The *Journal of Cotton Science 17:140–148 (2013)*
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AGRONOMY AND SOILS

Investigation of Physiological Growth, Fiber Quality, Yield, and Yield Stability of Upland Cotton Varieties in Differing Environments

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ABSTRACT

Decisions on cotton variety selection are typically based on producers past experience with the varieties and production sites. New germplasm is available every year for purchase and it is important for producers to note genotypic and phenotypic differences in varieties in their region in order to obtain high yields and good fiber quality. Research was conducted to evaluate cotton growth, fiber quality, and yield stability during 2010 and 2011 at fifteen on-farm production locations that were categorized into locations receiving greater than and less than 7.6 cm of precipitation during the blooming period. Each experimental site included four to twelve cotton rows spaced 97 cm apart with varying plot lengths. Varieties evaluated include: DP 0912 B2RF, DP 0920 B2RF, DP 1034 B2RF, FM 1740B2F, PHY 375 WRF, and ST 4288B2F. No-tillage or reduced tillage production systems were utilized with 10.5-12 seed m^{-1} of row at a planting depth of two cm. Plant height, number of nodes, nodes above white flower (NAWF), lint yield, yield quality, and yield stability were monitored and determined in order to evaluate variety response grown in multiple environments. Varieties did respond differently in this trial, indicating that differences in physiological growth patterns, lint yield, yield quality, and yield stability are evident when comparing varieties and amount of precipitation received during the blooming period. Therefore, quantifying the stability of commonly used varieties in the Midsouth United States is valuable knowledge to those who are making cultivar decisions in areas of variable rainfall.

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Cotton (*Gossypium hirsutum* L.) is cultivated in a wide range of climates and environments in the United States and around the world. These environments have a large impact on the growth, development, and quality of the crop. Environmental factors, some influenced by managing inputs and some not, will determine the crop's success by impacting plant growth and development, yield, and yield quality (Wells and Stewart, 2010). Therefore, producers and crop managers have to manage the crop to maximize yield potential regardless of what uncontrollable circumstances may be present in the environment (Wells and Stewart, 2010). Research has shown that cotton crops have no limit when it comes to plant development due to its indeterminate, perennial nature (Hearn and Constable, 1984). Limitations in cotton-producing environments such as, soil type, water availability, nutrient availability, and heat unit accumulation often relate to the extensiveness of the vegetative and reproductive growth of the crop, ultimately affecting yield.

Another factor influencing crop production, other than environmental conditions, is the plant's genetic makeup. Plant populations from differing genetic backgrounds often vary in results due to the environmental response; this is known as the genotype-environment interaction. Ideally, a variety would react in a positive manner in all situations regardless of limitations. However, there is not a single predominate variety adapted to all regions of cotton production because genotype-environmental interactions are prevalent wherever cotton is produced. A potential way to eliminate the effects of genotype-environmental interaction is by selecting varieties that are stable and limit interactions with the environment (Shah et. al., 2005). This has not only been proven beneficial to plant breeders, but can also be applied to production systems where producers are utilizing different environments in crop production. Many methods have been suggested for the evaluation of variety and yield stability. Eberhart and Russell (1966) found that measuring genotypic stability could be accomplished by comparing a single variety's yield with the average yield of all varieties over multiple environments. Each variety included in the experiments can be subjected to regression and parameters would provide estimates of stability by the following model:

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$$

Where Y_{ij} is the variety mean of the i^{th} variety at the j^{th} environment, μ_i is the mean of the i^{th} variety over all environments, β_i is the regression coefficient that measures the response of the i^{th} variety to varying environments, δ_{ij} is the deviation from regression of the i^{th} variety at the j^{th} environment, and I_j is the environmental index obtained as the mean of all varieties at the j^{th} environment minus the grand mean.

Environmental stress due to water deficit often negatively impacts cotton production systems (Pettigrew, 2004a). Water is often the most limiting factor in cotton production as it is essential to promote all growth functions from emergence to harvest (Gerik et al., 1996; Howell, 2001). Water deficit stress will typically reduce the plants ability to establish and retain blooms and fruiting structures which results in a potential negative impact on yield (Guinn and Mauney, 1984a; Guinn and Mauney, 1984b; Pettigrew, 2004a; Whitaker et al., 2008). Water stress will also result in plants that are stunted in growth with reduced leaf area, limiting the transpiration rate of the crop, and commonly resulting in the shedding of leaves and fruiting structures (Spooner et al., 1958). Therefore, plants grown in water stressed environments can result in a crop with diminished yield potential.

The objective of this study was to investigate cotton varietal responses to environmental conditions by using main-stem node counts, lint yield, lint quality, and yield stability of varieties, while making comparisons among environments.

MATERIALS AND METHODS

An experiment to investigate cotton plant growth, fiber quality, yield, and yield stability in various environments was conducted in West Tennessee through the University of Tennessee's Extension Service's County Standard Trials (CST), in conjunction with area producers in the 2010 and 2011 growing seasons. Of the sixteen varieties in the CST, six were chosen for evaluation in this research. The following varieties were evaluated: DP 0912 B2RF, DP 0920 B2RF, DP 1034 B2RF, FM 1740B2F, PHY 375 WRF, and ST 4288B2F for performance in non-irrigated scenarios. These cultivars were specifically chosen for their fit in a short-season growing environment. Although, all fifteen locations were examined for yield stability, only five county locations were utilized to examine physiological growth patterns each growing season (Table 1). All production scenarios were either a no-tillage system or conservation tillage system.

Table 1. Trial locations, soil types, heat accumulation, total precipitation and average yield where physiological measurements were recorded.

Location	Year	Soil Series/ Texture	Row Spacing (cm)	Planting Date	Harvest Date	Total DD 15.6[Z]	Total Precipitation[Z] (cm)	Average Yield (kg ha^{-1})
Cockett Co.	2010	Adler[Y] Silt Loam	97	5/25/2010	10/12/2010	1088	35	910
Fayette Co.	2010	Grenada[X] Silt Loam	97	5/7/2010	9/22/2010	1145	28	1350
Gibson Co.	2010	Collins[W] Silt Loam	97	5/13/2010	9/28/2010	1149	25	1240
Lake Co.	2010	Reelfoot[V] Silt Loam	97	5/6/2010	9/21/2010	1083	18	1210
Tipton Co.	2010	DeKoven[U] Silt Loam	97	5/24/2010	10/15/2010	1080	31	1090
Crockett Co.	2011	Grenada Silt Loam	97	5/26/2010	10/18/2010	1062	29	980
Fayette Co.	2011	Grenada Silt Loam	97	5/10/2010	10/16/2010	1076	24	1180
Gibson Co.	2011	Memphis[T] Silt Loam	97	5/19/2010	10/18/2010	1011	21	950
Lake Co.	2011	Reelfoot Silt Loam	97	5/16/2010	10/12/2010	1075	12	1280
Lauderdale Co.	2011	Grenada Silt Loam	97	5/20/2010	10/5/2010	998	21	1100

[Z] Climate information recorded from June 1st to August 31st of respective year.

[Y] Coarse-Silty, Mixed, Superactive, Thermic Fluvaquentic Eutrudepts

[X] Fine-Silty, Mixed, Active, Thermic Oxyaquic Fraglossudalfs

[W] Coarse-Silty, Mixed, Active, Acid, Thermic Aquic Udifluvents

[V] Fine-Silty, Mixed, Superactive, Thermic Aquic Argiudolls

[U] Fine-Silty, Mixed, Superactive, Thermic Typic Endoaquolls

[T] Fine- Silty, Mixed, Active, Thermic Typic Hapludalf

This experiment was implemented as a completely randomized design with varieties planted in random strips at each location. Plots ranged in size from four to twelve rows spaced 97 cm apart with various row lengths depending on field size (Table 1). Environmental differences were of importance, as environmental conditions varied with locations. The varying amount of rainfall acquired in these locations proved to be a significant factor, as water availability proves to be one of the most limiting factors in cotton production systems (Gerik et al., 1996; Howell, 2001). Amounts of precipitation acquired at locations were categorized as environments receiving more and less than 7.6 cm of rainfall throughout bloom duration. The 7.6 cm level of precipitation was chosen as it allowed for an equal number of observations of environments receiving greater than and less than 7.6 cm of rainfall. All production practices were managed by producers working in conjunction with and following recommendations set forth by the University of Tennessee Extension Service.

Evaluations of physiological growth response in cotton were conducted weekly for five weeks, starting when plots began to bloom. Main-stem node counts, including number of nodes, plant height, height of first fruiting branch (HFFB), and nodes above white flower (NAWF) were recorded weekly. The main-stem node measurements were quantified by numbering nodes above cotyledon. Data was recorded from ten plants selected at random from each plot and replicated three times. Additional measurements of interest included lint yield and fiber quality of varieties. Yield stability is a means to quantify the consistency or reliability of performance among differing varieties. A regression model, developed by Eberhart and Russell (1966), was used to measure relative yield stability of cotton varieties. In this model, yields of an individual variety are plotted along the y-axis and the mean yields of all varieties, including the one in question, are plotted along the x-axis. The mean lint yield of each CST represents the environment in which it was produced. For each variety, a straight line is fitted to the data points by least squares regression and a linear equation is generated. Varietal yield response across environments is indicated by the slope, y-intercept, and the coefficient of determination (R^2), which is the proportion of variation in a variety's yield that can be attributed to differences in production environment. Yield stability of a variety increases as its R^2 values increase. Yield data of six upland cotton varieties were analyzed from CST trials conducted in 2010 and 2011.

All rows of planted varieties were harvested using a spindle cotton picker that was calibrated and maintained by the producer. Harvested seed cotton weight was obtained using a boll buggy modified with a calibrated scale system. Sub-samples of seed cotton were collected from each plot and weighed prior to ginning. Gin turnout was determined for each sample using a 20-saw gin equipped with a stick machine, incline cleaners, and two lint cleaners at the West Tennessee Research and Education Center. Lint yields were calculated using seed cotton weights, gin turnouts, and harvested plot area. A sub-sample of lint of each entry was analyzed by high volume instrumentation classing procedures at the United States Department of Agriculture Cotton Classing Office in Memphis, TN (Sasser, 1981).

Data were subjected to analysis of variance using the PROC MIXED procedure of SAS (ver. 9.2; SAS Institute; Cary, NC). Means were separated using Fishers Protected LSD procedure with a 0.05 significance level. Additionally, regression analysis was used to determine yield stability. The coefficient of determination, slope, and y-intercept was calculated by linear regression.

RESULTS AND DISCUSSION

Year of the study was not significant based on ANOVA results, as both years accumulated adequate heat units and precipitation to produce a high yield potential cotton crop. Therefore, data were pooled across the two years of the study, and each location was considered as an environment. Locations nested within year and interactions of these effects were considered random, whereas variety, amount of precipitation at each location, and interactions of these effects were considered fixed effects.

Cotton Growth and Development. Limited responses to the amount of precipitation received during bloom were observed for plant growth parameters. Differences in plant structure among varieties were noted during the bloom period. HFFB data was similar for all varieties, therefore data is not presented. Node accumulation was not affected by precipitation amount during the bloom period in this study (Table 2). There was an observed effect on plant height due to differing varieties and environments. The variety that responded by adding the most plant structure during the blooming period was ST 4288B2F, with 22.4 cm of plant growth (Table 3). However, FM 1740B2F only added 17.2 cm of growth during bloom, which was the the lowest response of the six varieties evaluated. These main-stem node measurements and plant heights can serve as an indicator for variety's determinacy in a given production scenario. A variety that accumulates more plant structure, fruiting nodes and plant height, during the bloom period can potentially achieve higher yields. However, management practices such as fertilization, irrigation, and plant growth regulator applications will need to be utilized efficiently to better fit a specific variety in a specific situation to maximize yield potential.

Maturity. Cotton maturity was recorded throughout the blooming period by monitoring NAWF (Bourland et al., 2001). This is a main stem node count that is taken during the flowering stage of the cotton plant's life cycle. This is a measurement that shows the number of nodes from the apex of the plant to the upper most first position "white flower". Maturity was similar for all varieties included in this study and no effect was present due to differing varieties. There was a NAWF increase of 0.5 nodes at the end of evaluation in areas receiving greater than 7.6 cm of precipitation, indicating that where more precipitation was present during the blooming period maturity was slightly delayed regardless of variety, since there were no differences among evaluated varieties (Table 4). The decline in NAWF represents new fruiting site development and blooming rate (Bourland et al., 2001). In instances of dryland cotton production in a short season growing environment blooming rate often surpasses the plants ability to develop new fruiting sites. Additionally, fruit shedding due to drought stress, carbohydrate demand, and other nutrient diversion causes short season, dryland cotton to have a rapid reduction of NAWF values.

Table 2. Average number of nodes for six cotton varieties at ten locations in Tennessee during 2010 and 2011 under two moisture regimes.

Variety		Week1	Week 2	Week 3	Week 4	Week 5
	Location Rainfall (cm)	Plant Nodes (no.)				
DP 0912 B2RF		14.0	15.5	16.1	17.3	16.8
DP 0920 B2RF		14.1	15.5	16.0	16.9	17.3
DP 1034 B2RF		13.7	15.0	15.7	17.0	17.1
FM 1740B2F		13.5	15.1	15.7	16.6	16.7
PHY 375 WRF		13.9	16.0	16.2	17.6	17.5
ST 4288B2F		13.8	15.5	16.1	17.0	17.0
LSD (0.05)		NS	0.5	NS	0.7	NS
	< 7.6	13.6	15.1	15.6	16.6	16.7
	> 7.6	14.1	15.8	16.4	17.6	17.4
	LSD (0.05)	NS	NS	NS	NS	NS

Table 3. Average plant height for six cotton varieties at ten locations in Tennessee during the blooming period, 2010 and 2011 under two moisture regimes.

Variety		Week 1	Week 2	Week 3	Week 4	Week 5
	Location Rainfall (cm)	Plant Height (cm)				
DP 0912 B2RF		81.8	89.9	95.0	98.0	99.1
DP 0920 B2RF		75.9	85.3	92.2	93.5	94.5
DP 1034 B2RF		84.8	94.2	100.6	103.6	104.9
FM 1740B2F		77.0	85.3	91.2	92.7	94.2
PHY 375 WRF		83.3	97.0	100.8	106.2	104.9
ST 4288B2F		80.5	90.2	95.5	98.0	102.9
LSD (0.05)		6.1	6.9	6.4	8.4	7.9
	< 7.6	71.4	80.8	85.9	86.9	87.6
	> 7.6	89.7	99.8	105.9	110.5	112.8
	LSD (0.05)	NS	NS	NS	21.6	NS

Table 4. Average nodes above white flower for six cotton varieties at ten locations in Tennessee during the blooming period, 2010 and 2011 under two moisture regimes.

Variety		Week 1	Week 2	Week 3	Week 4	Week 5
	LocationRainfall (cm)			NAWF^Z (no.)		
DP 0912 B2RF		7.3	6.2	4.4	3.2	1.7
DP 0920 B2RF		7.2	6.1	4.1	3.2	1.7
DP 1034 B2RF		7.1	6.2	4.3	3.3	1.8
FM 1740B2F		7.0	5.8	4.1	2.9	1.3
PHY 375 WRF		7.3	6.6	4.6	3.7	1.6
ST 4288B2F		7.1	6.0	4.4	3.3	1.8
LSD (0.05)		NS	NS	NS	NS	NS
	< 7.6	7.1	6.0	4.2	2.7	1.9
	> 7.6	7.2	6.3	4.5	3.8	1.4
	LSD (0.05)	NS	NS	NS	NS	0.5

[Z]NAWF = Main stem Nodes Above first fruiting position White Flower

Lint Yield. Variation in lint yield and fiber quality was determined by variety and amount of precipitation received during the monitored blooming period. All six varieties that were evaluated during the growing season in areas receiving more than 7.6 cm of precipitation during the blooming period displayed an increase in yield compared to the same varieties grown in environments receiving less than 7.6 cm of rainfall, except DP 0912 B2RF and DP 1034 B2RF. In locations receiving more than 7.6 cm of precipitation during the blooming period, PHY 375 WRF, had the highest yield at 1280 kg ha^{-1} (Table 5). Whereas DP 0920 B2RF yielded 1140 kg ha^{-1}, the highest in areas that received less than 7.6 cm of precipitation during bloom. The variety with the highest increase in yield was ST 4288B2F, with a 220 kg ha^{-1} increase, when grown in areas receiving more than 7.6 cm of precipitation during the blooming period. The cultivar DP 1034 B2RF showed the smallest amount of lint yield gain when produced in locations with greater than 7.6 cm of precipitation by yielding 69 kg ha^{-1} more than the average of the other environments included in the study. These observations further the notion that increased moisture during the cotton blooming period, either from precipitation or supplemental irrigation is generally beneficial in most production systems. However, this data does not take in to account water availability for these locations or plant uptake/needs during the monitored blooming interval, both of these are important factors in determining cotton growth and yield. Therefore, understanding limiting conditions and adjusting management practices for environmental variability is essential for maximizing yield potential.

Fiber Quality. Micronaire was decreased for all varieties when greater than 7.6 cm of precipitation was received during the bloom period. Both DP 0912 B2RF and FM 1740B2F micronaire values were significantly reduced in locations with greater than 7.6 cm of precipitation avoiding discounts for high micronaire (Table 5). This indicates the value of the cotton crop can be increased with added moisture by decreasing micronaire (Allen and Lorenzo, 2011). A reduction in fiber strength was observed in all varieties in this study, with the exceptions of PHY 375 WRF and FM 1740B2F, that were grown in locations receiving the higher precipitation value during bloom. However, differences in fiber strength are determined more by genetic background and not growing environment (Meredith and Bridge, 1973).

Yield Stability. Mean cotton yields of the twelve varieties investigated in the fifteen CST tests conducted in 2010 and 2011 ranged from 980 to 1110 kg of lint ha^{-1}, and were averaged across environments and years. Thus, all varieties demonstrated high yield potential in these tests. Slopes of the linear regression ranged from 1.17 for DP 1028 B2RF to 0.87 of FM 1740 B2RF, indicating that DP 1028 B2RF has potential to have higher yields in higher yielding environments than does FM 1740 B2RF (Table 6). The Y-intercept values ranged from 124.91 of DG 2570 B2RF to -207.08 of DP 1028 B2RF, indicating that DG 2570 B2RF has higher yield potential in lower yielding environments (Figure 1.1 and 1.2).

Regression analysis found that R^2 values ranged from 0.89 for PHY 375 WRF and DP 0912 B2RF to 0.74 for PHY 367 WRF. This indicates that 89% of the variation in PHY 375 WRF and DP 0912 B2RF yield can be accounted for by differences in environment, but only 74% of the yield variation of PHY 367 WRF is due to differing environmental factors. More than 26% of the variation in yield in PHY 367 WRF is unaccounted for in this model, while only 11% of PHY 375 WRF yield variation was unexplained. These results suggest that the yield of PHY 367 WRF were less stable than those of PHY 375 WRF in the environments included in this study, since less yield variability can be accounted for by growing environment. A comparison of yield and stability rankings show there is little or no correlation between yield and yield stability. When selecting varieties for a production system, it may prove beneficial to look at yield stability as well as other desirable traits, like high yield potential. According to this study, ST 5458B2RF has better yields in both low and high yielding environments than other varieties evaluated. However, PHY 375 WRF and DP 0912 B2RF prove to be the most stable varieties included in this study, regardless of growing conditions, because of high R^2 values and positive slope of the regression line.

Table 5. Lint yield and fiber quality analysis of six cotton varieties at ten locations in Tennessee during 2010 and 2011 under two moisture regimes.

Precipitation Amount (cm)	Variety	Yield	Lint Percent	Micronaire	Length	Strength	Uniformity
		(kg ha^{-1})	(%)		(in.)	(g tex^{-1})	(%)
<7.6	DP 0912 B2RF	1020	38.1	5.1	1.09	31.0	82.2
	DP 0920 B2RF	1140	39.3	4.9	1.14	31.3	83.1
	DP 1034 B2RF	980	38.9	4.7	1.12	32.2	82.4
	FM 1740B2F	980	38.1	5.0	1.11	32.9	82.3
	PHY 375 WRF	1100	38.9	4.7	1.11	30.9	82.2
	ST 4288B2F	960	34.5	4.8	1.13	32.0	82.2
>7.6	DP 0912 B2RF	1110	36.4	4.8	1.07	29.6	81.5
	DP 0920 B2RF	1260	40.1	4.7	1.10	28.5	81.3
	DP 1034 B2RF	1050	39.2	4.6	1.14	30.5	82.5
	FM 1740B2F	1120	36.0	4.5	1.10	31.2	82.1
	PHY 375 WRF	1280	38.6	4.5	1.10	29.8	82.1
	ST 4288B2F	1180	35.5	4.6	1.13	30.8	81.6
LSD (0.05)		110	1.9	0.2	0.03	1.6	NS

Table 6. Yield stability of twelve cotton varieties at fifteen locations in Tennessee during 2010 and 2011.

Stability Rank	Variety	Mean Lint Yield[Z] 2010-2011	Yield Rank	Regression Parameters		
				y-Intercept Slope	Slope	R^2
		(kg ha^{-1})				
1	PHY 375 WRF	1090	4	-52.12	1.09	0.89
2	DP 0912 B2RF	1070	6	-6.63	1.03	0.89
3	FM 1740B2F	1010	11	91.96	0.87	0.85
4	DP 1034 B2RF	980	12	-96.59	1.03	0.83
5	ST 4288B2F	1030	9	66.40	0.92	0.82
6	DP 0920 B2RF	1100	3	-3.01	1.06	0.82
7	ST 5288B2F	1030	8	-119.03	1.09	0.82
8	ST 5458B2RF	1110	1	58.84	1.00	0.82
9	CG 3220 B2RF	1070	5	7.68	1.01	0.81
10	DP 1028 B2RF	1030	10	-207.08	1.17	0.78
11	DG 2570 B2RF	1100	2	124.91	0.93	0.76
12	PHY 367 WRF	1040	7	-66.05	1.06	0.74
	Mean:	1060		0.00	1.02	0.82

[Z] **Means averaged across fifteen County Standard Trial Locations.**

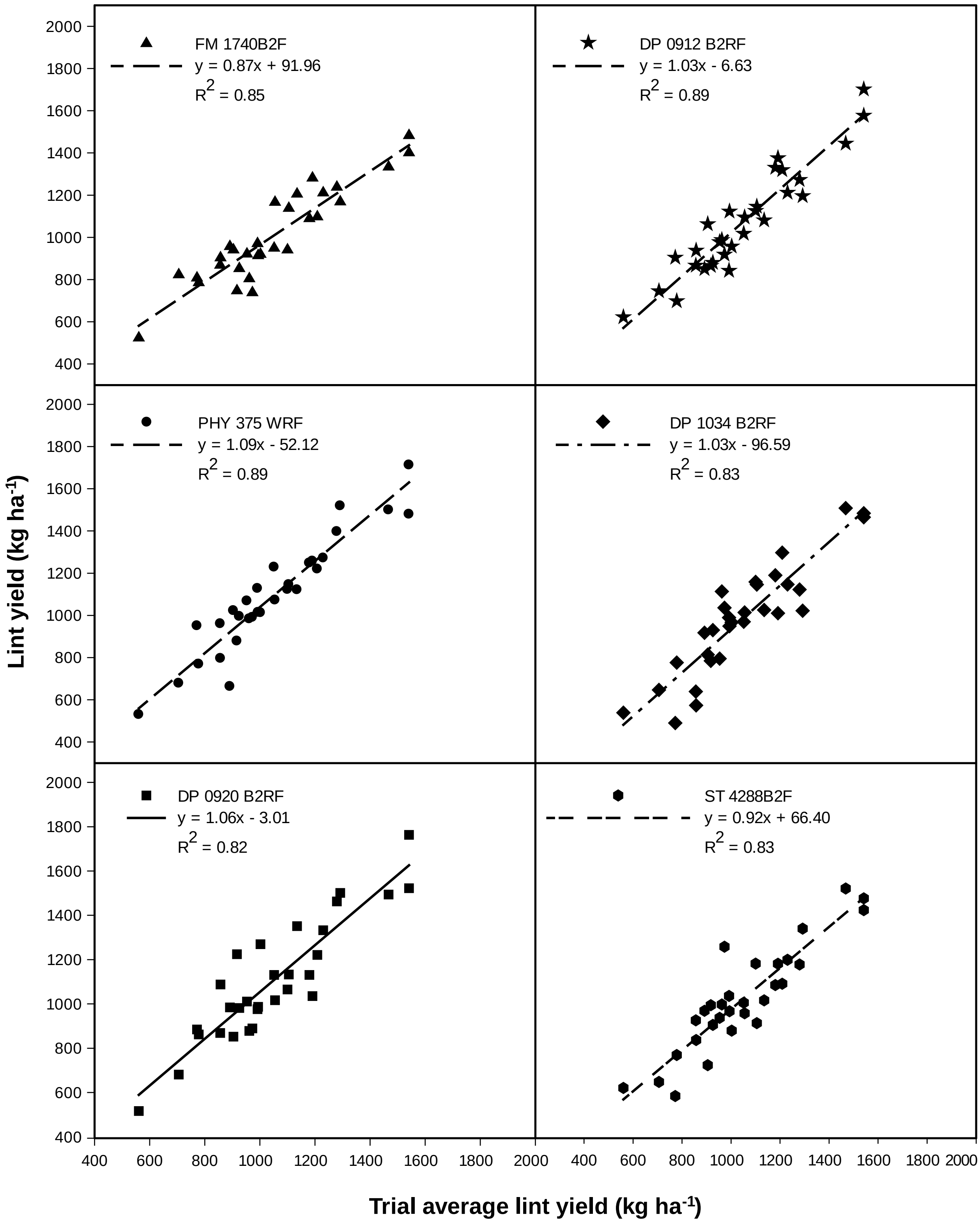

Figure 1.1 Yield stability analysis of six cotton varieties grown at fifteen locations during 2010 and 2011.

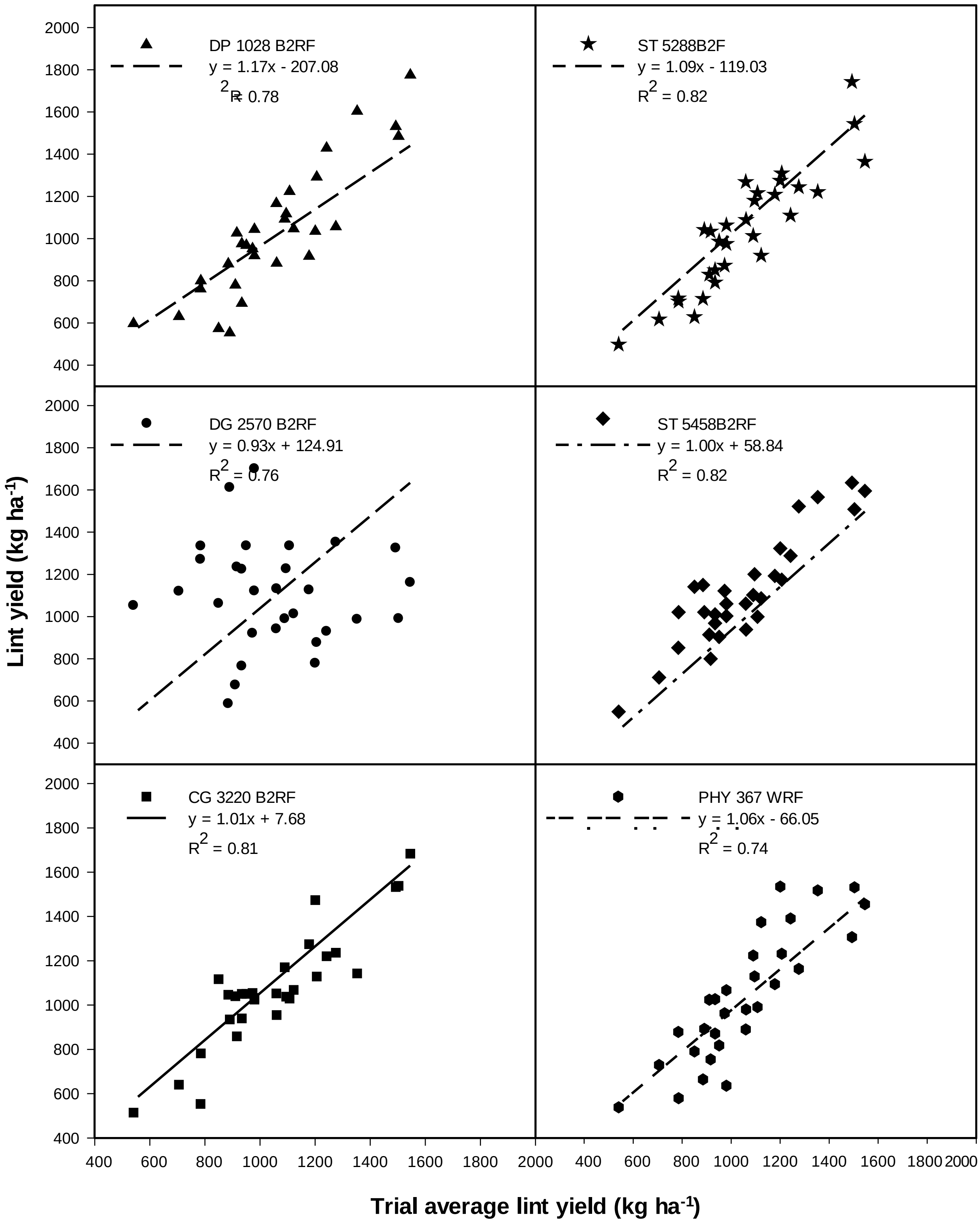

Figure 1.2 Yield stability analysis of six cotton varieties grown at fifteen locations during 2010 and 2011.

CONCLUSIONS

Results from trials conducted in 2010 and 2011 indicate that environmental conditions and varietal interaction play an important role in the success of cotton production in areas of variable precipitation. Benefits of plant height, lint yield, and micronaire was observed in these trials when grown in areas receiving more than 7.6 cm of precipitation during the monitored blooming interval. Likewise, maturity was slightly delayed when receiving more than 7.6 cm of precipitation during the evaluation time. These are expected results when increased amounts of precipitation are received or when supplemental irrigation is applied. However, further investigation of water availability and plant uptake/needs is needed in areas of highly variable soils and erratic precipitation in order to make better management decisions. Another factor effecting management decisions of producers, other than environmental conditions, is genetic population. The yield stability results of this experiment demonstrate that cultivars can be selected for a particular environment even with the constant release of new cultivars. Also, the results of this yield stability investigation indicate that there is no correlation between yield and yield stability for the six evaluated cultivars. This indicates that specific concerns of yield potential, yield stability, and environmental conditions will need to be assessed with the continuous release of new cultivars to ensure a manageable and efficient crop.

ACKNOWLEDGEMENTS

The authors wish to thank Tracy Bush, Matt Ross, Randi Dunagan, Jake Stewart, Catherine Clement, and Morgan Warren for assistance with establishment, maintenance, and harvest of these trials. This research was supported in part by Cotton Incorporated, Monsanto, and the Tennessee Agricultural Experiment Station.

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