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# Effectiveness of Selection in Upland Cotton in Stress Environments[1]

J. E. Quisenberry, Bruce Roark, D. W. Fryrear, and R. J. Kohel[2]


## ABSTRACT

**Much of the Upland cotton (*Gossypium hirsutum* L.) acreage grown in the United States is produced in environments where lack of moisture and low temperatures frequently limit production. The purpose of the current research was to test the effectiveness of selecting for lint yield in such stress environments as compared with an optimal environment. Random $F_3$ plants from a composite cross population were advanced two generations by self-pollination. The $F_4$ and $F_5$ progenies were grown at Lubbock, Big Spring, and College Station, Tex. in 1976, and the $F_5$ progenies were grown at the same locations in 1977. In both years, all locations were classified as deficient or adequate in temperature and moisture based on input heat units and available water. Genotype × environment interactions, within-location heritabilities, and genetic advance for lint yield were estimated.**

**In 1976, Lubbock was deficient in heat units and adequate in precipitation, Big Spring was adequate in heat units and deficient in precipitation, and College Station was adequate in both heat units and moisture. Entries were not significantly different for lint yield at either Lubbock or Big Spring, although the genotype × environment interaction was significant for these locations. At College Station, entries were significantly different, whereas the genotypes × environment interaction was not significant. We concluded that selection within the stress environments was largely based upon genotype × environment interactions. A significant genetic advance for lint yield was realized at all locations when the selection was made at College Station in an environment considered optimal for the growth of Upland cotton.**

***Additional index words:* Stress, Drought, Cotton breeding, Genotype, Temperatures, Heat units, *Gossypium hirsutum* L.**


ABOUT 40% of the land planted to Upland cotton (*Gossypium hirsutum* L.) in the United States is in the Southern Great Plains. All of this region is classed as semiarid, and is subject to extremes of climatic variation. Seasonal temperatures in the northern portion are marginal for the growth of a subtropically-adapted species such as cotton. Thus, insufficient precipitation and low temperatures of the region are annually a threat to the productivity and quality of the cotton crop.

Roark and Quisenberry (6), and Quisenberry (5), proposed that cotton cultivars adapted to the climatic rigors of the Southern Great Plains could be developed through the identification and selection of pertinent physiological traits. However, if such traits are not already present in currently grown cultivars, they would probably have to be introduced from obsolete material or unproductive race stocks.

A dilemma in selecting cottons for limiting environments is the extent to which yield potential depends upon potential productivity per se, that is, ability to yield well in most environments whether limiting or not, or an adaptation to a particular condition in a stressed environment, such as tolerances for temperature extremes or moisture deficits. The most common method of evaluating yield potential is to grow the cotton under optimal conditions. Obviously there is the question of whether or not such a plan would detect those cultivars that have special adaptations for stress environments. In this paper we compare the effectiveness of selection for line yield in a group of upland lines in what we have defined as optimal and stressed environments.

## MATERIALS AND METHODS

The study was conducted at Lubbock, Big Spring, and College Station, Tex. during the seasons 1976 and 1977. Lubbock (latitude 32° 42′ N, longitude 101° 50′ W, elevation 989 m) typified the northern cotton-producing areas of the Southern Great Plains. It is semiarid, a transitional area between the arid zone of the west and the humid climate of the east and southeast. Average annual precipitation is 47 cm, with irrigation water available from the Ogallala aquifer. Average annual temperature is 15.4 C, with an average of 23.6 C during the growing season from May to September. Yields of irrigated cotton relate closely to seasonal fluctuations in temperature.

Big Spring (latitude 32° 15′ N, longitude 101° 27′ W, elevation 771 m) is near the dividing line between the Southern Great Plains and the Edwards Plateau region of Texas, and is representative of the southern-most cotton production region of the Great Plains. The climate of Big Spring is semiarid with dry winters and warm summers. Precipitation averages 47 cm annually, most occurring in the form of thunderstorms from May through October. The average annual temperature is 17.2 C, with a growing-season average of 25.6 C. Irrigation is not available, so crop productivity is most closely related to variations in seasonal precipitation (1).

College Station (latitude 30° 35′ N, longitude 96° 21′ W, elevation 96 m) is located within the south central humid, subtropical zone. Precipitation averages 99 cm annually, with March the driest month and May the wettest. Average yearly temperature is 20.4 C, with an average of 26.1 C during the growing season. Moisture and temperature are usually adequate for high cotton productivity, but inadequate rainfall during July and August reduces yield during some seasons. The test site was in the alluvial plain of the Brazos River.

The entries were random lines pedigreed from a composite cross population designated HP-ACA (4). This population was developed by crossing six randomly chosen cultivars adapted for growth in the Southern Great Plains with four high-quality Acala cultivars, developed for irrigated farming in the western United States. The Plains cultivars were used as the female parents and Acalas served as the males. Each $F_1$ progeny was grown separately and equal amounts of $F_2$ seed bulked to form the initial composite population. Random $F_3$ plants were self-pollinated to generate the $F_4$ entries. Each $F_4$ entry was then self-pollinated to produce the $F_5$ entries. Of the 100 $F_3$ plants chosen, only 79 produced enough seed to generate $F_4$ and $F_5$ entries.

The 79 $F_4$ and $F_5$ entries were grown at all locations in 1976, whereas only the $F_5$ entries were grown in 1977. At Lubbock, 40 cm of water was applied, 20 cm prior to planting and 20 cm as a single irrigation in the summer. Irrigation was practiced in both years. The entries were planted at all locations in ran-

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[2] Research geneticist and plant physiologist, Cotton Prod. Lab., AR, SEA, USDA, Route 3, Lubbock, TX 79401; agricultural engineer, AR, SEA, USDA, P. O. Box 909, Big Spring, TX 79720; and research geneticist, AR, SEA, USDA, P. O. Drawer DN, Texas A&M Univ., College Station, TX 77840, respectively.

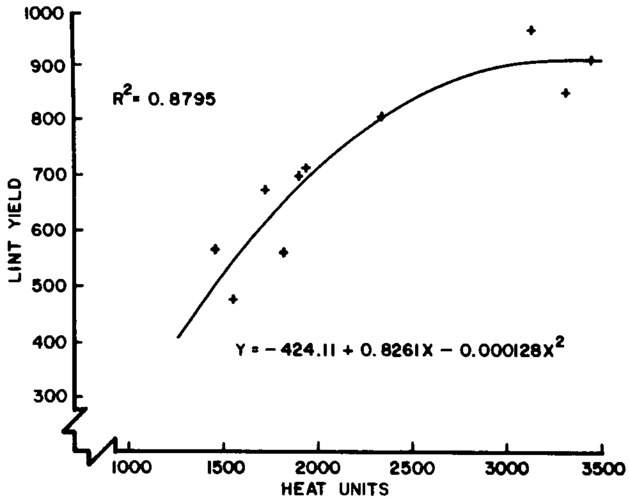


**Fig. 1. Relationship between lint yield and heat units at Lubbock, Tex.**

domized complete block designs with two replications. Planting dates were 19 May 1976 and 20 May 1977 at Lubbock, 7 June 1976 and 2 June 1977 at Big Spring, and 6 May 1976 and 11 May 1977 at College Station. Data were taken only on lint yield.

In 1976, $F_4$ and $F_5$ data were compared to assess the magnitude of any residual dominance effects in the population. The $F_5$ data from 1976 and 1977 were compared to estimate genotype × environment interaction at each location and for combined data in each year (2).

The environmental variables, temperature and precipitation, were used as measures of stress in a particular year and location. Each year-location combination was defined as either adequate or stressed by a deficit of either temperature, water, or both. Several factors other than temperature and precipitation can influence the yield of cotton. Cultural and tillage practices at all locations were conducted to minimize the effect of soil fertility, insects, and diseases on productivity.

To evaluate the adequacy of each year-location combination for the environmental variable of temperature, 20 C was subtracted from daily average temperatures during the period May through September. The residual values were then summed. We defined this total as heat units. Because a relationship between cotton yields and heat units was not available, a regression equation between yield and heat units was calculated with data from irrigated yield trials at Lubbock, Tex., provided by L. L. Ray, and with daily temperatures during 1969 to 1978. The yield values used were the means of the 10 highest-yielding entries in the Lubbock irrigated yield trials. Because all cultural and tillage inputs in these tests were conducted to maximize productivity, we assumed that these yield values were optimized for all environmental variables except temperature. Therefore, we concluded that the flexion point on the curvilinear plot thus developed approximated the number of heat units needed for optimal yields at Lubbock, Texas.

To evaluate the adequacy of year-location combinations for precipitation, the crop year (September to August) was divided into two periods, preseasonal (September to April) and seasonal (May to August). Burnett and Moldenhauer (1) evaluated 40 years of data on the relationship between precipitation and lint yields at Lubbock and Big Spring, Texas. They determined that production of 100 kg/ha of lint yield required 10 cm of seasonal or preseasonal precipitation at Lubbock and 11 cm at Big Spring. Grimes (3) showed that 85 to 95 cm of precipitation was required for optimal lint yields at Shafter, Calif.

## RESULTS AND DISCUSSION

The relationship between lint yield and heat units for Lubock, Tex. is shown in Fig. 1.) The flexion point indicated that about 3,326 heat units were required before temperature ceased to be a limiting factor on line yield at that location.

**Table 1. Characterization of years and locations for cotton lint yield by the use of heat units and precipitation; 3,326 heat units and 85 cm of precipitation comprise an adequate environment.**

| | | | Location | | |
|---|---|---|---|---|---|
| Year | Environmental parameter | | Lubbock | Big Spring | College Station |
| 1976 | Heat units† | C | 1,454 | 3,839 | 4,385 |
| | Precipitation | cm | 85‡ | 49 | 90 |
| | Preseason | | 34 | 27 | 60 |
| | Seasonal | | 51 | 22 | 30 |
| 1977 | Heat units† | C | 3,451 | 5,110 | 5,866 |
| | Precipitation | cm | 85† | 52 | 94 |
| | Preseason | | 43 | 30 | 82 |
| | Seasonal | | 42 | 22 | 12 |
| Long-term average | Heat units† | C | 2,471 | 4,253 | 5,618 |
| | Precipitation | cm | 47 | 47 | 99 |
| | Preseason | | 23 | 24 | 65 |
| | Seasonal | | 24 | 23 | 34 |

† Estimated from May through September. ‡ 40 cm of water added with irrigation 20 cm before planting and 20 cm during the growing season.

**Table 2. Mean squares from the analysis of variance for lint yield from $F_4$ and $F_5$ generations of cotton grown at three locations in 1976.**

| Source | Degrees of freedom | Mean square |
|---|---|---|
| Locations (L) | 2 | 14,460,318** |
| Generations (G) | 1 | 38,097 |
| L × G | 2 | 13,075 |
| Entries (E) | 78 | 77,507** |
| E × L | 156 | 34,788* |
| E × G | 78 | 33,539 |
| E × G × L | 156 | 22,591 |
| Residual | 474 | 25,774 |

*,** Significantly different at the 0.05 and 0.01 levels of probability, respectively.

With 3,326 heat units and 85 cm of precipitation as criteria for environmental adequacy, each location-year environment was classed as either adequate or deficient in temperature and precipitation (Table 1). In 1976, the Lubbock location was deficient in heat units but was made adequate in precipitation through irrigation. Big Spring had adequate heat units but insufficient precipitation. College Station had adequate temperature and moisture. Average lint yields in 1976 were 625, 493, and 911 kg/ha for Lubbock, Big Spring, and College Station, respectively.

The 1977 season at all locations was characterized generally by unusually hot and dry conditions (Table 1). At Lubbock, heat units and precipitation were adequate, whereas at Big Spring, temperatures were adequate but precipitation was deficient. Although the total precipitation for the growing season was greater than 85 cm at College Station there was only 0.79 cm of rainfall in July and below-normal rainfall in August. In 1977, average lint yields were 1,095, 386, and 483 kg/ha at Lubbock, Big Spring, and College Station, respectively.

Mean squares are presented from the analysis of variance of the $F_4$ and $F_5$ generations grown in 1976 at all locations (Table 2). No significant differences were found for generations or for first or second-order interactions with generations. Dominance effects for

Table 3. Mean squares from the analysis of variance for lint yields from $F_5$ entries of cotton grown at three locations and 2 years.

| Source | Degrees of freedom | Mean square |
|---|---|---|
| Locations (L) | 2 | 14,620,635** |
| Years (Y) | 1 | 48,382 |
| L × Y | 2 | 16,207,799** |
| Reps/L/Y (R/L/Y) | 6 | 69,467** |
| Entries (E) | 78 | 55,125** |
| E × L | 156 | 26,229 |
| E × Y | 78 | 27,367** |
| E × L × Y | 156 | 31,563** |
| E × R/L/Y | 468 | 17,109 |

** Significantly different at the 0.01 level of probability.

Table 4. Mean squares from separate analyses of variance for lint yields from $F_5$ entries of cotton at each location for 2 years.

| | | Mean squares | | |
|---|---|---|---|---|
| Source | Degree of freedom | Lubbock | Big Spring | College Station |
| Years (Y) | 1 | 17,449,296** | 674,444 | 14,133,029** |
| Reps/Y (R/Y) | 2 | 42,197 | 65,398** | 112,785* |
| Entries (E) | 78 | 29,480 | 20,356 | 57,327** |
| E × Y | 78 | 37,512** | 17,396** | 35,668 |
| E × R/Y | 156 | 11,937 | 10,009 | 28,893 |

*,** Significantly different at the 0.05 and 0.01 levels of probability, respectively.

Table 5. Estimates of variance components of lint yield in cotton for each location and for the average of all locations.

| | Location | | | |
|---|---|---|---|---|
| Source | Lubbock | Big Spring | College Station | Over locations |
| | Variance component | | | |
| Entries | 0† | 715 | 5,415** | 2,313** |
| Entries × Locations | | | | 0† |
| Entries × Years | 12,788** | 3,693** | 3,388 | 1,709** |
| Entries × Years × Locations | | | | 7,227** |
| Residual | 11,937 | 10,009 | 28,893 | 17,109 |

** Significant at the 0.01 level of probability. † Negative values for which the most reasonable estimate was assumed to be zero.

Table 6. Estimated heritability and genetic advance in cotton computed for progeny means for each location and for the average of all locations.

| Location | Heritability | Genetic advance | |
|---|---|---|---|
| | % | kg/ha | % |
| Lubbock | 0.0† | 0.0† | 0.0† |
| Big Spring | 14.1 | 18 | 4.1 |
| College Station | 37.8 | 80 | 11.5 |
| Over all locations | 39.9 | 54 | 8.1 |

† Negative values for which the most reasonable estimate was assumed to be zero.

Table 7. Effectiveness of applying 10% selection pressure on progeny means in 1976 at three locations.

| | | | Location where selections were grown in 1977 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1976 | | Lubbock | | | Big Spring | | | College Station | | |
| Location where 1976 selections were made | Population mean | Selection mean | Mean selections | Population mean | Actual genetic advance | Mean of selections | Population mean | Actual genetic advance | Mean of selections | Population mean | Actual genetic advance |
| | kg/ha | | kg/ha | | % | kg/ha | | % | kg/ha | | % |
| Lubbock | 627 | 788 | 1,031 | 1,095 | −5.8 | 383 | 386 | −0.6 | 481 | 483 | −0.5 |
| Big Spring | 506 | 636 | 1,113 | 1,095, | 1.6 | 399 | 386 | 3.5 | 538 | 483 | 11.4* |
| College Station | 916 | 1,233 | 1,177 | 1,095 | 7.5* | 426 | 386 | 10.5* | 556 | 483 | 15.1* |

* Statistically different from zero at the 0.05 level based on a t-test.

lint yield apparently had been eliminated from this population prior to the $F_4$ generation. The relationship between the $F_4$ and $F_5$ generations was consistent over all test locations. Mean lint yields (kg/ha) for the $F_4$ and $F_5$ entries, respectively, were 627 and 624 at Lubbock, 506 and 479 at Big Spring, and 916 and 906 at College Station.

The $F_5$ entries, grown in both 1976 and 1977, were used to estimate the genotype × environment interactions (Table 3). Years were not significantly different; however, locations and years × locations were significant. Significant differences were shown among entries averaged over all locations and years. Entries did not interact with locations, but did interact with years. The lack of significant entries × location interaction suggested that the entries with the highest yield potentials performed relatively well at all locations.

The second-order interaction, entries × years × locations, was significant (Table 3). In order to detect the origin of this interaction, and to better grasp the significance of its implications in possible selection schemes, we analyze the $F_5$ data within locations over years. This analysis (Table 4) showed that lint yields over years within locations were significantly different at Lubbock and College Station as was predictable from heat unit and moisture considerations (Table 1). At both Lubbock and Big Spring entries interacted with years. Such an interaction was not noted in the College Station set of data.

Estimates of variance components for each location and for the average of all locations are shown in Table 5. The entry variance component caused by genetic differences among entries, was less than zero at Lubbock, but it was assumed to be zero. At this location, no genetic variance was identifiable among the entries. The entry × years interaction component was significant and about the same size as the residual error. At Big Spring, the genetic variance component was not significant and was considerably smaller than the entry × year component. The interaction component was significant but was only about one-third as large as the error component. At College Station, the entry variance was significant and about twice as large as the nonsignificant interaction component. The error component was considerably larger than both. The variance components associated with all locations showed that the entry × location interaction was zero but that the second-order interaction component was large. The error component was larger than the sum of all the other components.

Phenotypic differences among entries at Lubbock and Big Spring were thus primarily caused by genotype × year interactions. At College Station, however, these differences were associated primarily with genotypic effects. Therefore, selection for lint yield should have been more effective at College Station than at Lubbock or Big Spring. Estimates of heritability and genetic advance for progeny means confirmed this result (Table 6).

Table 7 shows the results of applying 10% selection pressure in 1976 on $F_4$ entries and then evaluating the $F_5$ selections in 1977 at each location. Entries selected at Lubbock in 1976 had lower means than those of the overall population in 1977 at each location. Selections at Big Spring showed small, nonsignificant gains on overall means when grown at Lubbock and Big Spring, but surprisingly showed significant gains when grown at College Station. The observed improvement could be due to chance, but more study is needed before it can be dismissed as such. The selections made in 1976 at College Station were associated with significant genetic gains at all locations.

In our study, selection for lint yield was most effective in the College Station environment in 1976 where both heat units and water were adequate. Deficiencies in either of those environmental variables apparently caused us to apply selection pressure mainly to the genotype × environment component of the phenotypic expression. Therefore, we might expect that selection for lint yield may be ineffective when made at locations and/or seasons where environmental components limit production.

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