in the lines themselves. Testcross selection type means for grain moisture and stalk lodging revealed trends for those traits similar to those observed in the S_2 lines. Reduced mean stalk lodging of the testcrosses of visually selected lines in all environments shows that the slight improvement made in average line stalk quality was also imparted to their testcrosses.

Selection had few consistent effects on line or testcross estimates of genetic variances and genotype × environment variance components, heritabilities, correlations among traits, or predicted gains. Differences between selection types were observed occasionally for the estimates of some parameters, but they did not favor either selection type consistently. Selection practiced evidently did not alter gene frequency enough to change estimates of population genetic parameters relative to those that would be obtained from an unselected sample.

Although selection resulted in slight improvement of S_2 line grain-yield and S_2 and testcross stalk-lodging means, many of the individual S_2 and testcross entries superior for important traits were unselected entries. Obviously, many desirable and productive genotypes were not chosen by visual selection. These results are in agreement with studies conducted in self-pollinating species, which have suggested that visual selection is better suited for discarding undesirable genotypes rather than for selecting desirable ones (Frey, 1962; Hanson et al., 1962; Atkins, 1964). Visual selection is known to be an effective means of discarding these undesirable genotypes before yield-testing. Our results indicate that it is also worthwhile for the breeder to use visual selection techniques for stalk quality and grain yield. Rather than attempt to select for disease-free stalks and large, well-filled ears, as was done in this study, better results might be obtained for these traits by planting S_1 lines more densely to impose greater stress, leaving lines in the field as long as possible, and then discarding lines with unacceptable stalk breakage and barrenness. Other studies (Russell and Teich, 1967; El-Lakany and Russell, 1971; Russell and Machado, 1978) have indicated positive results from visual selection using dense plantings. Beyond discarding undesirable genotypes, the breeder's best option seems to be to test in replicated yield trials as many remaining progenies as resources will allow. Reliance on visual selection alone can be expected to result in the loss of superior inbreds and hybrids.

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