The *Journal of Cotton Science 20:40–45 (2016)*
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BREEDING AND GENETICS

Measuring Maturity in Cotton Cultivar Trials

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ABSTRACT

Measuring maturity in Upland cotton (*Gossypium hirsutum L.*) cultivar trials is a simple calculation of percentage of first harvest to total harvest when most trials are harvested twice. This provides a rough estimate of maturity. Today, cotton trials are rarely harvested twice because of the use of synthetic boll-opening agents. Breeding programs in states such as Arkansas and North Carolina have estimated maturity by either visually estimating percentage bolls open or actually counting open and closed (green) bolls. This study was conducted to determine the optimum combination of replicates, years, and locations of data needed to show 1 d difference in maturity between cultivars. Data were used from the Arkansas testing program for years 2005 through 2012 and from North Carolina for years 2007 through 2012. Arkansas program estimates percentage bolls open visually in all replicates and North Carolina program counts number of open and closed bolls in a short section of each plot in two replicates. For the Arkansas method, we would need to collect data from four replicates, 2 yr, and five locations or four replicates, 3 yr, and three locations. For North Carolina we would need 3 yr, four replicates, and three locations; or 3 yr, three replicates, and five locations; or 3 yr, five replicates, and two locations to provide the same level of precision. Single-year data could detect a 2 d difference in maturity using the Arkansas method and a 4 d difference in maturity using the North Carolina method. The Arkansas method is quicker and provides fairly accurate data on maturity and would be the recommended method to follow.

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Maturity in cotton (*Gossypium hirsutum* L.) has been an important agronomic factor since the days of the boll weevil (*Anthonomus grandis* H.), which was first introduced into the U.S. Cotton Belt in the early 1900s. Early maturing cotton was thought to increase the probability of avoiding high population counts of boll weevil with concomitant damage that occurred late in the growing season. Today, the choice of cultivars based on maturity continues to be critical for many cotton growers. Advantages of early maturing cultivars include: 1) increased ability to reach full maturity (particularly in the northern part of the cotton belt), 2) avoidance of late-season harvest problems, 3) farming of large acreage by spreading harvest time, 4) enabling fall land preparation, and 5) facilitating double cropping (e.g., winter wheat [*Triticum aestivum* L.] or cabbage [*Brassica oleraca* L.]).

The timeliness associated with maturity can be illustrated by the COTMAN cotton management system (Bourland et al., 1992, 2008). With COTMAN, late-season timing of crop management is based on the latest harvest completion date for an area, which is based on long-term weather data. In the northern part of the cotton belt, this completion date is primarily established by cessation (or slowing) of expected growing degree days above 60°F (DD60). In more southern regions, rainfall associated with hurricane season is often the primary factor. Once the latest harvest completion date is determined, long-term weather data for a location are used to determine the latest possible cutout date, that is, the date from which 85 DD60s can be expected in 50% of years. In northeast Arkansas, the latest harvest completion date is 1 November, and the latest possible cutout date is 10 August. Normal plant development in the COTMAN growth curve requires 80 d from planting to physiological cutout, so planting must occur before 21 May to have these 80 d available. Full maturity is often not achieved if planting date is delayed, emergence and early growth is hindered, or fruiting forms are lost. Use of early maturing cultivars is thus essential to lessen the effects of these problems.

Maturity measures in cotton can be affected by weather. For example, there was a significant cultivar difference in maturity in Australia in the 2000 to 2001 season of 5 d but no significant difference in the 2001 to 2002 season (Bange et al., 2006). Main and Allen (2011) reported a difference in maturity of 160 growing degree days (GDD) based on DD60 between 'Deltapine 444 BG/RR' and 'Deltapine 555 BG/RR'. If the average temperature during the maturation period in the fall is 26.7 °C, then there would be an 8 d difference in maturity between these two cultivars. However, if temperatures were above or below average then the difference in maturity would change.

There have been various methods used to measure maturity in cotton ranging from nodes to first fruiting branch, days to flower, nodes above cracked boll, nodes above white bloom, percentage first harvest, mean maturity date, number of vegetative branches, percentage bolls on vegetative branches, and percentage bolls open (Bourland et al., 2001; Main and Allen, 2011; Panhwar et al., 2010; Ray and Richmond, 1966; Richmond and Radwan, 1962; Richmond and Ray, 1966). Each method has advantages and disadvantages. Prior to the widespread adoption of boll openers, nearly all researchers harvested trials twice; an easy way to determine maturity was to calculate percentage first harvest—the most practical method given almost no additional work was required. Boll openers such as ethephon can mask differences in maturity and thus impact maturity measures such as percentage first harvest and percentage bolls open (unless the data are collected before the boll opener is applied).

States in the cotton belt conduct cultivar performance trials to provide data to growers, consultants, extension agents, and seed dealers on relative performance of the various cultivars on the market. Some states collect data on maturity using one of the methods previously mentioned. The ability to detect significant maturity differences and the level of precision affording quantitative distinctions has not been examined. The objective of this paper is to determine a combination of replicates, years, and locations necessary to show a 1 d difference in maturity between cultivars in Arkansas and North Carolina.

MATERIALS AND METHODS

Data for this study were obtained from the cotton cultivar trials in Arkansas for the years 2005 through 2012 and in North Carolina for the years 2007through 2012.

For Arkansas, boll opening was estimated from each plot in all four replicates of each trial with one exception where only three replicates were estimated. Methods used in each year generally followed those described by Bourland et al. (2013). Trials were located at Judd Hill, Keiser, Marianna, and Rohwer. All trials were replicated at least four times. A nonirrigated trial was included at Keiser in years 2005 and 2006. At approximately the time of defoliation, two ratings (one from each end of plot) were made. Green bolls at the top of the plant that did not appear to be harvestable were not included in the data collection.

For North Carolina, boll-opening data were obtained from two replicates in each trial. Trials were located in Bertie, Edgecombe, Johnston, Scotland, and Washington counties and were replicated for yield purposes five times. In each plot, 2 m of row were measured and both open and closed (green) bolls were counted from one row of the plot before defoliation. Bolls with any white showing were counted as open bolls. Bolls that were considered too small for harvest were ignored. Percentage open bolls was calculated from number of open bolls divided by total number of bolls.

The data were analyzed in 3-yr segments and 2-yr segments to provide an estimate of genotype*location, genotype*year, and genotype*location*year interactions. All genotypes common to all 2 or 3 yr were then included in the analysis. Sources of variation included genotype, year, location, replicate within location, year*location, genotype*year, genotype*location, genotype*year*location. All effects were considered random. Variances for genotype and the interactions were pooled across data sets to give an average variance. In addition, single year data were analyzed because they include many more genotypes and examination of these data would provide insight into accuracy of that data. Statistical analyses were performed using SAS 9.3 software (SAS Institute, Cary, NC).

The number of location*year combinations ranged from 11 to 13 in the six 3-yr data sets in Arkansas, whereas the number ranged from 9 to 11 in the four 3-yr data sets in North Carolina. The number of entries included in the analyses ranged from three to 13 in Arkansas and 11 to 22 in the North Carolina data.

Deltapine 444BG/RR is reported to mature earlier than Deltapine 555BG/RR as mentioned above (Main and Allen, 2011). For this study we assumed an average difference of 8 d. This is based on an average temperature of 27.8 °C for North Carolina for the month of September (www.weather.com), which is when most of the boll-opening data were collected. Data on boll opening on these two cultivars were reported to show an average difference of 24% in North Carolina (Bowman, 2005, 2007). Thus to show a 1 d difference in maturity, the least significant difference (LSD) for boll opening must be approximately 3%. Efforts were made to find the combination of replicates, years, and locations that would produce a difference in boll opening between cultivars that are 1 d different in maturity.

RESULTS AND DISCUSSION

Pooled variances for the 3-yr Arkansas data are shown in Table 1. By far, the largest variance was for genotypes. The genotype *location and genotype*year interactions as well as the three-way interaction were not significant. This allowed us to examine various combinations of replicates, years, and locations to meet our goal of detecting 1 d differences in maturity.

Table 1. Variances for boll opening using 3-yr data sets from Arkansas OVT[z] for years 2005 through 2012 and North Carolina OVT for years 2007through 2012

Source of Variation	Arkansas	North Carolina
	Pooled Variance	Pooled Variance
Genotype	496	385
Year*Genotype	81	122
Location*Genotype	61	109
Year*Location*Genotype	51	88
Error	46	82

[z] Official Variety Testing.

Because Arkansas typically uses four replicates in their data collection, we calculated predicted LSD values based on that number of replicates with varying numbers of locations and years in Table 2. Because the Arkansas program has a maximum five locations, we limited the combinations to five locations. Also, because cultivars change frequently (Bowman, 1998) we limited the number of years to three.

Our objective was to show significant differences, where they exist, in a reasonable number of locations and years. Ideally we would like to show significant differences in 1 yr. Given our objective was to show a 1 d difference in maturity and thus needing to show a significant 3% difference, it appears that 1-yr data are insufficient to achieve that level of precision. However, 2 yr with five or more locations or 3 yr with three or more locations would provide that level of precision in Arkansas (Table 2).

Table 1 lists the pooled variances using 3-yr data (2007-2012) from North Carolina. Similar to Arkansas data, the largest variance component was genotype. The two-way and the three-way interactions, although not significant, were larger than residual error. These nonsignificant interactions allowed us to use various combinations to achieve our desired level of precision.

Currently, the North Carolina Official Variety Testing program takes boll-opening data on two replicates in five trials, thus Table 3 lists predicted LSD values with that number of replicates. Not even with 3 yr and five locations per year would we achieve a desirable LSD of 3.0 (Table 3). We would not be able to achieve significant 3.0 LSD in 1 yr with the possibility of using up to all five replicates in each trial and all five locations (Table 3). The best we could do was a 7.2 LSD with that combination. If we set a goal of achieving adequate precision in 2 yr, we would need to use more than

Table 2. Predicted LSD values for various combinations of years and locations using four replicates per location in Arkansas and two replicates per location in North Carolina

Locations\ Years	Arkansas			North Carolina		
	1	2	3	1	2	3
1	20.2	11.5	8.5	37.9	21.6	16.0
2	11.9	6.6	4.8	22.0	12.2	8.8
3	9.0	4.8	3.4	16.4	8.9	6.4
4	6.9	4.0	2.4	13.5	7.2	5.1
5	6.5	3.4	1.4	11.6	6.2	4.4

five replicates and all five locations to get a 3.0 LSD (Table 4). In most years a trial is lost due to various reasons or data are not collected on time (if any cultivar is 100% open, then boll-opening data cannot be collected) so this rules out 2-yr data. Table 5 shows predicted LSD values if we used 3 yr of data. We would need to collect data on three replicates and all five locations. It is rare that all five locations provide valid data all 3 yr. We could collect data on four replicates and three locations, which is reasonable. Another possibility is using all five replicates and two locations.

Table 3. Predicted LSD values for various combinations of locations and replicates using 1 yr in North Carolina

Locations\ Replicates	1	2	3	4	5
1	56.6	37.9	30.4	26.1	23.2
2	32.3	22.0	17.7	15.2	13.5
3	23.9	16.4	13.2	10.3	10.1
4	19.6	13.5	10.9	9.4	8.4
5	16.9	11.0	8.8	8.1	7.2

Table 4. Predicted LSD values for various combinations of locations and replicates using 2 yr in North Carolina

Locations\ Replicates	1	2	3	4	5
1	31.9	21.6	17.4	15.0	13.3
2	17.8	12.2	9.8	8.4	7.5
3	11.4	8.9	7.2	5.8	5.5
4	9.9	7.2	5.8	5.0	4.5
5	8.9	6.2	5.0	4.3	3.9

Table 5. Predicted LSD values for various combinations of locations and replicates using 3 yr in North Carolina

Locations\ Replicates	1	2	3	4	5
1	23.4	16.0	12.9	12.1	8.9
2	12.8	8.8	7.1	4.9	3.4
3	9.2	6.4	5.2	2.8	2.6
4	7.4	5.1	4.0	2.4	2.2
5	6.3	4.4	3.4	1.7	1.6

Individual year data across locations are shown in Tables 6 and 7. These data include many more genotypes/entries from the analyses above as shown in the tables. Assuming you need a LSD of 3.0 to detect a 1 d difference in maturity, the average LSD for Arkansas is 5.5. This means that normally you could only detect a 2 d difference in maturity. In the best year (2005), you could only detect a 1.5 d difference using five locations and four replicates. In North Carolina the average LSD is 10.8 which means a 4 d difference. The best year was 2010 with four locations and then we could detect only a 2.5 d difference in maturity.

Table 6. Individual year data on boll opening from the Arkansas OVT for 2005 through 2012

Year	Entries	N[z]	Average Boll Open (%)	LSD
2005	28	20	64	4.8
2006	26	16	69	5.5
2007	38	16	66	4.9
2008	30	16	53	6.1
2009	30	11	55	6.3
2010	32	16	54	5.3
2011	24	16	54	5.3
2012	20	16	59	5.6

[z] Total number of replicates and locations.

Table 7. Individual year data on boll opening from the North Carolina OVT for 2007 through 2012

Year	Entries	N[z]	Average Boll Open (%)	LSD
2007 – Early	47	6	64	9.0
2007 – Medium	9	6	69	8.8
2008	34	8	66	8.2
2009	35	6	53	12.0
2010	35	8	55	7.3
2011	31	4	54	11.5
2012	40	6	54	18.6

[z] Total number of replicates and locations.

Two-year data analyses across locations are shown in Tables 8, 9, and10. For Arkansas, pooled variances could be calculated for all interactions and were similar to those calculated from 3-yr data (Table 8). The number of entries ranged from 12 to 19, and the LSD ranged from 3.7 to 4.3 (Table 9). The LSD values are nearly identical to those predicted based on 3-yr data, for example, 2 yr, four locations, and four replicates give a predicted LSD of 4.0 in Table 2, and in Table 9 the same number of data points gave an average LSD of 3.9. For North Carolina 2-yr data are shown in Tables 8 and 10. Pooled variances are nearly identical between 3-yr (Table 1) and 2-yr (Table 8) data sets. The number of entries in the 2-yr analyses ranged from 16 to 25 and the number of data points ranged from 10 to 14 (Table 10). The resulting LSDs are comparable between data sets of equal numbers (Tables 2 and 10).

Table 8. Variances for boll opening using 2-yr data sets from Arkansas OVT for years 2005 through 2012 and from North Carolina from years 2007 through 2012

Source of Variation	Arkansas	North Carolina
	Pooled Variance	Pooled Variance
Genotype	673	383
Year*Genotype	92	104
Location*Genotype	81	116
Year*Location*Genotype	76	99
Error	111	83

Table 9. LSD from 2-yr data sets from Arkansas for years 2005 through 2012

Years	Entries	N[z]	LSD
2005-2006	14	36	3.9
2006-2007	12	32	3.7
2007-2008	14	32	3.7
2008-2009	19	27	4.3
2009-2010	16	27	4.2
2010-2011	14	32	3.7
2011-2012	12	32	3.9

[z] Total number of replicates and locations

Table 10. LSD from 2-yr data sets from North Carolina for years 2007 through 2012

Years	Entries	N[z]	LSD
2007-2008	25	14	6.5
2008-2009	23	14	7.0
2009-2010	19	14	6.8
2010-2011	19	12	6.1
2011-2012	16	10	10.6

[z] Total number of replicates and locations.

CONCLUSIONS

Both Arkansas and North Carolina are in the northern part of the cotton belt and maturity is a critical factor in cultivar choice by growers. Even though we measured maturity slightly differently, the principle was the same, that is, estimating maturity through boll opening measurements. Maturity is a heritable trait as shown by the magnitude of variances. Environmental interactions with genotype exist but are much smaller. The Arkansas method of measuring boll opening by visual estimation appeared to be more accurate than the North Carolina method of counting open and green bolls in a short area of the plots. In the final analysis, 2 yr and five locations of data from four replicates should give a level of precision needed to show a 1 d difference in maturity in Arkansas. Whereas it would take 3 yr, four replicates, and three locations; 3 yr, three replicates, and five locations; or 3 yr, five replicates, and two locations to provide the same level of precision in North Carolina. Single-year data could normally detect a 2 d difference in maturity using the method of Arkansas and 4 d using the North Carolina method. The Arkansas method of estimating maturity is quicker, and as shown in the data, fairly accurate. The North Carolina method is more detailed, although not necessarily more accurate. For anyone wishing to start collecting maturity data, the technique by Arkansas of standing at each end of the plot and estimating boll opening would be recommended, although this would require some cotton experience.

REFERENCES

Bange, M., S. Milroy, and G. Roberts. 2006. Managing for crop maturity. CSIRO Plant Industry Cotton CRRC, Australian Cotton Grower Dec. 2006.

Bourland, F.M., A.B. Beach, D.P. Roberts, Jr., and C. Kennedy. 2013. Arkansas cotton variety test 2012. Arkansas Agric. Exp. Stn. Res. Ser. 607.

Bourland, F.M., N.R. Benson, E.D. Vries, N.P. Tugwell, and D.M. Danforth. 2001. Measuring maturity of cotton using nodes above white flower. J. Cotton Sci. 5:1–8.

Bourland, F.M., D.M. Oosterhuis, and N.P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main-stem node counts. J. Prod. Agric. 5:532–538.

Bourland, F.M., N.P. Tugwell, D.M. Oosterhuis, and M.J. Cochran. 2008. Initial development of the COTMAN program. p. 15–20 *In* D.M. Oosterhuis and F.M. Bourland (ed.). COTMAN crop management system. Univ. Arkansas, Agric. Exp. Sta., Fayetteville, AR.

Bowman, D.T. 1998. Using crop performance data to select hybrids and varieties. J. Prod. Agric. 11:256–259.

Bowman, D.T. 2005. Measured crop performance: cotton. North Carolina Agric. Res. Serv. Crop Sci. Res. Rept. No. 216.

Bowman, D.T. 2007. Measured crop performance: cotton. North Carolina Agric. Res. Serv. Crop Sci. Res. Rept. No. 222.

Main, C.L., and F. L. Allen. 2011. Tennessee cotton variety test results 2011 (online). Dept. of Plant Sci., Univ. Tenn. Knoxville, TN. Available at http://www.UTcrops.com. PB1742.

Panhwar, R., A.R. Soomro, B.A. Ansari, S.A. Panhwar, and S. Memon. 2010. Exploring most efficient and reliable parameters to measure earliness in cotton (*Gossypium hirsutum* L.) genotypes. Pak. J. Agric. 26:39–44.

Ray, L.L., and T.R. Richmond. 1966. Morphological measures of earliness of crop maturity in cotton. Crop Sci. 6:527–531.

Richmond, T.R., and S.R.H. Radwan. 1962. Comparative study of seven methods of measuring earliness of crop maturity in cotton. Crop Sci. 2:397–400.

Richmond, T.R., and L.L. Ray. 1966. Product-quantity measures of earliness of crop maturity in cotton. Crop Sci. 6:235–239.