Published May, 1966

Product-Quantity Measures of Earliness of Crop Maturity in Cotton[1]

T. R. Richmond and L. L. Ray[2]

ABSTRACT

We used 3 stocks of American Upland cotton, *Gossypium hirsutum* L., and the 3 possible crosses among them, as experimental materials for a study of *product-quantity* estimates of earliness of crop maturity. The investigation involved 3 measures of earliness: *(1)* amount of crop harvested (ACH); *(2)* percentage of crop harvested (PCH); and *(3)* mean maturity date (MMD). We took data and calculated genetic and statistical parameters on the parental lines and the F_2 populations of the 3 crosses. MMD, which gave the highest heritability values, was considered to be the most discriminating and the most reliable of the 3, both for studies of the genetics of earliness and for use in breeding programs in which earliness, without regard to total or potential yield, is the prime objective. The reliability of ACH and PCH measures in genetic analyses of earliness is subject to further question because of the correlation between their variabilities and the percentage of bolls open at the time of measurements. Since the method of calculating MMD does not take yield into account directly, ACH or PCH measures will be more effective in those phases of the breeding program in which maximum-yield-in-minimum-time is a major consideration. Of the two, ACH appears to be the more desirable. The importance of the proper date or period on which to base the calculations is emphasized. While no single measure stood out as being completely acceptable in all breeding situations or under all conditions, the experiments show that reasonably reliable measures or estimates of earliness of crop maturity in cotton are available for application to specific, well-defined plant breeding problems or crop improvement objectives.

THE occurrence of frost in the northern regions or higher elevations of the Cotton Belt, high probability of wind and rain storms in the early fall, mid- and late-season depletion of soil moisture, and mid- and late-season damage by certain diseases and insects are among the prime factors which limit cotton production in the United States. For more than 50 years, plant breeders have sought to mediate the consequences of these limiting factors by developing earlier maturing varieties. Compared with varieties of the pre-bollworm era of 50 or 60 years ago, current garicultural varieties of cotton are notably earlier in crop maturity. Nevertheless, economic and management factors associated with mechanized production and harvesting of cotton, as well as the prime factors just mentioned, emphasize the need for even more earliness.

The cotton plant is essentially indeterminate in fruiting habit and sets its bolls (fruits) over a period of weeks or months until one or more factors essential for growth and development become limiting. Thus, a changing environment has an opportunity to act on boll development and maturation over a relatively long period of time. Critical, reliable, and practical methods of measuring or estimating earliness of maturity in cotton are essential "tools" for manipulating earliness of crop maturity in a cotton breeding program.

In a recent paper Richmond and Radwan (2) reported on the results of a comparative study of seven methods of measuring earliness of crop maturity in cotton. Three of the measures (E-1 through E-3) dealt with number of days from planting to appearance of the first square, first bloom and first open boll, respecively, and, under a system of classification we are in the process of developing, they would fall in the *time-event* category. The other four measures (E-4 through E-7) were concerned with ratios of various fractions of the crop to the total crop and, under our system, they would be called *product-quantity* measures. The seven measures were highly correlated, but 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. Pertinent literature on methods of measuring earliness that now would be classified as time-event or product-quantity measures was reviewed by Richmond and Radwan (2).

The conclusions drawn by Richmond and Radwan (2) focused attention on product-quantity measures. Results of a critical study of three approaches to *product-quantity* measurement of earliness of crop maturity in cotton are reported in this paper.

EXPERIMENTAL METHODS

The three *product-quantity* measures of earliness of crop maturity in cotton used in the experiments reported here are identified and described as follows:

Amount of crop harvested (ACH) — Cumulative (a) weight of seed cotton, or (b) number of bolls, harvested (or ready for harvest) at a specified date or sequential harvest period.

Percentage of crop harvested (PCH) — Cumulative (a) weight of seed cotton, or (b) number of bolls, harvested (or ready for harvest) at a specified date or sequential harvest period, expressed as a percentage of the total crop.

Mean maturity date (MMD) — Weighted mean harvest date of several periodic harvests calculated by the formula given by Christides and Harrison (1) where the unit of measure for the weighting factor (w) may be either (a) weight of seed cotton or (b) number of bolls.

In 1958 we grew 10 stocks of American Upland cotton, *Gossypium hirsutum* L., representing a wide range in earliness of crop maturity, in a performance test on the Agronomy Farm at College Station, Texas. The purposes of this test were to survey the stocks for suitable parental material for a genetic study of earliness, and to provide preliminary information on the methods of measuring earliness of crop maturity in cotton. In a randomized-block design of 4 replications, plots consisted of single rows, 40 inches wide, and each plot contained 4 plants spaced 36 inches apart. The wide spacing of plants in the drill was used to minimize competition effects and to provide a relatively large number of bolls per plant for making the earliness estimates. Plant spacing may affect earliness, but the relative earliness of strains and varieties should remain constant across a wide range of plant spacings since it has been shown repeatedly that cotton has the ability to adapt to large differences in plant spacing. Earliness of crop maturity was estimated by two product- quantity measures, percentage of crop harvested (PCH) and mean maturity date (MMD). PCH measures were obtained for the cumulative weight of seed cotton obtained through the 2nd, 4th, and 6th weeks of the boll opening period. MMD was calculated from the periodic harvest weights. Mean values for the three PCH measures and the MMD meas-

[1] Contribution from the Texas Agricultural Experiment Station (South Plains Research and Extension Center, Lubbock, Texas), Texas A&M University in cooperation with the Crops Research Division, ARS, USDA. Taken in part from material submitted by the junior author in partial fulfillment of requirements for the Ph.D. degree at Texas A&M University.

[2] Research Agronomist, Crops Research Division, ARS, USDA (Professor of Agronomy, Texas Agricultural Experiment Station) and Associate Agronomist, South Plains Research and Extension Center.

ure are given in Table 1. The means were compared by the analysis of variance, and Duncan's multiple range test was used to separate means.

As shown in Table 1, the means of later-maturing varieties were not effectively separated by Duncan's test when PCH through the 2nd week was used as an estimate of earliness. Furthermore, the means of the earliest maturing varieties were not effectively separated when the percentage harvested through the 6th week was used as an estimate. Although the means were more regularly distributed when PCH through the 4th week was used as a measure, the MMD estimate gave an even more effective separation (fewer means within each nonsignificant class). Moreover, the MMD measure was equally effective in separating the means of the early-maturing varieties and the late-maturing varieties. Of the 10 strains and varieties tested, C. B. 3051 was the earliest maturing, and Z-106 and Contextum were the latest.

Data from the 10 stocks tested in 1958 provided a basis for selecting early and late maturing parental materials for subsequent experiments. 'C. B. 3051,' a strain procured from Yugoslavia by the U. S. Department of Agriculture and propagated at the South Plains Research and Extension Center at Lubbock, Texas, was chosen as the early maturing parent. Of the 10 stocks tested, 'Z-106' and 'Contextum' were the latest in terms of crop maturity; and because of their divergent origins and differences in branching habit, both stocks were chosen for use as late-maturing parents. Z-106 is a "doubled haploid" from a commercial variety. It was developed by the Cotton Improvement Group at College Station, Texas, and has been maintained by self-pollination for more than 25 years. Contextum, collected in Mexico by O. F. Cook in 1906, has been carried as a self-pollinated stock in the collection of primitive American Upland cottons at College Station for many years.

In the summer of 1958 we made crosses in all possible combinations among the three parental stocks. The parental stocks and F_1 progenies were grown in the greenhouse during the winter of 1958-59. Because of the difficulty of producing hybrid seed in adequate quantity and because the flowers on F_1 plants were self-pollinated to provide seeds for F_2 populations, F_1 bolls and seed cotton for product-quantity determinations were not available. Variance, heritability, and other genetic parameters were calculated from parental and F_2 data.

Plantings of the 3 parental stocks and F_2 seed of the 3 crosses among them were made at Lubbock, Texas, in 1959, to provide material for a comprehensive study of the 3 types of product-quantity measures (PCH, ACH, and MMD). Although the 6 populations (3 parental and 3 F_2) were replicated and randomized in the field design, collected data were analyzed on the basis of individual plants without regard to replication. Each F_2 plot contained approximately 32 plants and each parental plot 6 plants, spaced 3 feet apart. The exact numbers of plants on which statistical analyses were based are given in appropriate tables in the results section.

Harvests were made at weekly intervals during the boll maturation season except in two cases involving minor deviations from schedule caused by inclement weather. Two additional harvests (8th and 9th) were made after frost. These were divided on the basis of the degree of boll development rather than on intervals of time. The 8th harvest was composed of bolls which had opened sufficiently for the seed cotton to be harvested and the 9th harvest included only the extremely late-set bolls which did not open. In the calculation of MMD, harvest intervals were treated as if they were equal.

Table 1. Means of PCH and MMD measures of earliness of maturity* on 10 cotton strains and varieties.

Strain or variety	Mean PCH through:			MMD†
	2nd week	4th week	6th week	
'Z-106'	0 a	17.5 ab	50.7 a	5.96 a
'Contextum'	0 a	9.1 a	65.9 ab	5.87 ab
'M-8948'	2.1 a	35.7 abc	90.7 bc	5.09 abc
'C.A. 119 Ey'	0.7 a	46.0 abc	88.8 bc	4.86 bcd
'Deltapine 14'	1.0 a	36.9 abc	93.7 c	4.79 bcd
'Stormrider'	7.8 abc	46.3 abc	95.1 c	4.58 cde
'Gl. 17-2'	4.9 ab	52.9 bc	96.2 c	4.42 cde
'C.B. 3059'	17.9 bcd	67.9 cd	96.8 c	3.91 def
'Paymaster 54-B'	25.5 d	71.2 cd	97.4 c	3.57 ef
'C.B. 3051'	22.0 cd	94.8 d	99.6 c	3.24 f

* Within the same earliness estimate, means followed by the same letter did not differ significantly at the .05 level of probability when measured with Duncan's multiple range test. † Seven weekly harvests, weighted by seed cotton produced in each harvest period, and expressed as weeks from the beginning of the boll-opening period (July 28).

RESULTS

Several distinct differences in boll-opening patterns and in earliness of crop maturity among the three parental stocks — C. B. 3051, Z-106 and Contextum, grown at Lubbock in 1959 — can be seen in Fig. 1. The boll-opening peak of C. B. 3051 was reached at the 4th harvest; the peak of the Z-106 stock occurred just before frost, and that of Contextum after frost. In fact, 57% of the bolls of Contextum did not reach the dehiscent stage.

Amount of crop harvested (ACH). We made statistical analyses of the cumulative ACH estimates, based on the number of bolls per plant, through each harvest date. The means and their standard errors for the odd-numbered harvest dates are given in Table 2. A relationship was found between the percentage of the bolls harvested and the C. V. of ACH. Fig. 2 shows the C. V.'s for the ACH measures plotted against the percentage of bolls harvested at the time the measurements were taken. The C. V. for the ACH measurement seemed to be largely a function of the percentage of bolls harvested, with no distinct differences between the C. V.'s of parents and F_2 populations. At the late harvest dates, the C. V.'s of the Contextum population appeared to be slightly higher than those of other parental populations.

C. V.'s for the ACH measures were very high until about 20% to 25% of the crop was open, then they decreased gradually. Because of the extremely high C. V. values, it is doubtful that reliable estimates of earliness can be made with the ACH method if less than 20% of the crop is open.

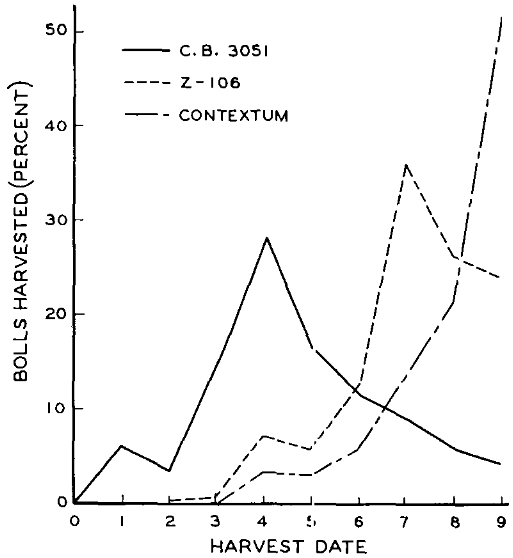

Figure 1. The percentage of bolls harvested on each date of harvest from the 3 parental stocks.

Table 2. Means and standard errors of ACH measures* through selected harvest dates for the parental and F_2 generations of 3 crosses.

Population	N	Number of bolls harvested through date:				
		1	3	5	7	9
			Parents			
C.B. 3051	26	2.3±0.5	8.6±1.2	24.2±1.8	32.0±2.0	34.5±2.2
Z-106	20	0.1±0.1	0.1±0.1	3.5±0.8	15.6±2.1	27.6±2.6
Contextum	19	0	0	3.3±0.8	15.4±3.3	50.2±5.1
			F_2's			
C.B. 3051 × Z-106	125	0.4±0.1	2.6±0.3	14.8±0.7	28.7±1.0	32.0±1.0
C.B. 3051 × *Contextum*	121	0.3±0.1	1.7±0.2	11.7±0.7	28.3±1.2	42.2±1.6
Z-106 × Contextum	113	0	0.3±0.1	3.5±0.4	14.8±1.0	35.1±1.3

* Calculated in terms of number of bolls.

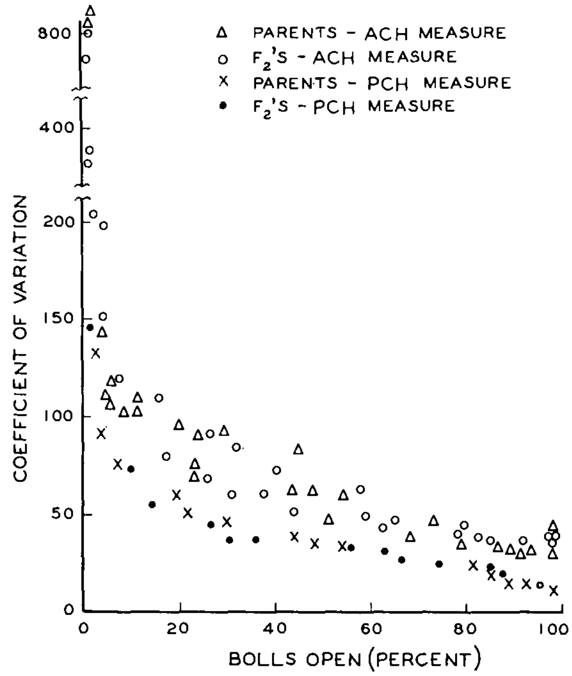

Figure 2. Coefficients of variation of ACH and PCH in relation to percentage of bolls open.

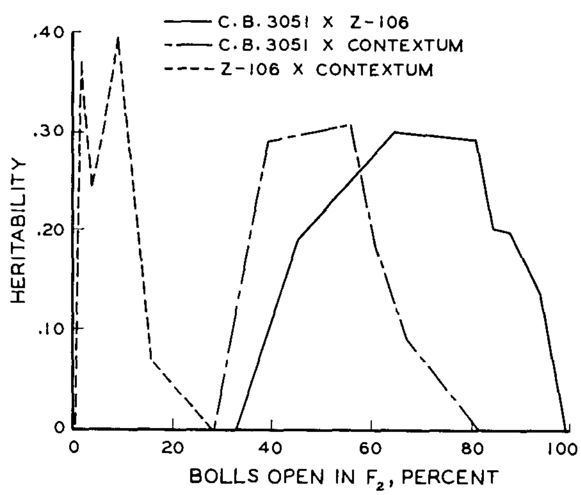

Figure 3. The relationship of the percentage of bolls open in the F_2 to heritability estimates calculated for ACH.

We made heritability estimates for the ACH measurements, using the arithmetic means of the parents to estimate environmental variances. In the C. B. 3051 × Z-106 and C. B. 3051 × Contextum crosses (early × late maturing parents), heritability estimates greater than zero were not obtained until after the 4th harvest, or when approximately 30% of the F_2 crop was open (Fig. 3). In Z-106 × Contextum (late × late maturing parents) the only heritability estimates above zero were those obtained at the early harvest dates. If, indeed, segregation occurred in this cross it must have involved genes which affected only the earliest maturing segment of the crop. In crosses of early × late parents, indications of genetic control of earliness were obtained only at the mid-to-late dates of harvest. Thus, selection of the "proper" or critical harvest date is considered to be extremely important in the genetic analysis of earliness when measured by the ACH method.

Table 3. Means and standard errors of PCH measures* through selected harvest dates for the parental and F_2 generations of 3 crosses.

Population	N	Percentage of bolls harvested through date: 4	6	7	8
		Parents			
C.B. 3051	26	54.2±5.2	86.7±3.3	94.5±2.4	98.3±1.0
Z-106	20	4.7±1.8	22.5±4.6	50.6±6.4	81.5±5.2
Contextum	19	1.6±0.7	7.5±2.6	19.7±4.5	42.7±6.2
		F_2's			
C.B. 3051 × Z-106	125	31.1±2.9	67.1±2.0	88.2±2.0	96.2±0.7
C.B. 3051 × Contextum	121	15.0±1.4	38.9±2.3	64.0±2.4	86.1±1.6
Z-106 × Contextum	113	1.2±0.3	10.4±1.3	27.4±2.0	56.8±2.5

* Calculated in terms of number of bolls.

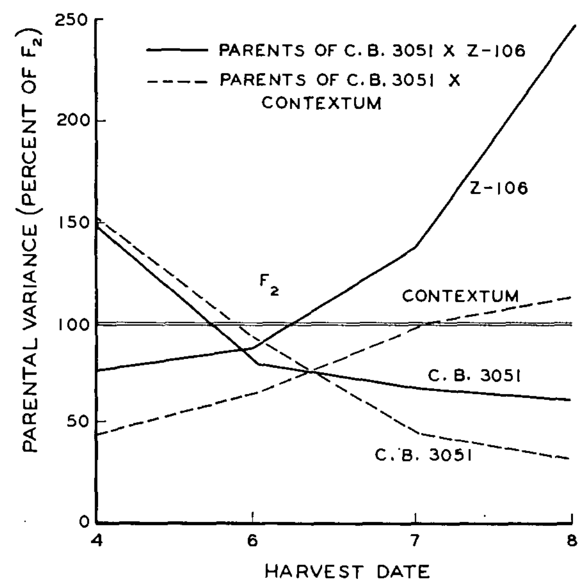

Figure 4. Parental variances of PCH measures as percentage of the variances of the F_2's.

Percentage of crop harvested (PCH). Analyses were made of the percentage of bolls harvested through the 4th, 6th, 7th, and 8th harvest dates as well as for the percentage of seed cotton harvested through the 6th date. Arcsin transformations were used in all analyses. Seed cotton weight and boll number data gave comparable estimates of earliness. Therefore, only the boll number data were used in extensive analysis. Means and standard errors for PCH are given in Table 3. Dominance of earliness was indicated in the F_2 of the C. B. 3051 × Z-106 cross, and to a lesser degree in the C. B. 3051 × Contextum cross. Lateness of maturity seemed to be dominant in the Z-106 × Contextum cross.

In Fig. 4 the variances of the parental populations are plotted as a percentage of the variance of their corresponding F_2 populations. A distinct relationship in these variances is evident; at the early (4th) harvest the variance of the early parent was greater than that of the F_2, but the variances of the late parents were less than those of F_2. On the other hand, at later dates of harvest the variance of the early parent decreased in relation to that of the F_2 while the variances of the late parents increased. The variances of the late parents exceeded the variances of the F_2 at the last date for which PCH was calculated. Only at the 6th harvest date were the variances of all parents less than those of corresponding F_2's. If the variance within a homozygous parental population had been due entirely to environmental factors, the variance of the F_2 should have exceeded the variance of the parents by the amount of additional variation caused by the segregating genes. The almost linear increase of variance of the late-maturing parents relative to that of the F_2, and a corresponding decrease of the variance of the early-maturing parents as the season progressed, suggest that the variance may be related to the percentage of bolls harvested.

Further evidence of this relationship was obtained by plotting the coefficient of variation (C. V.) against the percentage of open bolls harvested (Fig. 2). As in the case of the ACH measure, the graph shows that the C. V. of PCH bears a definite relationship to the percentage of bolls harvested. The C. V.'s for PCH were slightly lower than corresponding C. V.'s for the ACH measure. This was expected, since calculation of PCH removes a part of the variability due to yield differences. Also, as in the ACH determinations, the C. V.'s of the F_2's (segregating populations) were about the same as for the parental populations adjusted for percentage of bolls harvested. Of course, the standard deviation and the C. V. of PCH for all populations would be zero for the two extremes of the graph; namely, percentages of zero and 100. However, when the mean PCH was extremely low (less than 5%), the C. V.'s were very high.

Heritability estimates were determined. The arithmetic means of the variance of the parents were used to estimate environmental variance and the variance of the F_2 was used to estiamte total variance. Heritability estimates greater than zero were obtained for the PCH measure in the C. B. 3051 × Z-106 and Z-106 × Contextum crosses only at the 6th harvest date; they were very low, .14 and .03, respectively. Heritability estimates calculated from the data from the C. B. 3051 × Contextum cross exceeded .20 at the 6th, 7th, and 8th harvest dates. Slightly higher heritability estimates were obtained when the geometric means of the parental variance were used for the estimate of environmental variance.

Mean maturity date (MMD). Harvest periods, expressed in weeks, were weighted by: (a) number of open bolls and (b) seed cotton weights (in grams). MMD measures calculated by both weighting values are given in Table 4. MMD measures based on seed cotton weight were lower (earlier) than those based on the number of bolls harvested. Since the last (9th) harvest consisted only of unopen bolls, it was included in the measures based on boll number but not in those based on seed cotton weight. The differences between the two MMD measures were smaller in the earlier than in the later maturing populations, since a smaller portion of the crop was included in the 9th harvest in the early maturing lines.

Table 4. Means, standard errors, and variances of MMD measures† for the parental and F_2 generations of 3 crosses.

Population		Mean maturity date (MMD)†			
		Number of bolls		Seed cotton weight	
		Mean±SE	Variance	Mean±SE	Variance
		Parents			
C.B. 3051	26	5.56±.25	0.90	5.70±.20	0.61
Z-106	20	10.06±.37	1.31	8.29±.21	0.51
Contextum	19	11.79±.35	1.26	9.10±.25	0.67
		F_2's‡			
C.B. 3051 × Z-106	125	7.00±.14	1.27*	6.41±.03	0.62*
C.B. 3051 × Contextum	121	8.63±.16	1.82*	7.47±.09	0.61
Z-106 × Contextum	113	10.98±.15	1.32*	8.81±.08	0.44

† Expressed as weeks from the beginning of the boll opening period (September 8).
‡ F_2 variances with an asterisk exceed the mean variance of their respective parents.

The variances of the MMD measures of these populations also are given in Table 4. The only case in which the variance of the F_2 exceeded the mean variance of the parents was the cross CB 3051 × Z-106 when the MMD was calculated from seed cotton weights. In this cross, the F_2 variance was about 10% greater than the mean variance of the parents. When number of bolls was used to calculate the MMD, all F_2 variances exceeded the mean variance of the parents. However, in the Z-106 × Contextum cross, the difference was very slight. Since the highest heritability estimate, .41, was obtained from the C. B. 3051 × Contextum cross with MMD based on number of bolls, MMD measures calculated in this manner should be somewhat more efficient in detecting genetic effects than those based on weight of seed cotton.

DISCUSSIONS AND CONCLUSIONS

Not only were the environmental variances of the three measures of earliness of crop maturity large and their heritabilities relatively low, but the variances for the measures of the *percentage of the crop harvested* (PCH) and the *amount of the crop harvested* (ACH) were associated with the percentage of the crop open at the time the measurements were made. When the variances of these measurements were adjusted for the percentage of the crop open, they were approximately the same for the nonsegregating as for the segregating populations. Thus, a bias may be introduced when genetic parameters are calculated from variances of either of these two measures. Theoretically, the *mean maturity date* (MMD) measure of earliness would not present this bias because all harvest dates are used in its calculation. Nevertheless, the environmental portion of the variance of the MMD measure was found to be quite large. Variation was considerable among the heritability estimates obtained from the three *product-quantity* measure of earliness. However, heritability values for MMD were in most cases higher than those for ACH and PCH. Had it been possible to calculate data from F_3 progeny means, rather than from individual F_2 plants, higher and more encouraging heritability estimates probably would have been obtained.

All of the three earliness measures investigated could, with reasonable confidence, be used in evaluating earliness of crop maturity in the development of cotton strains and varieties in specified phases of practical breeding programs. In most farming enterprises, attainment of maximum product yield in the time (or season) available is the prime objective. In such cases, measures which relate crop production to time will be the most effective. Of the three product-quantity measures of crop maturity, the ACH method will come closest to fulfilling the stated objective, and the MMD method will fall the shortest. However, considerations other than the maximum-yield-in-minimum-time concept of earliness are involved in breeding for earliness of crop maturity in cotton. Often it is desirable to evaluate "pure" earliness, i.e., earliness without taking into account the effects of yield and certain other factors. The PCH or MMD methods of estimating earliness are not directly concerned with total yield. Also, since the MMD measure gave the highest heritability of the three measures studied, it should be more effective than the other methods for genetic evaluation, and for selection for earliness of maturity in the initial phases of a breeding program. Even though the two types of data on which MMD measures were based (boll number and seed cotton weight) resulted in highly correlated estimates of earliness, MMD calculated from the number of bolls harvested had the higher heritability value. Therefore, in a selection program, somewhat faster progress would be expected from the use of MMD measures calculated from boll number than with those calculated from seed cotton weights. Because killing frost occurred when a relatively large number of bolls on Contextum plants, and certain F_2 Contextum $\times$ Z-106 plants, were immature (unopen), this may have had a biasing effect. However, one would not choose a parent as late in crop maturity as Contextum for use in a practical breeding program in which earliness is one of the prime considerations.

Richmond and Radwan (2), in an analysis of the methods of estimating earliness of maturity of cotton, pointed out that several harvests should be made, and that "the weight of the picking which will give the best sampling of the material should be used as the base from which to calculate the earliness statistic." Evidence obtained in the present experiments, particularly with respect to the ACH and PCH measures, confirm and support the importance of choosing the proper base. In the light of the data obtained thus far, no single measure of earliness of crop maturity in cotton stands out as being completely acceptable in all breeding situations, or under all conditions. However, as the data show, and as this discussion points out, reasonably reliable measures or estimates of earliness of crop maturity in cotton are available for application to specific, well-defined plant-breeding problems or crop-improvement objectives.

LITERATURE CITED

1. Christides, B. G., and G. J. Harrison. 1955. Cotton growing problems. McGraw-Hill Book Company, New York.
2. Richmond, T. R., and Sami R. H. Radwan. 1962. A comparative study of seven methods of measuring earliness of crop maturity in cotton. Crop Sci. 2:397-400.