Published September, 1965

Fruiting Height Response: A Consideration in Varietal Improvement of Pima Cotton, *Gossypium barbadense* L.[1]

Carl V. Feaster and E. L. Turcotte[2]

THE Pima cotton industry involves a relatively small acreage in the southwestern United States. However, the crop is grown over a wide range of environments at altitudes from approximately 100 to 4,000 feet. During the fruiting season for the crop, the lower altitudes, ranging up to 1,500 feet, are characterized by high day and night temperatures. At the higher altitudes, 2,500 feet and above, day temperatures are high and night temperatures moderate. The minimum night temperatures in the 1,500- to 2,500-foot zone fluctuate between high and moderate from year to year. Observations to date indicate that minimum night temperatures near 80° F. are not conducive to efficient fruiting and should be considered as high.

Historically, only one commercial variety of Pima cotton has been grown at any given time, except during the periods of transition from one variety to another. To date, only seven varieties of Pima have been grown commercially in the Southwest. The first was the 'Yuma' variety, followed by 'Old Pima,' 'SxP,' 'Amsak,' 'Pima 32,' 'Pima S-1,' and 'Pima S-2' (2). Yuma, Old Pima, SxP, Amsak, and Pima 32 were developed directly or indirectly from a few cottons introduced from Egypt. Thus, they involved a fairly narrow germplasm base and were very similar in many respects. Pima S-1 was developed much differently. The parents of Pima S-1 included 'Sea Island,' Pima, and 'Tanguis' from *Gossypium barbadense* L., and a Stoneville variety from *G. hirsutum* L. These parents were crossed, the resulting F_1's were crossed, and selections in later generations were subsequently recrossed over a 20- to 25-year period. Pima S-2 was selected from the cross of an experimental Pima strain, 3–79, with Pima S-1.

One of the striking differences between Pima S-1 and the previous commercial Pima varieties is the height of the first fruit. The first fruit sets lower on Pima S-1; and Pima S-2 sets fruit lower than Pima S-1. The lower fruit set of Pima S-2 is more pronounced when grown at the lower than at the higher altitudes. This results in a variety × location interaction, with Pima S-2 relatively better adapted at the lower than at the higher altitudes.

One objective of the Pima varietal improvement program is to develop varieties with genotype × environmental interactions that result in the maximum production of fiber of acceptable quality. Our work is primarily concerned with these three considerations: the effect of predictable environmental variations on fruiting height, the relationship of fruiting height to yield, and the genetic system which favors a homeostatic effect.

LITERATURE REVIEW

Allard and Bradshaw (1) express opinions and cite literature pertinent to our work. A summary of some of their comments follows.

Plant breeders working with many crops agree in general that interactions between genotypes and environment have an important bearing on the breeding of improved varieties. However, opinions vary as to how these interactions may be utilized. Some breeders prefer to concentrate on genotypes that tend to mask certain interactions of genotype × environment. Still others prefer to separate the components of final characters such as yield and quality, and to work with the individual components in relation to environmental effects. Some prefer to determine the genetic systems most likely to give high and stable performance.

---

[1] Contribution from Crops Research Division, ARS, USDA, University of Arizona Cotton Research Center, Tempe, Arizona. Journal paper No. 1000 of the Arizona Agricultural Experiment Station. Received May 25, 1965.

[2] Research Agronomist and Research Geneticist, Crops Research Division, ARS, USDA.

Allard and Bradshaw suggest that variations of the environment can be divided into two categories—predictable and unpredictable. The predictable include large environmental differences such as oceanic and continental climates and soil types, as well as environmental characteristics, such as day length, which fluctuate in a systematic manner. It also includes certain agronomic practices. The unpredictable category includes, mainly, fluctuations in weather. The best indication of large environmental differences (usually predictable) is a large variety × location interaction when the crop is tested throughout a given area. The effect of location may be somewhat offset by cultural practices; however, there is evidence that the best corrective measure is to manipulate the genotype of the plant in such a manner as to make it adapted to the environment.

The unpredictable environmental variations are most clearly measured through high variety × year interactions. With an unpredictable variation, a strain must have a built-in buffering system in order to give a stabilizing or homeostatic effect. The homeostatic effect is generally accomplished either by individual buffering or population buffering. The former involves the use of heterozygous varieties, and the latter the use of varieties containing compensating genotypes.

Miller et al. (4, 5) studied the genotype × environmental interaction as related to yield testing Upland cotton varieties. In North Carolina, they found that both variety × year and variety × location sources of variation were very small and statistically nonsignificant. However, the second-order interaction of variety × location × years was large and highly significant, thus showing that the varieties responded differently under different environments. They concluded that the greatest interaction was realized from differences in rainfall and insect infestations, but there were no obvious effects from soil type. Breeding for adaptation to rainfall conditions and insect infestations can be somewhat hazardous, since they are unpredictable variations.

In cotton varietal improvement, breeding for a final character such as yield has been most general; however, selection indices have also been utilized (3, 6). The indices were based on components of yield and were assigned values according to their contribution to yield. Correlation of any given yield component with a predictable environmental variance was not an objective.

MATERIALS AND METHODS

In 1962 and 1963 a visual index, based on fruiting height as related to standards, was employed to characterize fruiting-height responses of Pima cotton as follows: Type 6, no fruiting low on the plant, such as is typical of Old Pima; Type 5, somewhat lower-fruiting, resembling Pima 32; Type 4, S-1 fruiting habit; Type 3, fruiting height similar to that of P8, an experimental strain somewhat lower-fruiting than Pima S-1; Type 2, Pima S-2 fruiting habit; and Type 1, extremely low-fruiting plants resembling certain Sacaton Short Internode derivatives.

In 1962, the entries in the Regional Pima Strains Test were typed for fruiting-height response at several locations at altitudes ranging from 1,200 to 4,000 feet. In 1963, the typing studies were expanded to include the typing of 56 strains and varieties at Tempe (1,200 feet) and Safford (2,900 feet), Arizona; Fabens, Texas (3,900 feet); and Stoneville, Mississippi.

In 1964 the visual typing index employed in previous years was discontinued in favor of a phenotypic index. The phenotypic index was an actual measurement of the height at which an appreciable amount of cotton began to set. Each unit of the index was 2½ inches. This unit of measurement was about the minimum difference that could be detected with reliability. The fruiting-height measurement was taken by placing a calibrated stick at the end of the row and sighting on the level of the lower fruit. The phenotypic scale, in contrast to the visual index, reveals differences in the level of fruiting at various locations and the magnitude of differences among strains.

RESULTS

Results from a visual typing of the entries in the Regional Pima Strains Test in 1962 showed that height of first fruit of all strains was lowest at high altitudes and highest at low altitudes. The strains maintained the same general order of fruiting heights at all altitudes, but differences among strains were greater at low altitudes. It was apparent that certain strains were better adapted to low and others to high altitudes. Strains best adapted to low altitudes began fruiting early and low on the plant and continued fruiting throughout the season. At high altitudes, the low fruiting characteristic was intensified and resulted in too low fruit set and short plants. These strains appeared to have tolerance to high night temperatures, since they were capable of fruiting at low altitudes during July and August, when minimum night temperatures were high. The strains without tolerance to high night temperatures were rank and did not set fruit until late in the season when grown at low altitudes. However, at high altitudes these strains set fruit fairly low, were not particularly late, and yielded well.

The results obtained in 1963 from typing 56 strains and varieties for fruiting-height response at 3 altitudes in the West and at Stoneville, Miss., served to support the response data from 1962. The Mississippi location was included because the daily minimum temperatures in the Delta during August are similar to those of the lower valleys of Arizona. Height of fruiting was lowest at Safford, Ariz., and Fabens, Texas, both high-altitude locations, and highest at Tempe, Ariz., and Stoneville. At Stoneville only Pima S-2 and experimental strain P15 began fruiting at anywhere near a desirable height, and they were among the lowest-fruiting strains at Safford and Fabens. Strains that began fruiting at the most desirable heights at Safford and Fabens were generally much too high-fruiting at Tempe and, especially, at Stoneville. The range in fruiting heights among strains was much less at Safford and Fabens.

Fruiting-height response certainly does not have much economic value per se, except for its possible association with yield. In the Regional Pima Strains Test at Tempe and Safford, the association of fruiting height and yield was −0.93 and +0.57, respectively. The correlation was highly significant at Tempe but nonsignificant at Safford.

In 1964 a typing test that included varieties and strains of fruiting-height types 2, 3, 4, and 5 was grown at Tempe (1,200 feet altitude), Marana (2,000 feet), and Safford (2,900 feet), thus representing low, intermediate, and high altitudes. At low altitude, the four genetic types gave a wide response, with all types fruiting relatively high (Figure 1). At the intermediate altitude, fruiting began at a lower level, with a range much less than at low altitude. At high altitude, it was still lower but showed only a slightly narrower range. The four genetic types varied to a highly significant degree at each altitude. Figures 2 to 5 include plants that show patterns of genetic types 2, 3, 4, and 5 at low and high altitudes.

Figure 6 includes indices of the entries in the 1964 Regional Pima Strains Test at Tempe, Marana, and Safford. Here again, as in the typing test, a given strain fruited highest at the low altitude, somewhat lower at the intermediate altitude, and lowest at the high altitude. The

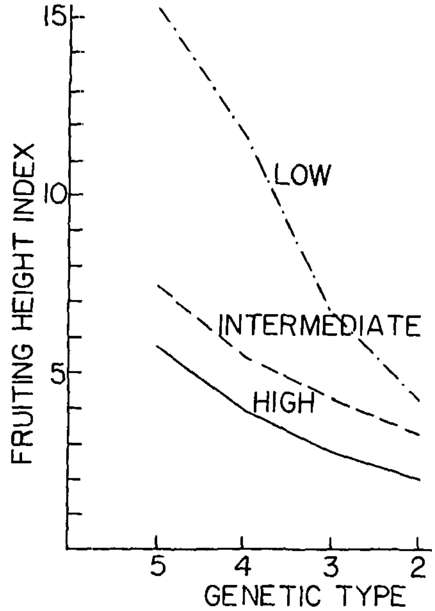

Figure 1. Fruiting-height response of four genetic types of Pima cotton at low (Tempe), intermediate (Marana), and high (Safford) altitudes, 1964.

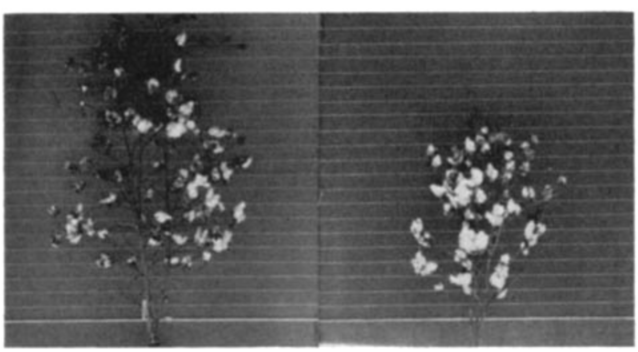

Figure 2. Fruiting pattern of genetic Type 2 grown at low altitude (left) and high altitude (right).

Figure 3. Fruiting pattern of genetic Type 3 grown at low altitude (left) and high altitude (right).

response also was determined for the entries in the Regional Pima Strains Test at Coolidge, Ariz. (1,500 feet altitude), and at the second location near Safford (Safford A) where soil fertility was far above average for the area. The fruiting of strains at Coolidge, similar to that at Tempe, gave a typical low-altitude response. The response of the strains grown under high-fertility conditions at Safford A (2,900

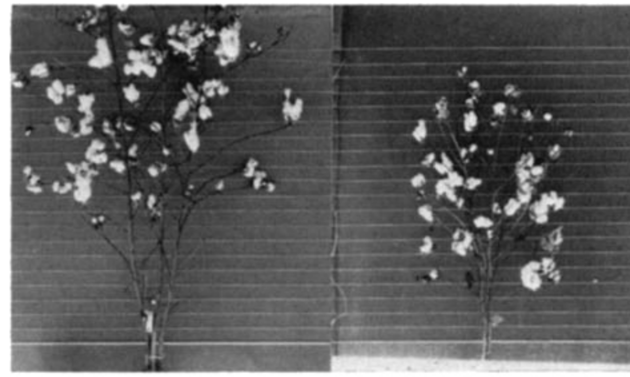

Figure 4. Fruiting pattern of genetic Type 4 grown at low altitude (left) and high altitude (right).

Figure 5. Fruiting pattern of genetic Type 5 grown at low altitude (left) and high altitude (right).

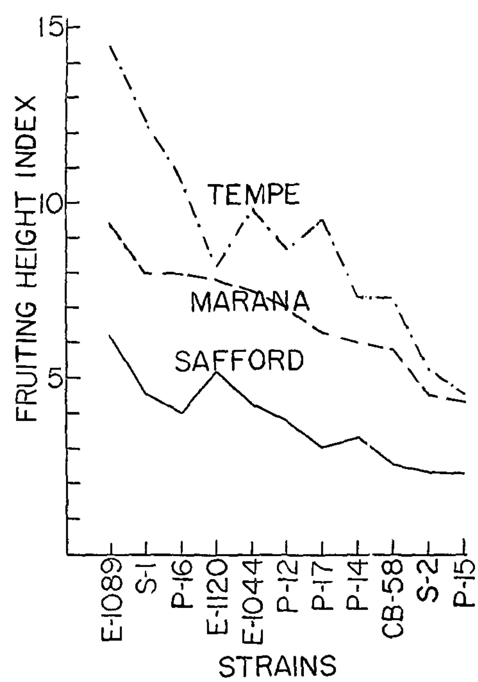

Figure 6. Fruit-height response, Pima Regional Strains Test, Tempe, Marana, and Safford, 1964.

feet) was similar to that at Marana (2,000 feet), thus showing somewhat higher fruiting than might be expected for the altitude.

Strains differed considerably in their response at the

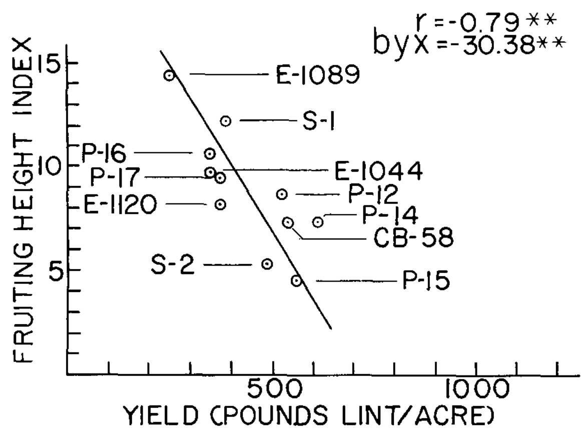

Figure 7. Fruiting-height response vs. yield, Pima Regional Strains Test, Tempe, Arizona, 1964.

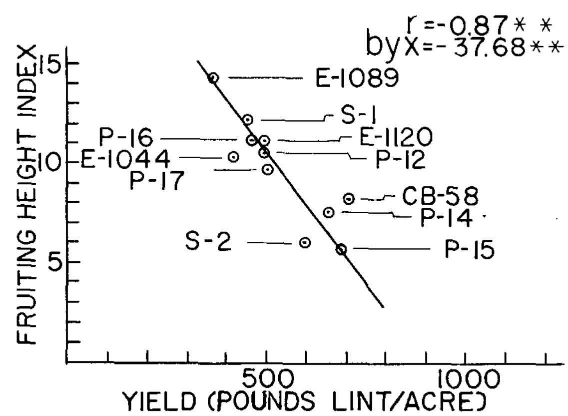

Figure 8. Fruiting-height response vs. yield, Pima Regional Strains Test, Coolidge, Arizona, 1964.

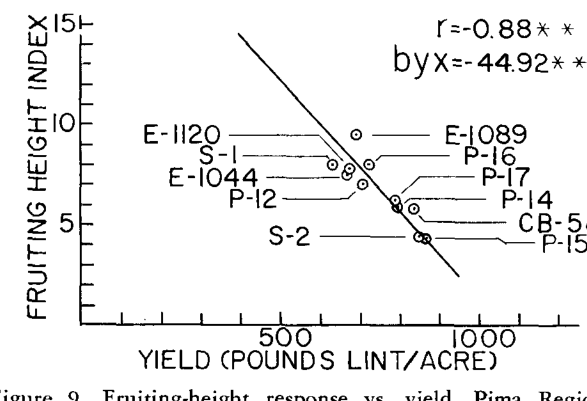

Figure 9. Fruiting-height response vs. yield, Pima Regional Strains Test, Marana, Arizona, 1964.

different altitudes. Strain E1089 had an index of 6.2 at Safford and 14.5 at Tempe—a difference of 7.8 units. P15, on the other hand, had an index of 2.3 at Safford and 4.5 at Tempe—a difference of 2.2 units. The variety × location interaction was highly significant.

The variety × location interaction for yield also was highly significant for the Regional Pima Strains Test. The association of fruiting height and yield at Tempe, Coolidge, Marana, Safford, and Safford A is shown in Figures 7 to 11.

At Tempe, there was a highly significant correlation of —0.79 between fruiting height and yield. The highest-

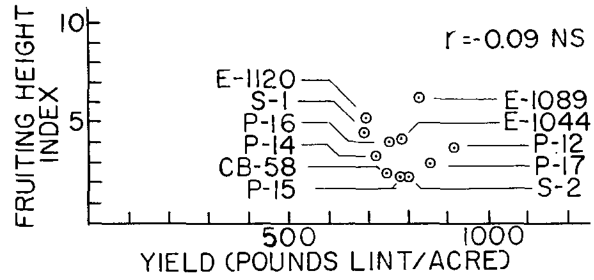

Figure 10. Fruiting-height response vs. yield, Pima Regional Strains Test, Safford, Arizona, 1964.

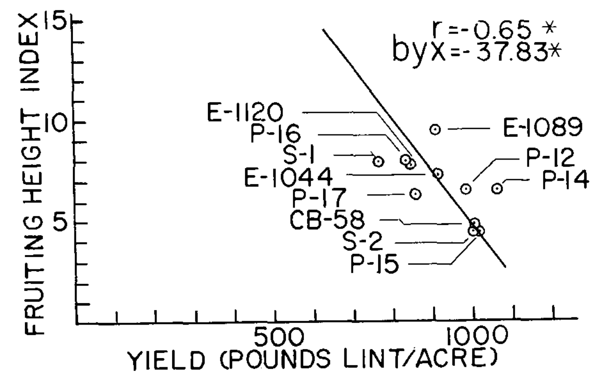

Figure 11. Fruiting-height response vs. yield, Pima Regional Strains Test, Safford A, Arizona, 1964.

fruiting strain, E1089, produced less than half the yield of several of the lower-fruiting strains. P15, the lowest, was second only to P14 in yield.

At Coolidge, another low-altitude location, the correlation of fruiting height and yield was —0.87 and was highly significant. Here again, E1089 was highest-fruiting and lowest in yield. Pima S-2, P14, CB58, and P15 were the lowest-fruiting and highest in yield.

At Marana, an intermediate altitude, strain E1089 was highest-fruiting but was not lowest in yield. P17, which fruited relatively high at the two low-altitude locations, Tempe and Coolidge, was somewhat lower-fruiting and differed little in yield from P14, Pima S-2, CB58, and P15. The correlation of fruiting height and yield was —0.88 and highly significant.

At Safford (2,900 feet), the yield differences and the relatively small fruiting-height differences were highly significant; however, the correlation between the two characters was nonsignificant. E1089, again the highest-fruiting strain, was third only to P12 and P17 in yield. All three were among the high-fruiting, relatively unproductive strains at the two low-altitude locations. Pima S-2, P15, and CB58 were extremely low-fruiting and yielded no more than the average for the test. This is the location where the correlation of fruiting height and yield was nonsignificant in 1963.

At Safford A, the index for all strains averaged 6.7 as compared to 3.8 for the Safford location where conditions were typical of the area. The correlation of fruiting height and yield was —0.65 and significant. Strain E1089 was again highest-fruiting and about average in yield. The most productive strains were average or lower in fruiting height.

DISCUSSION

At the low and intermediate altitudes, the negative correlation between fruiting height and yield was highly significant, but at high altitude, under growing conditions typical for the area, the correlation was nonsignificant. The difference in fruiting height between the highest and lowest yielding strains was greatest at low altitude, next greatest at the intermediate altitude, and extremely small at the high altitude.

This differential response indicates the desirability of having commercial varieties with specific adaptability. At low altitude, relatively low-fruiting strains are most desired. They begin fruiting early and continue throughout the season, thus producing highest yields. These strains seem to have tolerance to high night temperatures, as they are capable of fruiting at low altitude during July and August when minimum night temperatures are high. The strains without tolerance to high night temperatures do not set fruit until late in the season, and tend to be rank and low in yield. At high altitude, night temperatures are lower and all strains begin setting fruit relatively low on the plant. The very lowest fruiting strains are not usually the most productive, and the bottom crop is too low to allow efficient machine-harvesting.

Under typical growing conditions at high altitude, intermediate fruiting height is most desirable in terms of plant type, maturity, and yield. Normally, the highest-fruiting strains are too late. They set a fair bottom crop and a top crop only if frost is late. However, if grown under adverse conditions (e.g., salt and/or Verticillium wilt), they are reasonably early and may yield relatively well. Under high fertility conditions at high altitude, the lower-fruiting strains may be most desirable since high fertility tends to offset the effect that high altitude has on fruiting height and yield responses of a given strain.

At intermediate altitude, small variations in the minimum night-temperature levels from year to year result in a variable fruiting-height response. If the growing season is warmer than average, the fruiting tends toward the response typical of the low altitude. If the growing season is cooler than average, the fruiting tends toward the high-altitude response.

The Pima varietal improvement program includes selecting and testing at altitudes ranging from approximately 1,200 to 4,000 feet. The typing of strains for fruiting-height response offers a real basis for selecting plants or strains at a single location for the various areas of the Pima belt. When selecting at low altitude, low-fruiting plants or progeny rows offer the greatest potential for the lower valleys; however, higher-fruiting plants or progenies offer the greatest promise for high-altitude conditions. The high-fruiting selection, when grown at high altitude, begins fruiting lower and is usually productive.

The plant breeder, if selecting at high altitude, realizes the greatest possibilities from the intermediate to high-fruiting plants or progenies. They begin fruiting high enough above the ground for efficient machine-harvesting, are of desirable maturity, and generally yield well. Selecting low-fruiting plants at high altitude for possible production at low altitude is usually ineffective in that the selections may or may not be low-fruiting when grown at low altitude. All strains fruit relatively low at high altitude, but only those strains which have tolerance to high night temperatures will fruit relatively low at low altitude. The lack of high night temperatures at high altitude does not permit selection pressure for this character. The homeostatic effects due to tolerance to high night temperatures evidence buffering that is a property of specific genotypes. The varieties and strains from which data were obtained were either commercial varieties or advanced strains which were relatively homogeneous. Thus, this buffering is not associated with heterozygosity nor heterogeneity.

SUMMARY

The yield of Pima cotton was highly correlated with fruiting-height response under conditions of high night temperatures, but the two characters were not correlated under moderate night temperatures and growing conditions typical of the area. In the Pima cotton belt, minimum night temperature is largely a function of altitude and is a predictable environmental variable.

At low altitude, strains with tolerance to high night temperatures are best adapted. They begin fruiting early, continue fruiting throughout the season, and yield well. At high altitude, the night temperatures are moderate and tolerance to high night temperatures is unimportant. All strains begin fruiting relatively early, and low on the plant.

LITERATURE CITED

1. Allard, R. W., and Bradshaw, A. D. Implications of genotype-environment interactions in applied plant breeding. Crop Sci. 4:503–508. 1964.
2. Feaster, Carl V., and Turcotte, E. L. Genetic bases for varietal improvement of Pima cottons. Crops Research, ARS 34–31. 1962.
3. Manning, H. L. Realized yield improvement from twelve generations of progeny selection in a variety of Upland cotton. Empire Cotton Growing Rev. 50:329–351. 1963.
4. Miller, P. A., Williams, J. C., and Robinson, H. F. Variety × environment interactions in cotton variety tests and their implications on testing methods. Agron. J. 51:132–134. 1959.
5. ———, Robinson, H. F., and Pope, O. A. Cotton variety testing: additional information on variety × environment interactions. Crop Sci. 2:349–352. 1962.
6. Walker, J. T. The use of a selection index technique in the analysis of progeny row data. Empire Cotton Growing Rev. 37:81–107. 1960.