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A Comparative Study of Seven Methods of Measuring Earliness of Crop Maturity in Cotton[1]

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LACK of agreement among cotton breeders on the meaning of the term earliness of crop or boll maturity and on methods of measuring or estimating earliness in cotton is due in great part to the fact that the genus *Gossypium* is characterized by an indeterminate flowering and fruiting habit. The practical interest of cotton growers, as well as breeders, is in the relative time required to set and mature a crop of bolls.

The analysis of methods of measuring earliness of maturity in experimental stocks of American Upland cotton, *G. hirsutum* L., given here was part of a more comprehensive experiment designed to determine the inheritance of earliness as well as to study the relation of earliness to certain agronomic characters and to identify genetically some of the chromosomes on which genes for earliness might be located.

REVIEW OF LITERATURE

Extensive studies on the growth pattern of the cotton plant and the characteristics of the different varieties that condition early maturity have been reported by Ewing (3), Martin et al. (8), Harland (5), McNamara et al. (9, 10),

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Eaton (2), Lane and Hessler (7), and others. These studies were concerned with such measurements as first squaring date, first flowering date, first boll-opening date, length of square period, length of boll-maturation period, rapidity of flowering, rapidity of boll setting, rapidity of boll opening, amount of shedding, and various other factors associated with such characteristics.

In the 1920's and early 1930's a number of investigators used correlation methods in studies of interrelations among various quantitative characters in cotton, including earliness. Hodson (6) obtained an r value of +.54 for the correlation between days to first flower and days to first open boll. Griffee et al. (4), from a random sample of various varieties of Upland cotton, found that the percent of seed cotton harvested at first picking was negatively correlated with date of first flower, date of first open boll, seed index, and lint index.

MATERIALS AND METHODS

When considered in terms of rate of development and maturity of fruit, earliness of crop maturity in cotton may be defined as *the extent to which square initiation, flower occurrence, and complete boll ripening occurs in relation to the time of planting.* This definition does not take into consideration the amount of seed cotton produced, but it is believed to be useful in forming an understanding of the concept of earliness on which to base the research on methods of measuring earliness to be reported in this paper.

Of the several stocks tested in a preliminary study of crop maturity in 1958, CB 3051 and Contextum were chosen as the early- and late-maturing stocks, respectively, for the experiment reported here. The CB 3051 stock traces back to a Yugoslavian variety called Timok. Contextum was the name given by O. F. Cook to a stock he collected in Mexico in 1925. In recent years both of these stocks have been used in the breeding program of Substation No. 8 of the Texas Agricultural Experiment Station at Lubbock, Texas, and seeds of them were obtained from the Lubbock Station through the courtesy of L. L. Ray.

Two genetic marker stocks, Texas 429 and Texas 582, were used as parental lines in the phase of the comprehensive experiment designed to estimate the association between earliness and certain qualitative and quantitative characters. However, these two marker stocks differed in maturity and since "earliness" data on them and their hybrids with CB 3051 and Contextum were recorded, the data were used in the present study. Texas 429 carries dominant genes for okra leaf (L^o), red leaf (R_1), petal spot (R_2), brown lint (Lc_1), and naked seed (N). Texas 582 carries recessive genes for cup leaf (cu), frego bract (fg), virescent yellow leaf (v), cluster fruiting habit (cl_1), and glandless boll (gl_1). Only to the extent that as groups of genes they may have affected earliness or lateness of maturity in the two parental stocks did the dominant and recessive marker genes contribute to the study of earliness measurements.

Since the 4 stocks just described were used as parents in the comprehensive studies initiated in 1959, and since frequent reference will be made to them in this paper, their names or designations have been abbreviated and hereafter they will be identified as follows:

EM (early-maturing stock)—CB 3051
LM (late-maturing stock)—Contextum
MD (multiple-dominant marker stock)—Texas 429
MR (multiple-recessive marker stock)—Texas 582

F_1 seeds of the EM × MD, EM × MR, LM × MD, and LM × MR were available from the crosses made among the several experimental stocks surveyed in 1958. Six plants of each of the 4 parents and the 4 F_1's were grown in the greenhouse the following winter to obtain seeds from which F_2 populations were grown in 1959. Adequate numbers of seeds were obtained for planting all 4 F_2 populations. Seeds of the parental stocks, the 4 F_1's and the 4 F_2's were planted in paper cups in the greenhouse on April 5 and the resulting seedlings were transplanted to the field on April 23. Plants in the field were arranged in randomly distributed plots in rows 40 inches wide. Plots were 30 feet long and each plot contained 16 plants initially. This experimental planting received the same cultural treatments as other cotton genetic experiments at the Agronomy Farm.

Each plant in each plot was scored for first date of squaring, blooming, and boll opening. Open bolls were harvested, by individual plant, on August 10, August 20, and September 20. The number of bolls harvested at each picking was noted and the weight of seed cotton from each picking was recorded to the nearest 0.1 gram.

The seven measurements or estimates of earliness are identified and described as follows:

E-1—number of days from planting to appearance of first square of a size easily observable by the naked eye (⅛ to ¼ inch in diameter).
E-2—number of days from planting to appearance of the first bloom.
E-3—number of days from planting to opening of first boll.
E-4—ratio of number of open bolls at the first picking to total number of bolls produced, expressed as a percentage.
E-5—ratio of number of open bolls in the combined first and second pickings to total number of bolls produced, expressed as a percentage.
E-6—ratio of weight of seed cotton harvested at the first picking to total weight of seed cotton harvested, expressed as a percentage.
E-7—ratio of weight of seed cotton harvested in combined first and second pickings to total weight of seed cotton harvested, expressed as a percentage.

Those measurements of earliness expressed as percentages were transformed to angles prior to analysis to obviate the bias frequently encountered when percentage data are subjected to variance analysis. However, the means for these variables are given in the original scale in Tables 1 and 2.

Arithmetic means, standard errors, and coefficients of variation were calculated for each character in the different generations of the four crosses. Duncan's (1) multiple range test was used for testing the significance of the mean comparisons between parental means.

Phenotypic and genotypic correlations of the associations among the seven measurements of earliness were calculated. The simple correlation coefficient was used to measure the direction and degree of phenotypic association between earliness measurements, while the genotypic correlation coefficient was used to estimate the genetic associations. Phenotypic correlations were calculated from the observed F_2 variances and covariances, while genotypic correlations were calculated by partitioning variances and covariances of the F_2 into total genetic and environmental components by methods outlined by Rasmusson (11), and more recently demonstrated by Weber and Moorthy (12) and Niles.[3] The environmental variances and covariances were estimated from the P_1, P_2, and F_1 generations.

RESULTS

A detailed study of the 7 methods of measuring earliness (E-1 to E-7) was undertaken in 1959 to determine which

[3] Niles, G. A. A comparison of F_2 distributions of certain economic characters in crosses of six "Foreign" cotton stocks with an American Upland tester stock. Ph.D. Dissertation, Texas A. and M. College. 1959.

Table 1—Means of 7 measurements of earliness on parental stocks EM, LM, MD, and MR.

Character	EM	LM	MD	MR
E-1	43.62	52.35	54.55	53.77*
E-2	78.67	80.10	80.85	84.60
E-3	118.65	125.22	127.87	130.97
E-4†	47.46	7.23	2.03	0.86
E-5†	74.53	39.99	32.51	19.45
E-6†	48.93	7.87	2.02	0.93
E-7†	78.11	45.73	34.60	22.89

* Values connected by an unbroken line do not differ significantly.
† Means were calculated from transformed data but are shown in the original unit of measurement.

Table 2—Means, standard errors, and coefficients of variability of 7 measurements of earliness on P_1, P_2, F_1, and F_2 populations of crosses of EM and LM with MD and MR.

Population	N	E-1			E-2			E-3			E-4			E-5			E-6			E-7		
		$\bar{x}$	$s_{\bar{x}}$	C.V.	$\bar{x}$	$s_{\bar{x}}$	C.V.	$\bar{x}$	$s_{\bar{x}}$	C.V.	$\bar{x}$*	$s_{\bar{x}}$	C.V.	$\bar{x}$*	$s_{\bar{x}}$	C.V.	$\bar{x}$*	$s_{\bar{x}}$	C.V.	$\bar{x}$*	$s_{\bar{x}}$	C.V.
P_1(EM)	40	43.6	.27	3.9	78.6	.60	4.8	118.6	.62	3.3	47.4	1.77	25.7	74.5	3.34	35.3	48.9	1.81	25.7	78.1	3.45	35.0
P_2(MD)	40	54.5	.54	6.2	80.8	.54	4.1	127.8	.60	2.9	2.0	1.82	140.4	32.5	1.53	27.8	2.0	1.85	143.3	34.6	1.58	27.6
F_1	27	46.8	.68	7.5	80.1	.56	3.6	122.0	.50	2.1	24.7	1.69	29.5	74.3	1.86	16.2	25.2	1.66	28.5	76.5	1.88	15.9
F_2	250	48.6	.24	7.7	79.7	.22	4.3	122.0	.23	3.0	24.7	0.91	48.3	58.2	1.39	44.2	26.4	0.95	48.6	59.4	1.42	44.5
P_1(LM)	40	52.3	.37	4.4	80.1	.47	3.6	125.2	.58	2.9	7.2	1.55	62.6	39.9	1.53	24.6	7.8	1.57	60.8	45.7	1.53	22.6
P_2(MD)	40	54.5	.54	6.2	80.8	.54	4.1	127.8	.60	2.9	2.0	1.82	140.4	32.5	1.53	27.8	2.0	1.85	143.3	34.6	1.58	27.6
F_1	40	48.6	.47	6.1	80.1	.51	4.0	123.9	.54	2.7	11.7	1.56	49.3	50.3	2.29	32.0	12.3	1.63	50.2	52.5	2.31	31.4
F_2	229	51.5	.22	8.3	81.5	.23	4.2	127.3	.35	4.1	4.2	0.78	99.7	36.6	0.95	38.4	4.3	0.79	99.4	36.3	0.98	40.1
P_1(EM)	40	43.6	.27	3.9	78.6	.60	4.8	118.6	.62	3.3	47.4	1.77	25.7	74.5	3.34	35.3	48.9	1.81	25.7	78.1	3.45	35.0
P_3(MR)	40	53.7	.56	6.5	84.6	.70	5.2	130.9	.88	4.2	0.8	1.36	161.3	19.4	1.89	45.7	0.9	1.41	162.2	22.8	2.09	46.2
F_1	43	48.2	.50	6.8	78.2	.53	4.4	119.8	.38	2.0	30.0	1.67	32.9	89.3	2.56	29.7	33.8	1.72	31.7	76.3	2.63	28.3
F_2	225	49.4	.27	8.0	79.5	.36	6.8	122.1	.38	4.6	21.1	0.98	53.8	56.7	1.27	39.0	23.8	1.04	53.4	61.0	1.32	38.6
P_1(LM)	40	52.3	.37	4.4	80.1	.47	3.6	125.2	.58	2.9	7.2	1.55	62.6	39.9	1.53	24.6	7.8	1.57	60.8	45.7	1.53	22.6
P_3(MR)	40	53.7	.56	6.5	84.6	.70	5.2	130.9	.88	4.2	0.8	1.36	161.3	19.4	1.89	45.7	0.9	1.41	162.2	22.8	2.09	46.2
F_1	32	49.0	.47	5.4	79.2	.45	3.1	121.8	.37	1.7	16.8	1.15	26.8	60.7	1.62	17.8	18.4	1.14	25.2	69.0	1.60	16.1
F_2	250	51.2	.25	7.7	80.7	.29	5.7	124.8	.30	3.7	9.7	0.75	65.3	39.3	1.00	40.7	10.7	0.79	65.6	42.4	1.04	40.2

* Means were calculated from transformed data but are shown in the original unit of measurement

of them would give the most definitive, as well as the most practical, estimate. The means of the 4 parents, for the 7 methods of measuring earliness employed are given in Table 1. Significant differences in all earliness measurements, except E-2, were found between the early-maturing (EM) and late-maturing (LM) parents, thus justifying the choice of these two stocks as representatives of different maturity groups. In general, both of the genetic marker parents were later in maturity than EM or LM; only in the cases of E-2 and E-5 were nonsignificant differences obtained between the maturity parents and the marker parents. It should also be noted that in 4 of 7 cases MR was later in maturity than MD. It is of special significance that earliness measurements by 2 of the methods (E-3 and E-7) gave significant differences among the means of all 4 parents.

A more comprehensive evaluation of the measurements of earliness was made by calculating the variability within the parental lines and hybrid populations of the four crosses (EM × MD, LM × MD, EM × MR, and LM × MR). The means, standard errors, and coefficients of variability of each earliness measurement for the parental, F_1 and F_2 generations of each cross are shown in Table 2. These data alone do not afford a critical test of the similarities and differences among the earliness measurements, but they contribute to an interpretation of the validity of the mean differences given in Table 1 and the correlation analyses in Table 3.

Phenotypic and genotypic correlation coefficients of all possible paired combinations among the seven earliness measurements, calculated from F_2 data of the 4 crosses, are presented in Table 3. Reference to the table will show that with few exceptions the various earliness measurements are significantly associated. Because estimated environmental effects are removed in the calculation of genotypic correlation, this method gives a more precise estimate of the genetic associations than does the phenotypic method. Comparison of the correlation coefficients in Table 3 shows that in most cases the phenotypic and genotypic coefficients are similar in degree of significance and in direction. An exception to this pattern occurred in the cross LM × MD, where four genotypic correlations were quite small and nonsignificant. Furthermore, in the cross EM × MD the pattern of association was somewhat different from the patterns of the other three crosses in respect to both phenotypic and genotypic correlations. In this cross the correlation coefficients were smaller than similar coefficients in the other three crosses and inconsistencies were noted in

Table 3—Phenotypic and genotypic correlations among 7 measurements of earliness in F_2 populations from crosses of EM and LM with MD and MR.

Combination of methods	EM × MD		LM × MD		EM × MR		LM × MR	
	Phenotypic	Genotypic	Phenotypic	Genotypic	Phenotypic	Genotypic	Phenotypic	Genotypic
E-1 and								
E-2	.28	.36	.29	.18	.46	.80	.51	.67
E-3	.16	.13	.25	.42	.32	.29	.33	.28
E-4	.02	.06	-.19	-.24	-.37	-.33	-.28	-.28
E-5	-.15	-.17	-.20	-.32	-.21	-.28	-.43	-.65
E-6	-.08	.03	-.18	-.19	-.38	-.36	-.28	-.36
E-7	-.15	-.16	-.20	-.31	-.22	-.36	-.44	-.72
E-2 and								
E-3	.52	-.68	.52	.42	.70	.48	.66	.57
E-4	.15	-.60	-.49	-.43	-.50	-.73	-.57	-.62
E-5	-.11	-.11	-.24	.33	-.30	-.60	-.57	-.81
E-6	-.32	-.67	-.48	-.44	-.49	-.68	-.56	-.62
E-7	-.13	-.16	-.23	.33	-.31	-.62	-.57	-.84
E-3 and								
E-4	.13	-1.01	-.66	-.79	-.60	-.57	-.70	-.76
E-5	-.11	.10	-.48	-.43	-.41	-.65	-.58	-.86
E-6	-.57	-1.05	-.66	-.82	-.61	-.59	-.72	-.78
E-7	-.12	.09	-.47	-.41	-.42	-.70	-.59	-.91
E-4 and								
E-5	.12	-.01	.42	-.01	.39	.62	.57	.65
E-6	.98	1.03	.98	1.00	.97	.92	.98	1.07
E-7	.12	-.00	.42	.02	.38	.69	.56	.68
E-5 and								
E-6	.11	-.02	.42	.04	.40	.66	.57	.67
E-7	.99	.92	.95	.66	.98	.76	.98	1.05
E-6 and								
E-7	.13	-.00	.44	.07	.41	.75	.58	.66
Significant r								
5%	.13		.13		.13		.13	
1%	.16		.17		.17		.16	

the direction of the association, the most obvious difference being the highly significant negative genotypic association between E-2 and E-3, while the same correlations in the other crosses were positive and highly significant.

Of the genotypic correlations shown in Table 3, five values exceeded unity. These anomalous values obviously resulted from sampling errors in the environmental variances and covariances. Since the P_1, P_2, and F_1 generations were used for estimating environmental covariances and the genotypic component was obtained by subtracting the environmental estimate from the total covariance of the F_2 generation, sampling errors resulted in plus and minus directions about the true r value and were detectable when calculated values of r exceeded the theoretically maximum value. Thus in the application of the formula to these data a bias apparently was introduced into the estimation of genotypic covariance.

Phenotypic correlation coefficients between E-1, E-2, and E-3 and the other 4 measurements of earliness were negative. This is simply a mathematical expression of a biological phenomenon; i.e., the earlier the onset of squaring, flowering, and boll opening (expressed as number of days

from planting), the higher the values for number of bolls and weights of seed cotton in the early pickings.

DISCUSSION

Although methods E-3 and E-7 were the only 2 that gave significant differences among the means of all 4 parental stocks, correlation studies on F_2 populations showed that the 7 methods were, in general, highly correlated, both phenotypically and genotypically, in the crosses LM × MD, EM × MR, and LM × MR. In the cross EM × MD the pattern of association was less clear. It is obvious that in this experiment the estimated environmental effects were negligible in determining the degree of association. This indicates that the methods used were in fact measuring total genetic differences.

Although the results of this study showed that any one of the seven methods could have been employed with confidence in estimating earliness, their use is conditioned by certain advantages and disadvantages. The collection of data on first square, first flower, or first open boll requires daily checking of all the plants in the field over a long period. Furthermore, the first square to set, the first flower to bloom, or the first boll to open may not always be indicative of early maturity of the crop. Excessive shedding, slow rate of squaring, slow rate of flowering, slow rate of boll opening, and a long boll-maturation period all would tend to reduce the effectiveness of such data for the estimation of earliness. Earliness measurements based on the number of bolls matured at a given time in relation to the total number of open bolls harvested require that the bolls on each plant be counted. This is a tedious and time consuming job that would have to be done during the harvesting season when the experimental work load is heaviest. The above-mentioned disadvantages largely may be compensated for by using the weight of one or more pickings of seed cotton in relation to the total weight of seed cotton produced. One of the methods (E-7) used in this experiment embodies this principle. Method E-7 estimated or measured earliness of maturity in four parental stocks and in certain of their hybrids by expressing the combined weights of the first and second pickings as a percentage of the total seed cotton harvested. As evidenced by its ability to distinguish earliness of crop maturity, in comparisons of all 4 parents, with acceptable statistical precision, this method was 1 of the 2 most reliable of those studied. Method E-7, which may be characterized as a *stratified harvest* procedure, also is the most economical and the easiest to use in actual practice.

Those who would use a stratified harvest procedure for estimating earliness among strains or individual plants of cotton are cautioned that critical results may not always be obtained by the exact method used in the present experiment; i.e., earliness calculated from the combined weight of seed cotton from first and second pickings made 10 days apart and expressed as a percentage of the total harvest. The investigator must construct his formula to fit his material. For instance, only one prefinal harvest made 3 or 4 days before final harvest might be required to discriminate among closely related strains, whereas as many as 3 widely spaced prefinal harvests might be required in the case of segregating material or distantly related strains. Cotton agronomists will recognize at once that a "one prefinal harvest procedure" is essentially the same method of measuring earliness that is now in common use, i.e. earliness, expressed as the percentage of the total crop harvested at the first picking. The safest thing to do is to begin the stratified harvesting procedure soon after bolls in the group of plants or strains under test begin to open and continue to harvest at frequent intervals until some time after the bolls on the latest maturing plants or strains have begun to open. Then the weight of the pickings which will give the best sampling of the material should be used as the base from which to calculate the earliness statistic.

SUMMARY

Seven methods (E-1 to E-7) of estimating earliness were studied in 4 parental stocks of *Gossypium hirsutum,* CB 3051 (EM—early maturing), Conte:xtum (LM—late maturing), Texas 429 (MD—multiple dominant), and Texas 582 (MR—multiple recessive) and in the hybrid generations of the 4 crosses: EM × MD, EM × MR, LM × MD, and LM × MR.

The seven estimates of earliness were found to be significantly correlated in this study and therefore it was concluded that any one of them could have been used with confidence to estimate earliness in cotton on a single-plant basis.

Method E-7 (the combined weights of the first and second pickings expressed as a percentage of the total seed cotton harvested) was considered to be the most practical of those studied.

In discussing the application of earliness method E-7 to breeding and genetic problems it was pointed out that the exact method used in this study may not be suitable for every other experiment and that the investigator should adjust the formula to fit the material under investigation.

LITERATURE CITED

1. DUNCAN, D. B. Multiple range and multiple F tests. Biometrics. 11:1–42. 1955.
2. EATON, F. M. Physiology of the cotton plant. Ann. Rev. Pl. Phys. 6:299–328. 1955.
3. EWING, E. C. A study of certain environmental factors and varietal differences influencing the fruiting of cotton. Mississippi Agr. Exp. Sta. Tech. Bull. 8. 1918.
4. GRIFFEE, F., LIGON, L. L., and BRANNON, L. H. Biometrical analysis of Upland cotton grown at Stillwater, Oklahoma. Oklahoma Agr. Exp. Sta. Bull. 187. 1929.
5. HARLAND, S. C. Early maturity in cotton. Trop. Agr. Trin. 6:114–116. 1929.
6. HODSON, E. A. Correlation of certain characters in cotton. Arkansas Agr. Exp. Sta. Bull. 169. 1920.
7. LANE, H. C., and HESSLER, L. E. Effect of minimal temperature on axillary bud development of Upland cotton. Texas Agr. Exp. Sta. Misc. Pub. 303. 1958.
8. MARTIN, R. D., BALLARD, W. W., and SIMPSON, D. M. Growth of fruiting parts in cotton plants. J. Agr. Res. 25: 195–208. 1923.
9. MCNAMARA, H. C., HOOTON, D. R., and PORTER, D. D. Differential growth rates in cotton varieties and their response to seasonal conditions at Greenville, Texas USDA Tech. Bull. 710. 1940.
10. ————, HUBBARD, J. W., and BEHETT, R. E. Growth and development of cotton plants at Greenville, Texas. USDA Cir. 401. 1927.
11. RASMUSSON, J. Studies in the inheritance of quantitative characters in *Pisum.* Hereditas 20:161–180. 1935.
12. WEBER, C. R., and MOORTHY, B. R. Heritable and nonheritable relationship and variability of oil content and agronomic characters in the F_2 generation of soybean crosses. Agron. J. 44:202–209. 1952.