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BREEDING AND GENETICS

Visual Selection for Yield in Cotton Breeding Programs

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ABSTRACT

Cotton breeders routinely discard progeny rows that visually appear low yielding. Such a process is essential, because it would be highly inefficient to continue to work with progeny that have no commercial value. A dilemma for all breeders is whether they are inadvertently discarding promising lines. Cotton breeders from four states conducted a 2-year study to determine if visual selection was an effective method of selecting for yield. To accomplish this, progeny rows in replicated preliminary yield trials for seedcotton yield were visually rated. Correlations between visual ratings and actual yields ranged from -0.22 to 0.70, and there were differences among breeders in their ability to select superior-yielding genotypes. High-yielding genotypes that were visually rated low would have been discarded in every study. This is an inherent danger in visual selection, but recurring placement of high-yielding check cultivars and the use of a grid system should alleviate some of this problem. Generally, high-yielding genotypes were rated higher than low-yielding genotypes. Range of yields, mean yields, plant height, and soil type did not affect a breeder's ability to visually rate the plots for seedcotton yield.

Visual selection was the first breeding method practiced by man. Beginning in the 1700s, visual selection within cotton (*Gossypium hirsutum* L.) cultivars resulted in the development of adapted, successful cultivars in the USA (Niles and Feaster, 1984). In the early 1800s, Henry W. Vick in Mississippi developed 'Hundred Seed' and later 'Jethro', which were selected by workers in the field from the largest and most productive plants of 'Petit Gulf' (Moore, 1956). With so much variability in the stocks of introduced cultivars, "good" plants were easy to identify and progress was made toward yield improvement (Richmond, 1951).

There is some evidence that visual selection in the early generations is effective in identifying superior phenotypes. Phenotypic variability among individual plants is large even for established cultivars (Kohel and White, 1963; Thomson, 1973a). Gardner (1961) devised a method of stratifying the selection block in order to manage environmental variability among plants. Verhalen et al. (1975) used Gardner's grid system to improve selection in cotton by 20 to 35%. Meredith and Bridge (1973) used visual selection to identify F_2 plants that had higher yielding F_3 progeny. The 5.7% gain in yield was significant, but the authors recommended that selection begin in the F_3 generation due to nonadditive gene effects evident in the F_2 generation.

In later generations, selection among unreplicated progeny becomes a challenge. In a typical cotton breeding program, actual harvest of hundreds or thousands of rows may be impossible. Yet a breeder must quickly evaluate and select superior lines for advancement (Allard, 1966). Effectiveness of selection for superior phenotypes declined from single hills to single rows to multi-row plots in a study by Thomson (1973b). Variability due to inter-genotypic competition that increased from single hills to multi-row plots was thought to be involved.

Whether visual selection can be used to identify superior phenotypes of cotton prior to replicated yield trials when the breeding material is in the progeny row stage (single or two-row short plots) needs to be determined. Such selections have been documented in other crops. In soybean, *Glycine max* (L.) Merr., poor-yielding lines could be discriminated visually, although lodging hampered their accuracy (Hanson et al., 1962). Kwon and Torrie (1964) found that the range in yield affected the ability to visually select in extremes in yield. Both of these studies showed that visual selection on single progeny rows was

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only half as effective as actual yield determination for identifying superior-yielding phenotypes.

Dao and Ram (1992) observed a positive correlation of 0.36 between visual yield rating and actual yield in soybean and concluded this was an effective discrimination method, although lodging hampered their judgment in scoring for high yield. Plant height and maturity of plants also influenced judgment. Byth et al. (1969) also found positive phenotypic correlations between visual yield ratings and actual measured yields.

The ability of three breeders to select superior lines of soybean has been compared (Helms et al., 1995). Two of three breeders were able to select lines that were higher yielding than the population average and were just as effective as selection based on weighed yields. This study involved crosses of adapted with unadapted lines, but most crosses in a typical commercial cotton breeding program are usually among adapted lines only.

Response to visual selection in small grains was minimal. In oat (*Avena sativa* L.), visual selection for high or low yield was ineffective (Frey, 1962). Stuthman and Steidl (1976) were not able to consistently select high or low yielding lines and cautioned against discarding large numbers of oat progeny via visual selection. Studies by Briggs and Shebeski (1970) on wheat (*Triticum aestivum* L.) concluded that selection intensity of visual ratings should be low because of inaccuracies in choosing the best-yielding lines. Selection intensity in triticale (*Tritioco secale* W.) via visual rating for yield should be low also (Salmon and Carter, 1978).

The objective of this study was to determine if visual selection could be effectively used to determine the highest yielding lines in unreplicated nurseries for advancement to replicated trials. Information from this study could aid cotton breeders in deciding whether to discard potentially low yielding lines in progeny rows prior to actual yield testing to make their breeding program more efficient.

MATERIALS AND METHODS

The study was conducted in 2001 and 2002 in Arkansas, Louisiana, Mississippi, and North Carolina. Data from Arkansas are reported only for 2002. Mean seedcotton yield and, when available, range of yields, soil type, and plant height, were analyzed to determine their impact on the ability to choose higher yielding genotypes.

In Arkansas, 188 progeny rows were rated for yield by three persons, one each with greater than 30 yr, greater than 4 yr, and less than 1 year of breeding experience. The plots were 12 m long and four rows wide and harvested by machine. Two check cultivars were used and a check was planted in every 6th plot. The accuracy of the visual assessments was compared with actual measured seedcotton yields. Visual ratings of yield potential were based on a scale of 0 to 9, where 0 = poor yield potential and 9 = excellent yield potential.

In Louisiana in 2001, a strains test was rated for seed cotton yield on three replicates at three locations. Yield potential was rated using the 0 to 9 scale. Plots were four rows and 12.2 to 15.3 m long. Ratings were made on the center two rows. There were 20 entries in the trial. Visual ratings were taken prior to defoliation.

In Mississippi, the official early-maturing state-wide variety test at Brooksville was rated for seedcotton yield in 2002. The test had 32 entries and four replicates. Yield potential was rated using a 0 to 5 scale, where 0 = poor yield potential and 5 = best yield potential.

In North Carolina, visual ratings on a scale of 1 (worst yield potential) to10 (best yield potential) were made on all advanced breeding line (strain) trials at three locations in 2001 and two locations in 2002. Each plot consisted of two rows, 12 m long with 3 or 4 replicates per test. Every replicate was rated. Seedcotton yields were correlated with visual ratings. Eleven tests were rated in 2001 and 15 in 2002.

The genetic material in the studies at Arkansas, Louisiana, and North Carolina are typical of cotton breeding programs. Since the genetic material in the Mississippi trial was part of a state-wide variety trial, the material had been tested and selected prior to entry into the trial. In either case, the objective of this study was to determine if breeders could visually discern higher yielding genotypes without going through the expensive process of yield testing all progenies.

In all replicated trials, correlations were run as if entries were not repeated. Correlation coefficients were examined between identical trials at the two separate locations in both years of the North Carolina data.

RESULTS AND DISCUSSION

In Arkansas, all three breeders had significant ($P \leq 0.05$) positive correlations between their visual ratings and actual yields, and higher correlations were associated with greater experience (>30 yr, $r = 0.51$; >4 yr, $r = 0.48$; and <1 yr, $r = 0.36$).

Table 1 shows the distribution of ratings and the mean seedcotton yield for each rating. With four exceptions, mean seedcotton yield increased with higher visual ratings by the breeders. The breeder with more than 30 years of experience had the best progression of increasing yield with higher ratings. The breeder with 4 years of experience tended to rate the plots lower than the other two breeders.

More interesting was their ability to choose the best and the worst lines. Table 2 shows the seedcotton yields of the top and bottom 10% of the lines and the ratings they received. If a rating criteria of 6.0 to retain was applied, four (including the highest) of the top 10% would have been rejected. Two of these were the checks. Four of the bottom 10% would have been retained and all four were near each other in the field. This points to a potential difficulty in identifying superior lines that may appear different from what is considered to be "normal". The breeder with more than 30 years of experience would have rejected only one of the top 10% (the second was a check), whereas the breeders with greater than 4 years of experience and with less than one year of experience would have rejected eight and three, respectively. Relying on visual selection to evaluate phenotypes that appear different from current high-yield phenotypes may result in the loss of potentially good material. Of course, many breeders do not discard enough lines due to the danger of throwing away excellent material. Yield trials are expensive and any technique to expedite the process of eliminating less-than-desirable genotypes may be warranted.

The Louisiana study conducted by two breeders with many years of experience demonstrated the effect of leaves on the plant in obscuring the ability to visually rate for yield (Table 3). Correlations were all nonsignificant. There was little difference between the two breeders in their ability to determine seedcotton yields. There was a trend, although not statistically significant, for correlations to be higher and positive for the higher yielding location (St. Joseph). There was little difference in the range of yields at the three locations.

In Mississippi, the correlation between seedcotton yields and visual rating was 0.49 (significant at $P = 0.001$). Using a scale of 1 to 5 and assuming the breeder saved the plots rated 4 or 5, five plots of 128 plots would have been erroneously discarded on the basis of their visual ratings, but their actual yield exceeded the average of the 5 rated category. The average yield for plots rated 5 was 2682 kg/ha, and for plots rated 4 was 2526 kg/ha, while plots rated 3 averaged 2186 kg/ha. The closeness in the average between 4 and 5 shows the difficulty in differentiating the higher yielding plots. A breeder would not want to choose only plots rated 5 since 15 plots with yields above the average for 5 would have been discarded.

Table 1. Comparison of visual quality ratings by three breeders and seedcotton yield of 188 progeny at Keiser, AR in 2002

Visual rating[z]	Years of cotton breeding experience					
	>30 yr		>4 yr		<1 yr	
	No. progeny	Mean ± sd (kg/ha)	No. progeny	Mean ± sd (kg/ha)	No. progeny	Mean ± sd (kg/ha)
0	0		1	129	0	
1	0		1	1745	1	129
2	1	129	1	1221	0	
3	1	1743	22	2615 ± 621	10	2622 ± 841
4	15	2490 ± 602	49	3025 ± 364	31	2810 ± 467
5	36	2896 ± 516	55	3143 ± 370	35	3064 ± 358
6	68	3064 ± 362	45	3178 ± 475	23	2985 ± 503
7	52	3240 ± 413	9	3330 ± 298	45	3216 ± 405
8	15	3508 ± 402	5	3776 ± 393	36	3272 ± 640
9	0		0		7	3114 ± 459

[z] Visual rating of yield potential on a scale of 0 to 9, where 0 = poor yielding to 9 = excellent yielding.

Table 2. Actual rank of the top and bottom 10%-yielding cotton progeny in 2002 compared with the visual ratings given by three breeders with different levels of experience

Rank		Seedcotton (kg/ha)	Visual ranking by cotton breeders (years of experience)^z >30 yrs	>4 yrs	<1 yr	Average
1		4842	5	3	3	3.7
2		4695	8	6	8	7.3
3	(check)	4310	7	8	7	7.3
4	(check)	4274	4	6	7	5.7
5	(check)	4071	7	8	8	7.7
6	(check)	3961	7	7	7	7.0
7	(check)	3924	6	5	6	5.7
8		3924	8	5	9	7.3
9		3889	7	6	7	6.7
10		3889	6	6	6	6.0
11		3870	7	4	7	6.0
12		3852	7	6	5	6.0
13		3834	7	5	8	6.7
14	(check)	3815	8	8	8	8.0
15		3778	6	4	8	6.0
16		3760	7	5	7	6.3
17		3760	8	5	8	7.0
18		3742	6	5	5	5.3
19	(check)	3723	7	6	8	7.0
170		2384	4	5	4	4.3
171		2384	4	4	5	4.3
172		2366	7	6	8	7.0
173		2330	4	3	4	3.7
174		2293	5	4	3	4.0
175		2256	5	4	4	4.3
176		2256	6	6	7	6.3
177		2183	5	3	4	4.0
178		2091	7	6	6	6.3
179		2054	4	3	3	3.3
180		2054	6	3	4	4.3
181		2054	6	6	8	6.7
182		1889	4	3	3	3.3
183		1852	4	3	5	4.0
184		1761	5	3	3	3.7
185		1743	3	1	3	2.3
186		1651	5	3	6	4.7
187		1229	4	2	4	3.3
188		129	2	0	1	1.0

^{z} Visual rating of yield potential on a scale of 0 to 9, where 0 = poor yielding to 9 = excellent yielding.

Table 3. Correlations between visual yield ratings by two breeders and actual seedcotton yield in Louisiana in 2001

Location	Mean yield (kg/ha)	Yield range (kg/ha)	Correlation (*r*)	
			Breeder A	Breeder B
Bossier City	**867**	**519**	**-0.22**	**-0.09**
St. Joseph	**1210**	**620**	**0.14**	**0.06**
Winnsboro	**802**	**604**	**-0.19**	**-0.20**

Since the entries were replicated four times in this study, entries that were rated 5 in one replicate were examined in the remaining three replicates. Soil variability between and within replicates may have been a factor. There is often soil variability in most breeders' nurseries because the better fields are used for yield and quality trials. Seven of the nine entries rated 5 in one or more replicates had ratings 3 or below in at least one replicate. Only three had ratings of 3 or below in two replicates. This would suggest that high-yielding check plots should be planted (spaced) at intervals to assist in making valid comparisons for selection.

In North Carolina, correlations between visual ratings and actual yields averaged 0.38 in 2001 and 0.51 in 2002 (Table 4). Only three correlations were not significant in 2001 and one in 2002. In 2002, correlations improved throughout the day with lowest correlations occurring in the morning. One corn breeder (Don Thompson, personal communication, 2003) takes visual disease ratings three times on his plots, not trusting his initial numbers.

Several of the trials in North Carolina were identical, i.e. had the same entries and replicates, but were planted at different locations. There was inconsistency between those trials. In 2001, trial 1 (0.55) was the same as trial 6 (0.32), trials 2 and 7 were the same (0.11 vs. 0.70), trials 3 and 8 were the same (0.40 vs. 0.56), trials 4 and 10 were the same (0.08 vs. 0.40), and trials 5 and 11 were the same (0.56 vs. 0.06). In 2002, trials 4 and 15 (0.84 vs. 0.29), trials 5 and 10 (0.50 vs. 0.39), trials 6 and 11 (0.40 vs. 0.60), trials 7 and 12 (0.55 vs. 0.61), trials 8 and 13 (0.38 vs. 0.66), and trials 9 and 14 (0.51 vs. 0.47) were the same. The correlation between the visual ratings and mean yield was -0.34. It was thought that it may be easier to visually rate for yield at higher yield levels, but the negative correlation indicated otherwise.

One would also think that trials with a larger range of yields would have larger correlation coefficients with their visual ratings, i.e. easier to tell the difference, but that wasn't always the case. Trials 4 and 10 were the same with trial 4 having the largest range of yields (1343 vs. 901), but the lowest correlation coefficient (0.08 vs. 0.40).

Soil types were examined but no definite conclusion can be drawn because only two soil types were used in the North Carolina study. Plant height was also examined, but the correlation between visual rating and plant height was not significant (r = -0.20).

In 2002, ratings (0 to 10) and their mean yields for NC were 1 = 879, 2 = 1279, 3 = 1698, 4 = 2519, 5 = 3060, and 6 = 3341 kg/ha. No plots were rated 7 or better. There was a positive trend for higher yields with higher visual ratings.

In this study, seven breeders rated plots in four states. There were differences among breeders in their ability to discern high-yielding plots, but in the Arkansas and Louisiana studies these differences did not appear to be large.

Overall, the data supports the idea that some selection for yield can be made on a progeny row basis. The Louisiana study demonstrated the difficulty in rating plots for yield when the leaves have not been removed and suggested that visual rating should not be attempted before defoliation. It is recognized that some good-yielding lines will be discarded due to imprecision of the visual rating system and soil variability. As the number of progeny rows to evaluate is increased, a breeder might be more willing to accept the loss of a few good lines in exchange for time/cost savings. The placement of high-yielding check cultivars at appropriate intervals is highly recommended. Gardner's grid system (Verhalen et al., 1975) would infer that selections be made in small blocks, thus the check cultivar should enhance the ability to select the best within small grids or blocks.

The eye needs to be trained in estimating potential yield. Conducting a second rating at least on the first hundred progeny rows may be necessary to improve correlations. Size of bolls and number of bolls must be mentally factored into the breeder's judgment when making ratings.

Table 4. Correlations between visual yield ratings and actual seedcotton yield, range of yield, mean yield, soil type, and plant height in North Carolina

Test	r^z	Yield range (kg/ha)	Mean yield (kg/ha)	Soil type	Mean plant height (cm)
2001					
1	0.55*	1479	3703	Norfolk loamy sand	91
2	0.11	1071	4007	Norfolk loamy sand	91
3	0.40**	1122	4088	Norfolk loamy sand	91
4	0.08	1343	3266	Goldsboro fine sandy loam	86
5	0.56**	1734	2989	Goldsboro fine sandy loam	86
6	0.32*	1598	3484	Goldsboro fine sandy loam	86
7	0.70**	1785	3418	Goldsboro fine sandy loam	86
8	0.56**	1785	3512	Goldsboro fine sandy loam	86
9	0.50**	1122	2951	Goldsboro fine sandy loam	91
10	0.40**	901	3761	Goldsboro fine sandy loam	99
11	0.06	901	3647	Goldsboro fine sandy loam	99
2002					
1	0.51**	1564	1733	Goldsboro fine sandy loam	81
2	0.44**	1666	1599	Goldsboro fine sandy loam	81
3	0.51**	1989	1990	Goldsboro fine sandy loam	81
4	0.84**	1530	2132	Goldsboro fine sandy loam	94
5	0.50**	1649	2256	Goldsboro fine sandy loam	94
6	0.40**	1632	2608	Goldsboro fine sandy loam	94
7	0.55**	1972	2666	Goldsboro fine sandy loam	94
8	0.38**	1734	2951	Goldsboro fine sandy loam	94
9	0.51**	1377	2885	Goldsboro fine sandy loam	94
10	0.39**	901	1286	Goldsboro fine sandy loam	76
11	0.60**	1003	1304	Goldsboro fine sandy loam	76
12	0.61**	935	1210	Goldsboro fine sandy loam	76
13	0.66**	986	1028	Goldsboro fine sandy loam	76
14	0.47**	1139	999	Goldsboro fine sandy loam	76
15	0.29	748	83 8	Goldsboro fine sandy loam	76

^{z} **Correlation coefficients designated * and ** are significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.**

Another factor to consider is the orientation of the rows. Rows east-west may be difficult to rate depending on whether you were facing the sun or not. In such cases, a second rating at the other end of the plots may be in order.

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