Published September, 1987

Stability in Yield and Fiber Quality of California Cotton[1]

Shu Geng, Qifa Zhang, and D. M. Bassett[2]

ABSTRACT

Stable performances in crop yield and quality traits over a wide range of growing conditions are desirable from a standpoint of management and marketing. In this paper, we have studied the stability of yield and quality of 43 cotton (*Gossypium hirsutum* L.) cultivars tested in California cotton breeding programs over 18 yr (1966–1983). There is a positive correlation between mean yield and the stability coefficient for yield. This association suggests that cotton cultivars producing higher yields are, in general, lower in stability. Exceptions, however, are observed in a few cultivars, suggesting that selection for specific adaptation does not automatically lead to reduction in general adaptability. Quality scores are less responsive to environmental changes than yields. Still, a negative correlation between mean quality scores and stability coefficients of fiber qualities is observed. Thus, changes brought about by plant breeding have resulted in progressive changes in the direction of higher quality and greater stability of quality. Our analysis shows that plant breeding in the last 18 yr has simultaneously improved yield and quality in California cotton, and that future selections for new cultivars with emphasis on quality may result in greater economic returns.

***Additional index words:* *Gossypium hirsutum* L., Genotype × environment interaction, Adaptation, Adaptability, Selection, Reparameterization.**

GENOTYPE × ENVIRONMENT interactions (GE) have been studied in cotton (*Gossypium hirsutum* L.) (Miller et al., 1962) and many other crop species (Hill, 1975). A general finding to date is that the GE effect is prevalent wherever looked for. Sometimes plant breeding has been considered to have achieved progress for many specific adaptations in a few environments at the cost of long-term stability. This may pose serious problems for developing long-term strategies of management and marketing. Thus, attention has frequently been directed at the need to evaluate cultivars on the basis of stable performance over a wide range of growing conditions.

Many methods have been proposed to evaluate stability. Finlay and Wilkinson (1963) suggested that the mean yield and the regression of yield on environments provide information for selecting cultivars with broad adaptability. Eberhart and Russell (1966) described a desirable cultivar as one with a high mean, a regression coefficient of unity, and a small deviation from regression. Plaisted and Peterson (1959) proposed a method of obtaining estimates of the GE effect

[1] Contribution from the Dep. of Agronomy and Range Science, Univ. of California, Davis, CA 95616. Received 5 May 1986.

[2] Professor, Dep. of Agronomy and Range Science; postdoctoral researcher, Dep. of Genetics; and cotton specialist, Dep. of Agronomy and Range Science, Univ. of California, Davis, CA 95616.

Published in *Crop Sci.* 27:1004–1010 (1987).

for each cultivar under study. Shukla (1972) redefined this estimate as "stability variance" and devised a test for the significance of the GE component of a cultivar. Bilbro and Ray (1976) used regression to estimate adaptability and deviation from regression to measure stability of cotton cultivars. However, a complete balanced two-way table is required in order for these methods to be applicable. An early review of the statistical methods for analyzing genotype × environment interactions was given by Freeman (1973).

In cultivar trials, large data sets are often accumulated over years and at different locations. Since these trials are long-term with changes in cultivars and locations over years, they cannot be analyzed by methods described above. Recently, Zhang and Geng (1986) proposed a method that allows stability parameters of cultivars grown in different environments to be reparameterized and to be comparable.

Improvement of lint quality has also been an important goal in many plant breeding programs and notable progress has been achieved in many cases (Bingham, 1981). However, there have been few reported studies comparing the stability of quality in different cultivars. Little is known about the consequences to the cultivar stability from selection for improved quality.

In this paper we report a study of data from cotton cultivar trials in California during the last 18 yr. The objectives are to assess the stability of yield and quality, and the relationship between them.

MATERIALS AND METHODS

The performance data of 43 cotton cultivars observed during a period of 18 yr (1966–1983) were analyzed in this study. The majority of the entries were from breeding trials conducted in the San Joaquin Valley, but cultivars introduced from other states were also included in earlier years. Both the number of cultivars being tested and the number of testing sites differed between years.

Within a year and location, a randomized complete block design was employed. The following measurements were included in our analysis:

1. Lint yield: The mean production of the plots harvested, expressed in weight of lint per hectare;
2. 50% span length: The length on the test specimen spanned by 50% of the fibers scanned at the initial starting point;
3. 2.5% span length: Length on the test specimen spanned by 2.5% of the fibers scanned at the initial starting point;
4. Uniformity: The ratio of the 50% span length to the 2.5% span length;
5. T1: The fiber strength of a bundle of fibers measured on the stelometer with two jaws holding the fiber bundle separated by a 3.12-mm spacer, expressed in centinewtons per tex;

The cultivar stability was analyzed by using the method of Zhang and Geng (1986). The method breaks a continuous trial into mutually exclusive periods according to the use of standard cultivars. In case two standard cultivars are involved in the tests over the years, there is a period of time when only the first standard cultivar is used (Period 1) followed by a period when both standard cultivars are used (Period 2), and a third period when the second standard cultivar is used alone (Period 3). Three steps are involved in the analysis: (i) regress the standard cultivars on cultivar averages in environments of Period 2 during which both standard cultivars were grown; (ii) regress cultivars under test on the standard cultivars; the cultivars grown in the first period are regressed against the first standard cultivar and the other cultivars are regressed on the second standard cultivar; and (iii) transform, through a procedure of reparameterization, the regression computed for each cultivar on the standard cultivar into the regression of the cultivar on environmental means of Period 2.

The reparameterization transforms the stabilities of cultivars grown in different periods on a common ground as if they were obtained from environments of Period 2. The interpretation of the stability parameters estimated by this procedure will be the same as those proposed by previous workers (e.g., Eberhart and Russell, 1966).

Two cultivars, 'SJ-1' and 'SJ-2', were included as the standard cultivars in our study. SJ-1 was used from 1966–1974 and SJ-2 was used in the period of 1971–1983. At least one of these two standard cultivars was present for any given year and location. Consequently, these 18 yr were divided into three periods: the first period, 1966–1970; the second period, 1971–1974; and the third period, 1975–1983. The means of the standard cultivars were first regressed on the environmental means of the second period. Those cultivars grown in the first period were regressed against the standard cultivar SJ-1 and all the other cultivars were regressed against the standard cultivar SJ-2. The regression coefficient obtained for each cultivar was subsequently transformed into the regression of that cultivar on environmental means of the second period through the reparameterization procedure.

The measurement of yield for each cultivar was directly used as input in estimating stability parameters of yield. For the quality data, the three attributes of quality for each cultivar were first standardized and then subjected to the principal component analysis (Morrison, 1976). The scores of the first principal component were used to estimate stability parameters of the quality.

RESULTS AND DISCUSSION

Stability in Yield and Quality

The regressions for the mean yields of the two standard cultivars on environmental means were computed using the data of the experimental sites with six or more cultivars. The regression coefficient computed on environmental means for SJ-1 was 1.08 ± 0.05 in the period 1966–1970, and 1.07 ± 0.04 in the period of 1971–1974. These two regression coefficients were not significantly different, indicating that no marked increase of cultivar mean yields occurred in the second period compared to the first period. The regression coefficient for SJ-2 was 1.09 ± 0.03 in the period 1971–1974, and 0.92 ± 0.05 in the period 1975–1983. A student's t test shows that these two regression coefficients differ significantly at the 1% level. The significant reduction of the regression coefficients in the third period suggested that significant improvements in the mean yields of cultivars occurred in later years compared to the period 1971–1974.

The stability parameters for each cultivar estimated using the reparameterization procedure are presented in Table 1. Cultivars presented in Table 1 are ordered according to the year of the tests from early to lately tested cultivars. The tabulated parameters for the two

Table 1. Stability parameters estimated for yields and quality scores of cotton cultivars grown in California from 1966–1983.

Time order	Cultivar	Yield Mean	Yield b	Yield R^2	Quality score	Quality b	Quality R^2
		kg ha^{-1}					
1	SJ-1	1019	1.07	0.97	0.22	1.02	0.83
2	4-42 (1966)	943	0.92	0.85	−0.14	0.90	0.64
3	Hopicala	935	1.00	0.95	−0.22	1.03	0.56
4	NM 1517-D	885	0.90	0.96	0.16	0.79	0.44
5	NM 1517-V	839	0.90	0.90	0.00	0.88	0.49
6	DP. 5540	837	0.80	0.67	−1.38	1.92	0.77
7	Stnville 7A	957	1.01	0.93	−2.29	0.91	0.48
8	Auburn 56	988	0.96	0.95	−2.32	1.21	0.93
9	Coker 201	977	0.97	0.77	−1.64	1.03	0.62
10	Pymst 54B	708	0.86	0.78	−1.56	1.04	0.58
11	S155	1013	0.82	0.96	−0.19	0.54	0.46
12	4-42 (1958)	954	0.95	0.85	0.24	0.78	0.69
13	DPL 16	986	0.96	0.83	−1.14	0.77	0.61
14	Pymst-111	847	0.62	0.60	−1.06	0.75	0.68
15	Ariz 6218	899	0.87	0.78	−0.01	0.96	0.52
16	4-42	890	0.83	0.88	0.67	0.82	0.58
17	S913	872	1.09	0.95	1.18	0.29	0.09
18	SJ-2	1182	1.09	0.97	0.43	0.97	0.83
19	S918	949	1.00	0.99	0.83	−0.27	0.11
20	S845	921	0.98	0.69	0.84	−0.30	0.16
21	T1307	1138	0.93	0.86	0.62	0.84	0.78
22	NM 1517-70	1055	0.94	0.86	0.07	0.70	0.59
23	Lock 4789A	822	0.92	0.79	−0.93	0.69	0.61
24	Coker 310	1102	1.17	0.87	−0.96	0.92	0.86
25	T4852	1111	0.97	0.86	0.44	0.69	0.74
26	T5690	1226	0.97	0.86	0.69	0.71	0.63
27	G8160	1035	0.93	0.92	−0.65	0.51	0.44
28	DPL 61	1050	1.06	0.85	−0.87	0.78	0.74
29	St. 213	1014	0.90	0.85	−1.20	0.69	0.71
30	T6310	1310	0.86	0.89	1.04	0.07	0.01
31	T6892	1319	0.79	0.87	1.64	−0.20	0.04
32	T7	1326	0.80	0.92	1.40	−0.08	0.02
33	C-1	1349	1.05	0.82	1.11	0.49	0.33
34	DP90	1253	0.92	0.74	0.03	0.66	0.48
35	C-9	1395	1.03	0.80	0.42	1.15	0.49
36	C-11	1431	1.47	0.77	1.23	−0.22	0.08
37	C-13	1305	1.12	0.75	0.58	0.34	0.19
38	GC510	1364	1.15	0.80	1.02	0.40	0.23
39	GC555	1316	1.09	0.69	0.83	0.34	0.28
40	SJV 100	1270	1.08	0.85	0.06	0.57	0.42
41	CPCSD C-14	1125	1.37	0.90	0.34	0.51	0.40
42	CPCSD C-16	1164	1.08	0.53	0.73	0.34	0.14
43	GC-457	1102	1.28	0.89	1.17	0.27	0.19

standard cultivars were computed using the data of the second period. The following cultivars have their upper limits of the 95% confidence intervals smaller than or equal to unity; 'NM 1517-D', 'S155', 'Pymst-111', '4042', 'T6310', 'T6892', and 'T7'. Thus, the true regression coefficients for these cultivars are significantly smaller than unity.

Among all the cultivars tested, only 'Coker 310' has the 95% confidence interval distinctly larger than unity and 'CPCSD C-14' contains 1.00 as the lower limit of the 95% confidence interval.

The statistic R^2 provides additional information for the evaluation of cultivar stability. The R^2 values of SJ-1 and SJ-2 are both 0.97, indicating that the linear relationships between these standard cultivars and the environmental means are almost perfect. The R^2 values for 'DPL 5540', Pymst-111, 'S845', 'GC555', and 'CPCSD C-16' are smaller than 0.74, whereas R^2 values for all the other cultivars are $\geq$0.74. We consider that a linear regression adequately describes the variation of a tested cultivar, if the R^2 is $\geq$0.74. The stability of the cultivars in this case will be judged mainly by the regression coefficient. For those cultivars whose R^2 values are <0.74, the deviation from regression is further tested by the F test in evaluating the stability. Thus, NM 1517-D, S155, 4042, T6310, T6892, and T7 are more stable than an average cultivar. Stability of Pymst-111 cannot be determined with certainty because the R^2 of this cultivar is only 0.60. Coker 310 and CPCSD C-14, with regression coefficients significantly larger than unity, also have high R^2 values (0.87 and 0.90, respectively), indicating that the yields of these cultivars are more sensitive to changes in environmental conditions than an average cultivar.

The quality score (qs) of the first principal component has the following form:

$$qs = 0.61\ (50\%\ \text{span length}) + 0.59\ (\text{uniformity}) + 0.54\ (\text{T1})$$

There are two interrelated features of the stability parameters for quality scores that are in sharp contrast to the features of yield as indicated in Table 1. First, R^2 values for many cultivars are <0.50 and nearly zero for some others. This is especially the case for almost all the cultivars tested since 1975.

The second feature concerns the regression coefficients. The regression coefficient of quality score for each cultivar is plotted against the regression coefficient of yield in Fig. 1. The standard errors of the regression coefficient of quality are on average greater than those of yields. Among the 41 cultivars tested, 6 have regression coefficients larger than unity. However, only the regression coefficient for DPL 5540 is significantly >1.00. The remaining cultivars exhibit two patterns: (i) the regression coefficients of most of the cultivars tested in the early years are not significantly different from unity; and (ii) the regression coefficients of most of the cultivars tested in the later years are either significantly smaller than unity, or not different from zero.

Four different stability groups can be defined from Fig. 1: (i) cultivars lying to the lower-left quadrant of the point (1.0, 1.0) are stable for both yield and quality; (ii) those in the upper-left quadrant are stable for yield but less stable for quality; (iii) cultivars lying in the lower-right quadrant are stable for quality scores but less stable for yield; and (iv) those in the upper-right quadrant are less stable for both yield and quality. Twenty-one out of the 41 cultivars tested fall in the lower-left quadrant, indicating that about half are stable in both aspects. In fact, most of the cultivars lying in this quadrant were tested in the 1970s. The regression coefficients of the cultivars T6892 (no. 31) and T7 (no. 32) are exceptionally small, indicating high stability. Five cultivars are located in the upper-left quadrant and all of them were tested in the 1960s, indicating that cultivars introduced in that period were stable in yield but less stable in quality. Fourteen cultivars, most of which were tested in the late 1970s and 1980s lie in the lower-right quadrant. This shows that cultivars introduced in more recent years are stable in quality but less so in yields. Only 'C-9' (no. 35) is unstable for both quality and yield.

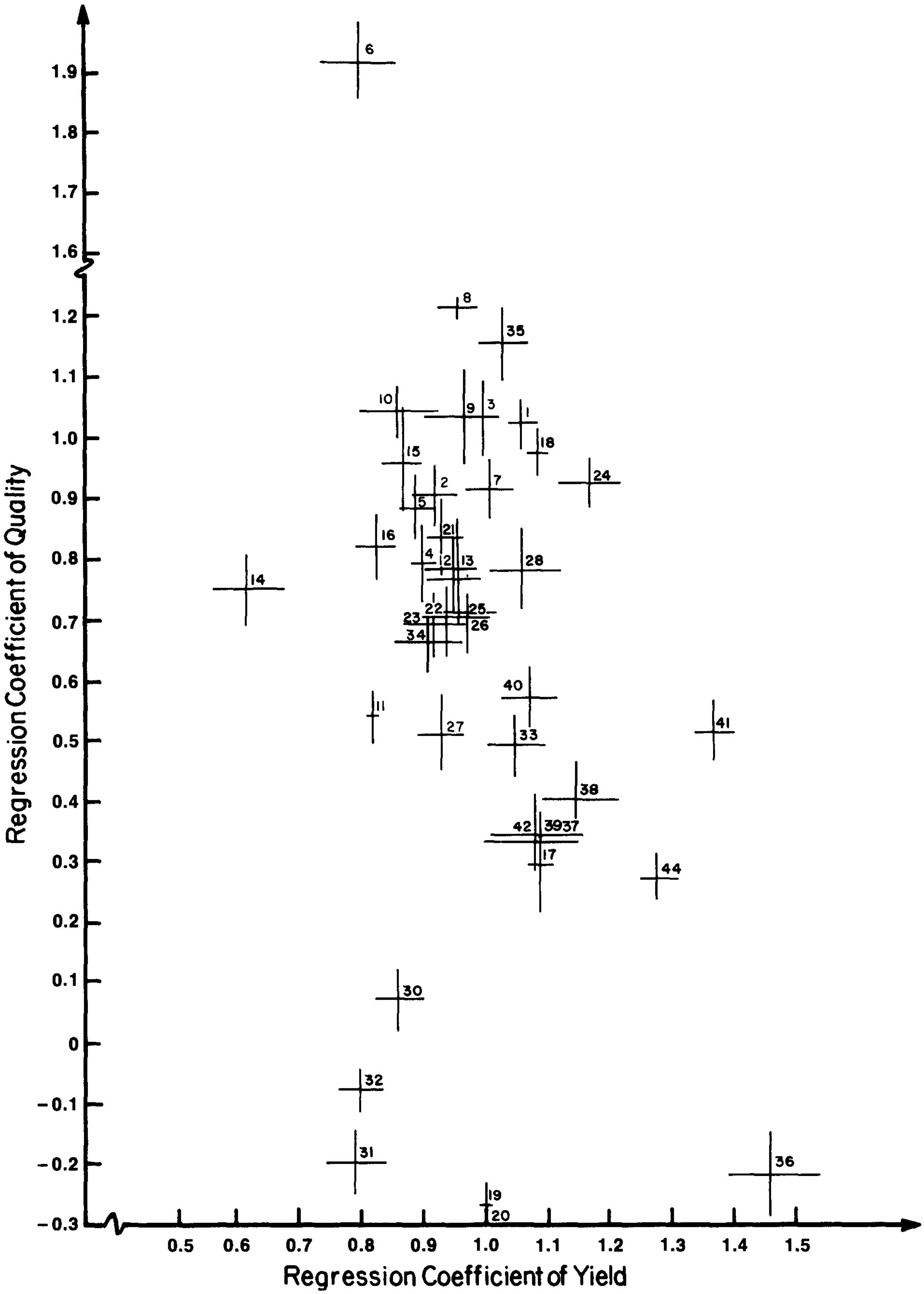

Fig. 1. Stability coefficients of yield and quality (± SE) for cotton cultivars grown in California from 1966–1983.

Stability and Means of Yield and Quality

The regression coefficient is plotted against yield of each cultivar as shown in Fig. 2. The regression coefficients and the mean yields of the cultivars tested in the later years average greater than those of cultivars tested earlier. There is a correlation between yields and regression coefficients, suggesting that higher yielding cultivars are lower in stability. Most of the cultivars tested in the 1960s are on the lower left, and the cultivars tested in the 1980s are on the upper right. Four of the six cultivars that lie on the lower-right part of the graph yielded higher than 1230 kg/ha. These cultivars were introduced in the early 1980s, suggesting that breeding for high yield does not necessarily result in low stability.

Figure 3 shows a plot of regression coefficients of quality against the mean quality score of each cultivar. There is a negative correlation between regression coefficients and quality scores, indicating that cultivars with better qualities are also more stable. The cultivars lying on the upper-left part of the graph were tested in the 1960s, and those located on the lower-left part were mostly tested in 1970s. Almost all the cultivars tested in the 1980s lie on the lower right. This shows that plant breeding has resulted in a progressive improvement of both quality and stability of quality.

Mean yield and quality score of each cultivar are presented in Fig. 4. All the cultivars tested on or after 1974 lie on the upper right, indicating a combination of high quality and high yields. Several cotton cultivars, exemplified by cultivars T6310, T6892, and T7, combine high yields with high quality and stability.

Stability Selection for Yield and Quality

Adaptation and adaptability are two distinct genetic properties of a cultivar. In general, successful plant breeding is considered to achieve its goal by breeding for adaptation in specific environments at the cost of general adaptability (Simmonds, 1962). Thus, breeding for high performance could result in cultivars of low stability.

In cotton, lint yield represents biological productivity and hence adaptation. Stability, on the other hand, reflects the adaptability of a cultivar. The mean yield of SJ-1 is 1027 kg/ha for the years 1966–1970, and 1033 kg/ha for the years 1971–1974. Thus, little improvement in environmental conditions occurred during these years. The mean yield of SJ-2 is 1103 kg/ha for the period of 1971–1974, 1219 kg/ha for 1975–1979, and 1280 kg/ha for 1980–1983. The increase in yield is roughly 16% in the 1980s compared to that of the late 1960s and early 1970s. The mean yield of all cultivars tested in the 1980s is 1279 kg/ha and in the

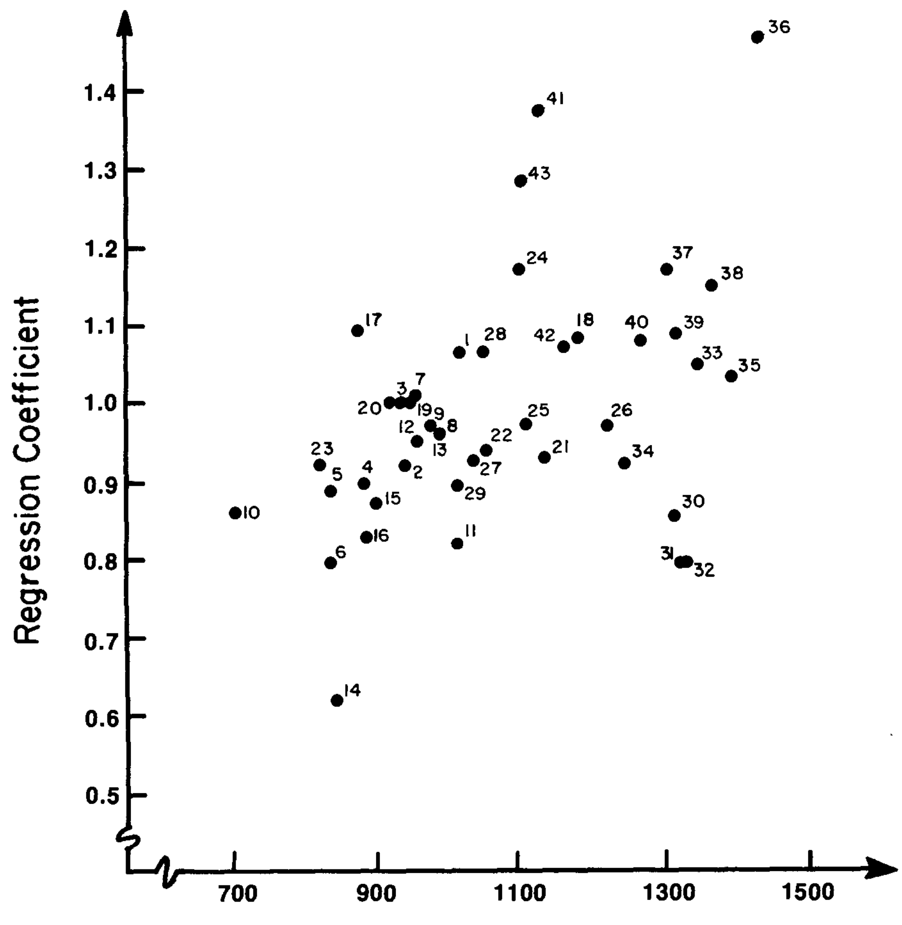

Fig. 2. Stability coefficients of yields and mean yields for cotton cultivars grown in California from 1966–1983.

late 1960s is 917 kg/ha, an increase of about 40%. The improvement due to plant breeding would thus account for about 24% of the total increase. Breeding for adaptation has, therefore, been achieved during the last 18 yr; however, a decrease in yield stability over the years is shown by the regression coefficient. Thus, adaptation is obtained at the cost of adaptability.

However, there are cultivars such as T6310, T6892, and T7, which are both high yielding and stable. This suggests that breeding for adaptation does not always result in reduction in adaptability. Simmonds (1981) showed that for various cereals past selection has produced responsive cultivars, whereas in potato (*Solanum tuberosum* L.) and sugarcane (*Saccharum officinarum* L.) more stable cultivars have been developed. Thus, adaptability may well be a feature that depends both on the genetic system of the particular crop and on the selection process.

Our results also show that quality scores are less responsive to environmental changes than yields, as indicated by the regression coefficients. This is in agreement with several previous reports (Miller et al., 1959; Bridge et al., 1969; Morrison and Verhalen, 1973), which showed a relatively small GE interaction with respect to fiber quality as compared to yield. Though there was not a concerted effort to select for stability of quality, it has been improved among recent cultivars as a result of selection for quality. The highly significant negative correlation between the quality score and stability suggests that simultaneous change of quality and stability may be an inherent feature rather than simply a coincidence. If improvement of quality in breeding programs is considered as adaptation under artificial selection, then adaptation and stability interact synergistically rather than antagonistically. This suggests that adaptability may differ from one trait to another.

The different behavior of stability of quality from stability of yield indicates that selection for better quality may be fruitful. The economic value of a cultivar is determined multiplicatively by the yield and quality of the product. Thus, where selection for further increase in yield has proven to be difficult, as in many intensive agricultural systems, breeding for quality may result in more rapid economic returns. Even in the cases where breeding for yield is expected to achieve

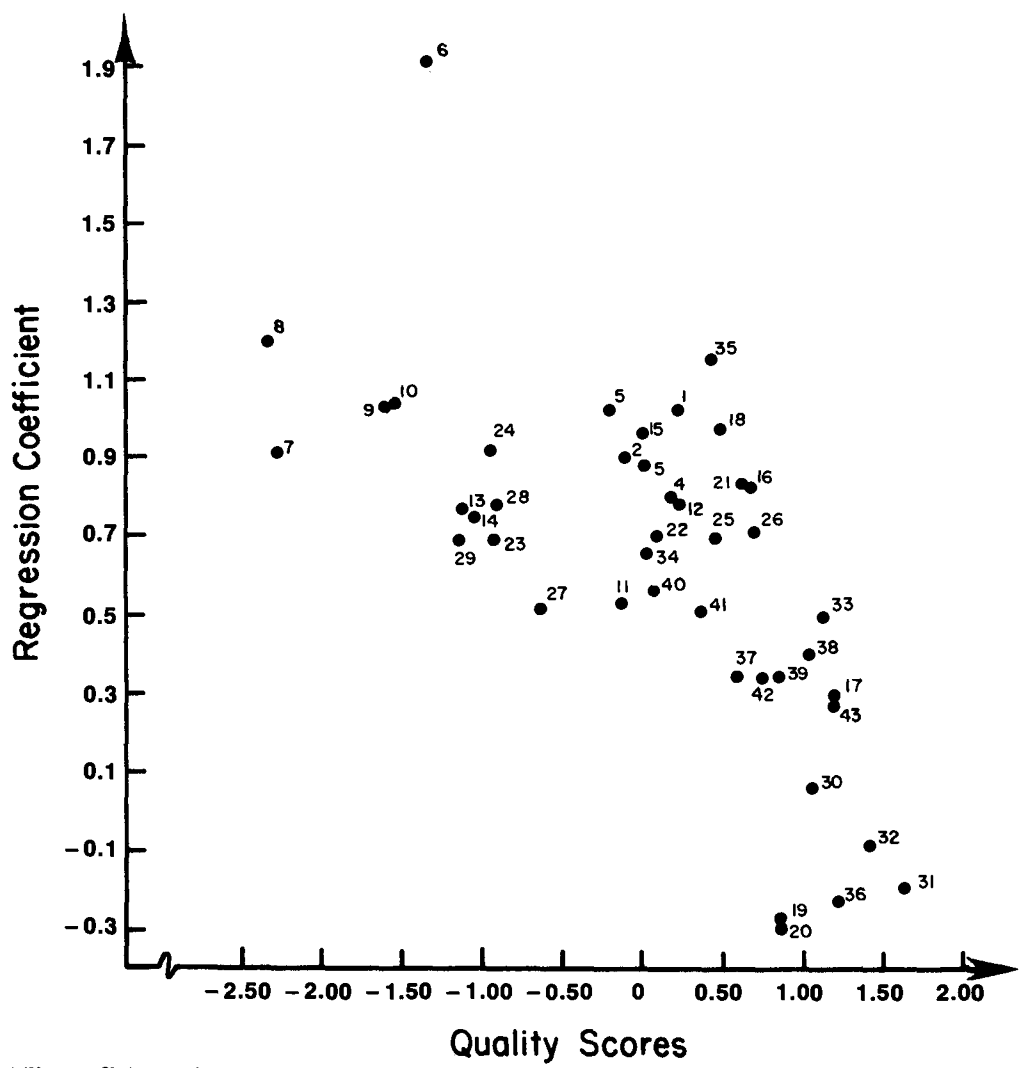

Fig. 3. Stability coefficients of quality scores and mean quality scores for cotton cultivars grown in California from 1966–1983.

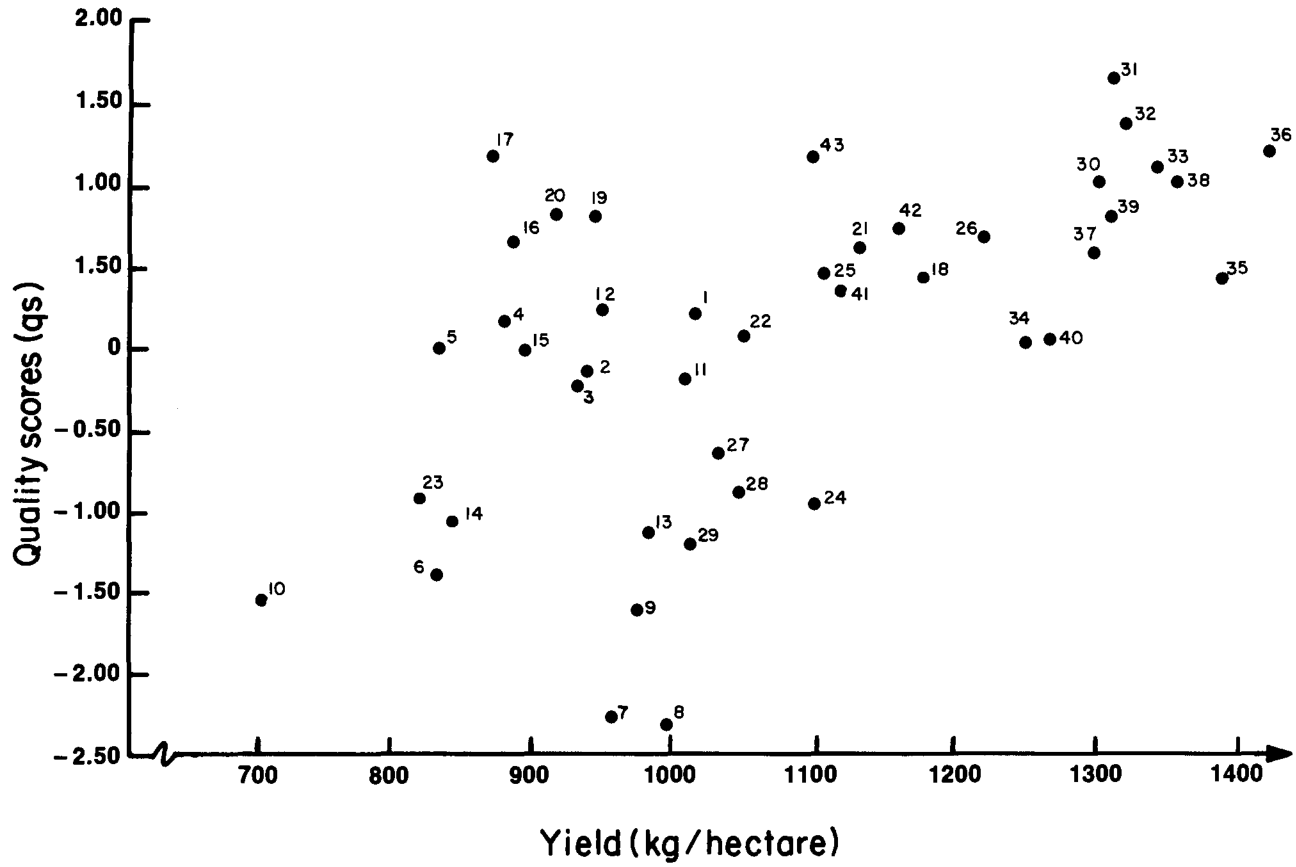

Fig. 4. Mean quality scores and mean yields for cotton cultivars grown in California from 1966–1983.

the fastest economic returns, it may still be a better strategy to direct equal attention to the simultaneous improvement of yield and quality rather than breeding for high yield alone.

ACKNOWLEDGMENTS

This research was partly supported by a Faculty Research Grant of the University of California. The authors would like to express their sincere appreciation to the reviewers for their constructive and helpful comments.

REFERENCES

Bilbro, J.D., and L.L. Ray. 1976. Environmental stability and adaptation of several cotton cultivars. Crop Sci. 16:821–824.

Bingham, J. 1981. The achievement of conventional plant breeding. Phil. Trans. R. Soc. London, B 292:441–455.

Bridge, R.R., W.R. Meredith, Jr., and J.F. Chism. 1969. Variety × environment interactions in cotton variety tests in the Delta or Mississippi. Crop Sci. 9:837–838.

Eberhart, S.A., and W.A. Russell. 1966. Stability parameters for comparing cultivars. Crop Sci. 6:36–40.

Finlay, K.W., and G.N. Wilkinson. 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res. 14:742–754.

Freeman, G.H. 1973. Statistical method for the analysis of genotype-environment interactions. Heredity 31:339–354.

Hill, J. 1975. Genotype-environment interaction—A challenge for plant breeding. J. Agric. Sci. 85:477–493.

Miller, P.A., H.F. Robinson, and O.A. Pope. 1962. Cotton variety testing:Additional information on variety × environment interaction. Crop Sci. 2:349–352.

----, J.C. Williams, and H.F. Robinson. 1959. Variety × environment interactions and their implications on testing methods. Agron. J. 51:132–134.

Morrison, D.F. 1976. The structure of multivariate observations: I. Principal components. p. 266–289. *In* Multivariate statistical methods. 2nd ed. McGraw-Hill Book Co., New York.

Morrison, W.C., and W.C. Verhalen. 1973. A study of genotype-environment interactions in cotton and their implications on future variety and strains testing in Oklahoma. p. 59–62. *In* J.M. Brown (ed.) Proc. Beltwide Cotton Prod. Res. Conf., Phoenix, AZ. 9–10 Jan. National Cotton Council, Memphis, TN.

Plaisted, R.L., and L.E. Peterson. 1959. A technique for evaluating the ability of selections to yield consistently in different locations or seasons. Am. Potato J. 36:381–385.

Shukla, G.K. 1972. Some statistical aspects of partitioning genotype-environmental components of variability. Heredity 29:237–245.

Simmonds, N.W. 1962. Variability in crop plants, its use and conservation. Biol. Rev. 37:422–465.

----. 1981. Genotype (G), environment (E) and GE components of crop yields. Exp. Agric. 17:355–362.

Zhang, Q., and S. Geng. 1986. A method of estimating varietal stability for data of long-term trials. Theor. Appl. Genet. 71:810–814.