EVALUATION OF TESTING LOCATIONS IN CENTRAL AND SOUTH TEXAS

A Thesis

by

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ABSTRACT

Performance yield trials are some of the most expensive processes in a cotton breeding program. Cotton plots require a great deal of land, agronomic inputs, and plot-sample processing. Much of the equipment is expensive and specialized such as the harvesters, gins, and fiber measurement devices. Therefore it is important to only test strains and cultivars in the most distinguishing environments. Traditionally the best testing environment has been in the Mississippi Delta near Greenville, MS. More recently it has been thought that growing environments in Australia are allowing breeders there to distinguish high-yielding, broadly adapted genotypes. The program of the Cotton Improvement Lab at Texas A&M University in College Station, TX, regularly conducts performance trials throughout Central and South Texas. Several stability tests such as the ‘cultivar superiority measure’, ‘ecovalence’ and ‘stability variance’ were used in AgroBase™ to determine stability. Biplot analysis was also used to characterize testing locations. Based on data collected from 2008 to 2012 from the commercial cultivar tests, it was concluded that the high-yielding locations at Weslaco and College Station are the best locations at identifying cultivars with the highest yield potential, but many of the dryland locations are better locations for determining stable and repeatable fiber qualities. Cultivars such as Tamcot 73 and PHY 375 WRF that have been tested extensively in the region showed more stability in comparison to other cultivars in this study.

DEDICATION

This work is dedicated to my creator for his entire blessing along the way, my Husband Shwan for his patience understanding, my parents for their endless love and encouragement & my brothers and sisters for their support throughout the entire process. Thank you all for everything you have done. Thank you for your patience, support and unconditional love during this process.

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NOMENCLATURE

U.S.	United States of America
CIL	Cotton Improvement Lab
CS	College Station, Texas
TH	Thrall, Texas
CH	Chillicothe, Texas
CM	Commerce, Texas
SP	San Patricio County, Texas
CC	Corpus Christi, Texas
WS	Weslaco, Texas
Dry	Dry Land (Non-Irrigated)
Irr	Irrigated Land
HVI	High Volume Instrumentation®
UI	Fiber Length Uniformity
DP 0935 B2RF	Deltapine (Monsanto) 0935 Bollgard II®, Round-Up Ready Flex®
FM 1740B2F	Fibermax 1740 Bollgard II®, Round-Up Ready Flex®
PHY 375 WRF	Phytogen 375 Widestrike®, Round-Up Ready Flex®
ST 5458B2RF	Stoneville 5458 Bollgard II®, Round-Up Ready Flex®
AEA	Average-Environment Axis
AEC	Average-Environment Coordination
GE	Genotype by Environment Interaction

GGE	Genotype and Genotype By Environment Interaction
MET	Multi-Environment Trials
PC	Principal Component
PCA	Principal Component Analysis
SVD	Singular Value Decomposition
SVP	Singular Value Partitioning

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CHAPTER I

INTRODUCTION AND BACKGROUND

From an economic standpoint, cotton (*Gossypium spp.)* is one of the important fiber crops in the world (Lee, Woodward, et al., 2007, Meng, Li, et al., 2010). The seeds from the plant are an important source of oil and protein and generally account for about 10% of the crop's total value.

Cotton is an important cash crop in the United States. The U.S. is the leading global cotton exporter followed by China and India and is the third ranking producer of cotton behind those same countries (USDA, 2013). Texas accounts for almost half of the US cotton crop. Other important cotton producing states are Georgia, Arkansas, Mississippi, North Carolina, Tennessee, Arizona, Missouri, Alabama, California, South Carolina, and Louisiana (USDA, 2012).

Cotton breeding in the U.S. began with individual farmers in the 1800s reselecting superior plants from germplasm originally introduced from Mexico. Since then it has developed from simple selection, to pollen manipulation and in the 1990s to transgenic transformation.

Production of agronomic crops are governed by three factors: environment, genotype, and cultural practices. Cultural practices such as irrigation, fertilization, and pesticide control have a crucial role in determining lint yield and fiber quality. Weather factors are an important source of variation affecting the suitability and distribution of cultivars and production practices (Kardol, et al., 2010, Marjanovic-Jeromela, et al., 2011, O'Neill, et al., 2008). Success of new cultivars depends on yield performance, fiber quality, and agronomic adaptation. Successful commercial cultivars that are widely planted typically perform well over a broad array of environmental conditions (Becker and Leon, 1988). Genotype x environment interactions (GE) are responsible for differences in yield stability among genotypes. Several methodologies have been proposed to estimate these types of interactions (Huehn, 1990). It is essential to have the cultivars tested in multiple environments for multiple years to have an estimate of potential yield, fiber quality, and tolerance of abiotic and biotic stresses.

Value of Cultivar Testing

Cultivar testing is a method of providing more information about cultivar performance and stability over a wide range of soil types and environments. Texas A&M AgriLife Research conducts commercial variety trials (CVT) yearly to determine the productivity of cultivars in Central and South Texas as well as the Rolling Plains region (Meritt, et al., 2011). Most important cotton producing states in the U.S. have similar testing programs.

Genotype x Environment Interaction

Genotype x environment interaction (GEI) has been defined as the failure of genotypes to achieve the same relative performance in different environments (Baker, 1988, Yang and Baker, 1991). Performance of cotton cultivars like other crop cultivars depends on three important factors: genetic capacity, environment, and the interaction between the cultivar and environment (Dutta, et al., 2012, Myers and Bordelon, 1997, Yan and Hunt, 2001). Thus, it is important to understand the GEI in order to predict the outcome of a breeding project (Jackson, et al., 1996, Yan and Hunt, 2001). The breeders often must be aware of potential epigenetic factors. For instance, Zhang, et al. (2011) reported that cotton plants grown in salty soil triggered gene expression that allowed certain genotypes a greater tolerance of the stress. Likewise, cultivars with enhanced host plant resistance would be expected to perform better under pest pressure than cultivars lacking such resistance. The GEI allows breeders to project what traits are essential for stable performance in challenging environments.

Stability Assessment

Most cotton breeders use the pedigree selection method in their breeding programs. In this program, individual plants are initially only selected at a single location and year. In the pedigree selection method, individual cotton plants are usually selected from early-generation segregating populations. Seed from that plant is planted to a progeny row at one and sometimes two locations during the next growing season. As lines are advanced through observation rows and into strain trials, they are tested in more years and more locations depending upon the resources of the program. Identification of testing environments that most accurately estimate broad-sense adaptability of a cultivar helps plant breeders know which locations they should use to make early-generation selections and initial testing a priority.

Developing a successful new cultivar generally requires initial selections from a large population (Piepho, et al., 2008). The two essential features of a cultivar are identity and reproducibility. Identity refers to a distinguishing morphological or physiological phenotype that sets a cultivar apart from others. Reproducibility refers to that same identity and population structure of the cultivar remaining consistent from one generation or growing season to the next. Stability of cultivar performance is not necessarily a trait that breeders can select when choosing to advance individual plants; however, it is a characteristic that can be tested in advanced generation strain trials at multiple locations and years.

There are several methods for estimating stability. Plaisted and Peterson (1959) proposed one of the earliest stability procedures by estimating the mean variance component for pairwise GEI. Later, Plaisted (1960) introduced another variance component for GEI, where the genotype effect was eliminated from the data set and the measure for the stability was the GEI variance from this subset (Ngeve and Bouwkamp, 1993). Wricke (1962) and Wricke (1964) introduced the ecovalence concept, which is the contribution of a genotype to the total GEI sum of squares. The ecovalence concept may be called an ‘agronomic concept’ of stability if small values are desired, because in this case it describes properties desirable in crop production (Becker, 1981).

Another way to evaluate stability in plant variety trials is a coefficient of regression, which was proposed by Yates and Cochran (1938) by which the GEI is partitioned by calculating a regression of the response variable, for example yield, of a given genotype in different environments. Finlay and Wilkinson (1963) used the regression of mean individual yield on the grand mean of all varieties grown in a particular site, and the basic yields were measured by a logarithmic scale in an effort to characterize stability.

Eberhart and Russell (1966) calculated the regression of mean yield of an environmental index by the difference between the environmental mean and the grand mean of all environments to estimate stability. Shukla (1972) used the stability variance, where a genotype is considered relatively stable when its stability variance is nearly equivalent to the environmental variance. A cultivar general superiority is another method to evaluate stability and it is explained by Lin and Binns (1988) as “the distance mean square between the cultivar's response and the maximum response averaged over all locations.”

GGE Biplot is another method to evaluate the GEI and to evaluate a cultivar’s inherent stability across locations. It was termed GGE biplot because it displays the two sources of variation affecting yield, which are genotype main effects and GEI effects (Gauch, 2006). The biplot was introduced by Gabriel (1971) and recently has been used as a visual, easily-interpreted method to analyze multi-environment trail data or stability analysis (Lubbers, 2003, Yan and Kang, 2003).

Yield Components

Cotton is similar to many other important field crops, where yield is a function of the plant’s reproductive capacity, which, in cotton’s case, is defined as the number of seeds per unit of land surface (Kawano and Masuda, 1980, Southam and Buxton, 1957).

While the cotton seed itself has substantial economic value, the predominat value of the crop is the amount of fiber yield. Therefore the fraction, more commonly known as ‘lint percent’, is arguably the most important and most easily manipulated yield component of cotton.

Most cotton production programs enhance cotton yield by increasing fiber numbers per ovule (Seagull and Giavalis, 2004). The cotton fiber is a differentiated epidermal cells originating from the outer integuments of the ovule (Ji, et al., 2003). Fiber development can be characterized through four distinct stages:

1) Initiation, which starts three days post anthesis during which the number of fibers per ovule is determined.
2) Elongation, which starts three to twenty days after anthesis. This is when the fiber length is determined.
3) Secondary cell wall biosynthesis and maturation from twenty days until the boll opening.
4) Maturation from twenty days until the boll opening (Lee, et al., 2007, Zhang, et al., 2011).

The relationships among components related to cotton yield is complicated (Worley, et al., 1974). Usually, fiber yield is determined by two main components, the number of seeds produced per area unit, and the weight of individual fiber. The selection for smaller bolls can contribute to higher lint yields, which in turn results in smaller seed size (Culp and Harrell, 1975). This relationship typically results in an increase in lint percent (Bednarz, et al., 2006, Bridge, et al., 1971, Miller and Rawlings, 1967).

Fiber quality is an important determinant of the value of the cotton crop. In general, cotton fiber qualities are more stable across environments than yield. Nevertheless, it is important to consider fiber parameters when estimating the total value of the crop.

Fiber micronaire is a measure of the maturity and/or the fineness of cotton fibers. Micronaire is determined by forcing air through a specified weight of lint. The rate of airflow is related to fiber thickness. Finer fibers result in more fibers per specified weight and, therefore, have greater resistance to air flow. Micronaire values of 3.4 or below indicate either fine or perhaps immature fibers. Values of 5.0 or higher generally indicate coarse fibers. Values of 3.5 to 4.9 are usually preferable and indicate mature, well-developed fibers. Fibers in this micronaire range also avoid discounts in the marketplace. Fiber length is reported in hundredths of an inch as measured by High Volume Instrumentation and is the average of the longest 50 percent of the fibers in the sample, usually referred to as the upper half mean (UHM). Long fibers are desirable because they produce greater yarn strength, aid in spinning finer yarns, and can be processed at higher speeds (Table 1) (Meritt, et al., 2011).

Table 1. High Volume Instrumentation (HVI) fiber lengths as reported in inches and descriptive designations (Meritt el.al, 2011).

HVI fiber lengths (cm)	Descriptive Designation
Below 2.46	Short
2.46- 2.79	Medium
2.79-3.25	Long
Above 3.25	Extra long

Fiber length uniformity index (UI) provides a relative measure of the length uniformity of cotton fibers. Uniformity is calculated as the ratio of the average length of all fibers to the average length of the longest 50 percent of the fibers in the sample. High uniformity values indicate uniform fiber length distribution and are associated with a high quality product and with low manufacturing waste (Table 2).

Table 2. Length uniformity ratios and descriptive designations (Meritt el.al, 2011).

Length uniformity ratios (%)	Descriptive designation
Below 77	Very low
77-79	Low
80-82	Average
83-85	High
Above 85	Very high

Yarn strength and ease of processing are positively correlated with strong fibers. Strength values are reported in grams of force required to break a bundle of cotton fibers with the holding jaws separated by 1/8 inch. The size of the bundle of fibers is described in tex units. Fiber strength is described from very low to very high within UHM classifications (Table 3). Table 4 is the fiber elongation and descriptive designations.

Table 3. Fiber strength (g/tex) categories and descriptive designations (Meritt el.al, 2011)

HVI 1/8-inch gauge fiber length group	Descriptive designation
Short (2.44 cm or less)	
18-19	Very low
20-21	Low
22-23	Average
24-25	High
26-27	Very high
Medium (2.46- 2.79 cm)	
17-19	Very low
20-22	Low
23-25	Average
26-28	High
29-31	Very high
Long (2.82-3.25cm)	
18-20	Very low
21-23	Low
24-26	Average
27-29	High
30-32	Very high

Table 4. Fiber elongation and descriptive designations (Meritt el.al, 2011).

Fiber elongation (%)	Descriptive designation
4.9 and below	Very low
5.0-5.8	Low
5.9-6.7	Average
6.8-7.6	High
7.7 and above	Very high

Research Objectives

Objectives of this study are to examine GEI effects as they relate to the stability of cotton cultivars and to compare multiple statistical procedures within the software program ‘AGROBASE’ (Agronomix Software Inc., 2014).

More specific goals are:

1. Compare statistical tools (Ecovalence, Stability Variance, Cultivar Superiority Measure, and GGE biplot) in describing stability (GxE) of cotton cultivar performance in terms of: lint yield, lint percent, fiber length, strength, length uniformity, micronaire and elongation.
2. Identify the best locations and years for testing and individual plant selections. The term ‘best’ will be defined as the location and year that gave the most accurate estimation of broad adaptability and the greatest contribution of the genotype effect to the phenotypic performance. Locations under consideration

will be limited to those used by the Texas A&M AgriLife Research - Cotton Improvement Lab.

From these goals, we should be able to determine the most suitable parametric procedure to evaluate and describe cultivar stability. In turn, we should be able to recommend to breeders the most appropriate procedure to estimate genotype performance and stability most accurately, and recommend the best locations to conduct cotton trials in Central and South of Texas.

CHAPTER II

MATERIAL AND METHODS

Seven locations were included in this study (Table 5). Many of the locations had trials that were both irrigated and non-irrigated.

Table 5. Locations of Commercial Variety Tests (CVT) in Central and South Texas with soil types, years tested, and irrigation status (Meritt, et al., 2011).

Location	Soil type	Harvested					Irrigated
		2008	2009	2010	2011	2012	
Weslaco	Hidalgo cl[1]	Yes	Yes	Yes	Yes	Yes	Yes
Weslaco	Hidalgo cl[1]	Yes	Yes	Yes	Yes	Yes	No
Corpus Christi	Victoria clay	Yes	Yes	Yes	Yes	Yes	No
San Patricio Co.	Victoria clay	Yes	Yes	Yes	Yes	No	Yes
San Patricio Co.	Victoria clay	Yes	No	Yes	Yes	No	No
College Station	Westwood sl[2]	Yes	Yes	Yes	Yes	Yes	Yes
College Station	Westwood sl[2]	Yes	Yes	Yes	No	Yes	No
Thrall	Burleson clay	Yes	Yes	Yes	No	Yes	No
Commerce	Houston Black cl[3]	Yes	Yes	Yes	No	No	No
Chillicothe	Abilene cl	Yes	Yes	Yes	No	Yes	No

1. scl=sandy clay loam 2. sl=silt loam 3. cl=clay loam

Plots in all trials were grown with two rows, one of which was harvested with a modified plot picker. Row widths varied between 95- and 100-centimeter, and between 10 and 14-meter in lengths depending on the location.

Commercial variety test data was collected from 2008-2012. During this time, 169 cultivars were tested, but they varied from one year to the next and from location to location. In an attempt to standardize the data set only a few of the 169 cultivars were included in the analysis. These particular cultivars were tested in most of the years and most of the locations.

Lint yield was calculated by the seed cotton weight of the harvested plot x the lint percent as determined from a boll sample x by the area of the plot. Lint percent was calculated from a 25- or 30- boll samples that were hand harvested. Those samples were ginned on laboratory scaled gins with no lint cleaning. The reported lint percent is a fraction of the lint to seed cotton weight (Meritt, et al., 2011).

Fiber Quality

Fiber quality was measured with a High Volume Instrument (HVI) mechanism at the Texas Tech University Fiber and Biopolymer Research Institute at Lubbock, TX. The traits measured were micronaire, length, strength, length uniformity, and elongation (Meritt, et al., 2011).

Data from all performance trials were analyzed as randomized complete block designs. Least significant differences (LSD) are used to determine if two cultivars are different at k=100, which approximates the 5% probability level. Values reported for any two cultivars at each location that differ by more than the LSD value are expected to be different in 95 of every 100 comparisons. The test average (mean) and the coefficient of variation (CV) also are reported for each characteristic evaluated at each location. The coefficient of variation is a measure of the uniformity of the test site (e.g. soil uniformity, drainage, disease, etc.). Lower coefficients of variation are desirable.

Stability analysis use tools found within Agrobase include: Ecovalence, Cultivar Superiority Measure, and Stability Variance. These analyses were used within years. Locations and years were evaluated using biplot analysis.

CHAPTER III

RESULTS AND DISCUSSION

Suitability of Testing Locations for Assessing Lint Yield

The diversity of testing locations used by the Texas A&M AgriLife Research's Cotton Improvement Lab at College Station, TX, is great both in terms of physical distance and in climates. Determining the optimal testing environment for a breeding program is crucial, especially for rapid progress in early generation selection steps when seed is limited and the number of lines is large.

The most critical trait of most cotton breeding programs is lint yield. When examining lint yield across locations and years several important observations can be made (Table 6). In 2008, trials that were irrigated had relatively high lint yields and coefficients of variation ranging from 10.8 to 15.1%. According to Gomez and Gomez (1994) field trials with a coefficient of variation (CV%) of less than 20% suggests reliability. Except at the non-irrigated trial at Commerce, lint yields at non-irrigated locations were generally much lower than irrigated trials and had much higher CV's.

In 2009, rainfall across the state was above normal and there was an excellent yield response to the additional soil moisture. Nevertheless, trials grown with irrigation typically yielded 2X or 3X the amount of lint compared to trials without the benefit of irrigation. In comparison to 2008, the values of CV's were lower. In 2010, most test locations had similar mean yields except for trials at Thrall and Commerce, which both suffered from severe drought. Again, CV's were low (< 12%) to moderate (< 20%).

The highest temperatures and most extreme drought situation for all years involved in this study occurred in 2011. Several testing locations were abandoned due to drought, but the testing locations that were retained and irrigated had exceptionally high yields. This is not surprising since cotton tends to produce the highest lint yields in climates with high steady temperatures, clear sunlight and abundant soil moisture maintained with consistent irrigations (e.g. production areas in Arizona and Australia).

Yields were again high at the Weslaco and College Station testing locations both for irrigated and non-irrigated trials in 2012. The San Patricio irrigated testing location was lost due to salinity contamination in the irrigation water, the testing site at Chillicothe was lost due to severe herbicide drift, and the test at Commerce was lost due to severe drought.

Irrigated trials at Weslaco and College Station, TX, were consistently the highest lint yielding among this collection of trial locations and typically had among the lowest coefficients of variation. Interestingly, Chillicothe had on average the lowest CV, which is surprising because it typically has the least stable early-season and late season temperatures.

Table 6. Cotton lint yield and coefficients of variation (CV) from 2008 to 2012 at Central and South Texas cotton cultivar testing locations.

	2008		2009		2010		2011		2012					
Location	Lint (kg/ha)	CV	Lint (kg/ha)	CV	Lint (kg/ha)	CV	Lint (kg/ha)	CV	Lint (kg/ha)	CV	Avg Lint (kg/ha)	Rank	Avg CV	Rank
CS-irr	1601	10.8	1493	10.5	1220	15.8	1975	11.4	2408	7.6	1739	2	11.2	3
CS-dry	267	29.8	507	18.8	1044	11.1	-	-	2401	12.5	1054	7	18.1	9
WS-irr	1309	15.1	1952	9.2	1424	11.4	2119	11.5	2968	6.4	1954	1	10.7	2
WS-dry	-	-	1320	17.6	1641	12.2	1857	10.4	1939	11.5	1689	3	12.9	6
SP-irr	1170	14.7	1379	9.3	1405	12.1	1490	14.4	-	-	1361	5	12.6	5
SP-dry	956	15.6	-	-	1397	15.9	1121	12.1	524	25.6	999	8	17.3	8
CH-irr	-	-	1279	9.3	1452	10.1	-	-	-	-	1365	4	9.7	1
CC-dry	650	22.0	755	12.0	1296	13.8	1118	12.5	611	14.4	886	9	14.9	7
CM-dry	1516	11.0	1453	8.4	626	16.2	-	-	-	-	1198	6	11.9	4
TH-dry	582	23.8	405	13.4	592	13.7	-	-	993	40.1	642	10	22.8	10
Mean		17.9		12.1		13.2		12.1		13.8			13.7	

Suitability of Testing Locations for Fiber Quality

High-quality fiber is critical to cotton remaining competitive against other natural and synthetic fibers. At the producer level, fiber traits can contribute substantially to the profitability of their crop. As such, most cotton breeders pay close attention to cotton fiber quality within their programs. Therefore it is important to identify the best testing locations to assess fiber quality.

Cotton fiber micronaire is a combined measure of fineness and maturity. Cotton fiber that is relatively mature and yet fine can have a similar value to cotton fiber that is relatively immature and yet coarse. Spinners generally prefer cotton fiber that is both mature and fine. This allows for a higher thread count in finished products and mature fibers tend to retain dyes, which in turn prevents cotton textiles from quickly fading after being washed.

At the marketplace, a micronaire values of 5.0 or more and values of 3.4 or less receive discounts, with lower micronaire values incurring harsher penalties than values above the higher threshold (Ethridge and Hudson, 1998; Larson et al., 2002). While micronaire values of individual cultivars varied significantly within each trial with many going above and below the discounted thresholds, the mean micronaire of most testing locations were within the non-discounted range (Table 7). There were some exceptions. In 2008, the mean micronaire value of the non-irrigated trial at San Patricio County was 5.1. In 2009, the mean micronaire value at the College Station non-irrigated was 5.0. In 2010, there were several trials that suffered high-micronaire readings, but in 2011 there were no substantial problems.

The environmental factors that affect micronaire are not well understood. There is speculation that it could be the result of sunlight directly hitting developing cotton bolls. Many producers attempt to control potential high-micronaire crops by early defoliation and thus terminating fiber prematurely (Larson et al., 2002). While this approach may keep cotton out of the micronaire discount range, the long term marketing implications are not well-received by textile mills expecting fully mature cotton fibers because of processing complications and relations to other fiber properties (Foulk and McAlister, 2002; Smith, 1991). Breeding efforts over the last three decades has resulted in a slight trend upwards of micronaire values in newly released cultivars (Kuraparthy and Bowman, 2013).

Table 7. Fiber micronaire mean values and coefficients of variation (CV) from 2008 to 2011 at Central and South Texas cotton cultivar testing locations.

	2008		2009		2010		2011		Avg			
Location	Micronaire (units)	CV	Micronaire (units)	CV	Micronaire (units)	CV	Micronaire (units)	CV	Micronaire (units)	Rank	Avg CV	Rank
CS-irr	4.8	4.4	4.6	7.9	4.7	5.3	4.6	5.0	4.7	4	5.6	9
CS-dry	3.8	4.1	5.0	5.2	4.2	5.7	-	-	4.4	9	5.0	8
WS-irr	4.5	3.5	-	-	5.0	3.5	4.0	7.8	4.5	7	4.9	7
WS-dry	-	-	-	-	5.1	3.7	4.6	5.4	4.8	3	4.5	6
SP-irr	4.7	4.1	-	-	5.1	2.7	-	-	4.9	2	3.4	2
SP-dry	5.1	3.4	-	-	4.9	3.2	-	-	5.0	1	3.3	1
CC-dry	4.8	5.3	4.5	3.4	-	-	4.4	4.0	4.5	6	4.2	5
CM-dry	-	-	4.6	4.0	-	-	-	-	4.6	5	4.0	3
TH-dry	4.7	3.8	-	-	4.1	4.3	-	-	4.4	8	4.0	4
Mean	4.6	4.1	4.7	5.1	4.7	4.1	4.4	5.5	4.6		4.3	

Perhaps the most important fiber trait, especially for open-end spinning, is fiber length (Cai et al., 2013). It has been well-documented that fiber length is negatively affected by drought stress, especially when that drought stress occurs on developing bolls prior to 20 days post anthesis (Loka et al. 2011; Snider et al., 2013). Over the last two decades the average fiber length of the US crop has improved dramatically due in large part to improved genetics related to fiber length (Kuraparthy and Bowman, 2013).

In the trials in this study, fiber length was the best at Weslaco and San Patricio County in 2008, and the shortest fiber on average was harvested from the Corpus Christi trial location (Table 8). In 2009, the longest fiber was measured from the Commerce location and it also had excellent lint yields. In 2010, when rainfall was above normal at all locations, fiber length was also good at all test locations. In 2011, all irrigated trials had fiber length longer than cotton harvested from non-irrigated trials. This was likely a result of the severe drought of 2011 which probably hurt fiber length development at the non-irrigated testing sites.

Table 8. Fiber length mean values and coefficients of variation (CV) from 2008 to 2011 at Central and South Texas cotton cultivar testing locations.

	2008		2009		2010		2011		Mean			
Location	Length (cm)	CV (%)	Length (cm)	CV (%)	Length (cm)	CV (%)	Length (cm)	CV (%)	Length (cm)	Rank	Mean CV (%)	Rank
CS-irr	2.90	2.3	2.67	4.4	2.87	2.2	2.97	2.3	2.84	5	2.8	9
CS-dry	2.64	2.1	2.79	4.2	2.95	1.9	-	-	2.79	7	2.7	8
WS-irr	3.00	1.6	-	-	2.97	1.9	2.92	2.2	2.97	2	1.9	2
WS-dry	-		-	-	2.84	2.6	2.77	2.8	2.82	6	2.7	7
SP-irr	3.00	2.2	-	-	2.92	1.9	-	-	2.97	3	2.0	3
SP-dry	2.87	2.1	-	-	2.95	1.4	-	-	2.92	4	1.8	1
CC-dry	2.67	2.4	2.59	1.6	-	-	2.72	2.9	2.67	9	2.2	5
CM-dry	-	-	2.97	2.6	-	-	-	-	2.97	1	2.6	6
TH-dry	2.72	2.4	-	-	2.79	2.1	-	-	2.74	8	2.3	4
Mean	2.82	2.2	2.77	3.2	2.90	2.0	2.84	2.5	2.85		2.3	

Fiber length uniformity is largely a function of the absence of short fibers (less than one centimeters) and the abundance of long fibers (more than three centimeters) (Thibodeaux et al., 2008).. Drought stress can negatively impact length uniformity and there is a strong genetic influence as well. Because length uniformity is a ratio between the longest and shortest longest fibers, it is expressed as a percentage. Those values typically fall between 79-85% for more than 95% of all commercial cotton grown in the U.S. Due to the narrow range of variability in these values, coefficients of variation would be expected to be low (Abdi, 2010),, which is what was observed in this data set (Table 9). All the non-irrigated trials in 2011, which were severely affected by drought stress, had low UI values (< 82%). Similar measures were ascertained from the non-irrigated trial at Corpus Christi in 2009 and the non-irrigated trial at College Station in 2008. An interesting aspect of this data set is that some non-irrigated trials that were subjected to drought stress had UI above 82%, which suggests that there may be a critical boll developmental stage at which UI is affected and the drought stress during these tests did not hit the plants at that stage of susceptibility.

Table 9. Fiber length uniformity index mean values and coefficients of variation (CV) from 2008 to 2011 at Central and South Texas cotton cultivar testing locations.

	2008		2009		2010		2011		Avg UI			
Location	UI (%)	CV	UI (%)	CV	UI (%)	CV	UI (%)	CV	(%)	Rank	Avg CV	Rank
CS-irr	83.3	1.0	81.4	1.4	82.9	1.1	84.0	0.8	82.9	6	1.1	6
CS-dry	80.1	1.3	82.7	1.5	83.2	0.8	-	-	82.0	7	1.2	9
WS-irr	83.8	0.8	-	-	84.6	0.8	83.1	1.1	83.8	3	0.9	2
WS-dry	-	-	-	-	83.8	1.1	82.4	0.9	83.1	5	1.0	4
SP-irr	84.2	0.8	-	-	84.3	0.7	-	-	84.3	1	0.8	1
SP-dry	83.5	1.1	-	-	84.3	0.7	-	-	83.9	2	0.9	3
CC-dry	82.6	1.2	80.9	0.9	-	-	81.8	1.1	81.8	8	1.0	5
CM-irr	-	-	83.5	1.1	-	-	-	-	83.5	4	1.1	8
TH-dry	81.3	1.1	-	-	82.1	1.1	-	-	81.7	9	1.1	7
Mean	82.7	1.0	82.1	1.2	83.6	0.9	82.8	1.0				

Fiber strength is most important in cotton fibers spun with high-speed rotor spinning mechanisms. Fiber strength in the US crop has improved dramatically over the last three decades (Kuraparthy and Bowman, 2013). Fiber strengths of more than 30 g/Tex are common in much of the US crop and fibers with those levels of strength are generally classified by textile mills as ‘strong’. Moreover, it is not uncommon to see commercial cotton with fiber strength in excess of 34 g/Tex (Hague, 2014). Fiber strength, like all fiber traits, is controlled by environmental, genetic, and environmental X genetic factors. Fiber strength is generally thought to be less quantitatively inherited than many other fiber traits such as fiber length, elongation and micronaire (Meredith, 2005). Abiotic stress such as drought, salinity, and cold temperatures can all negatively affect fiber strength (Hsieh et al., 2000).

Fiber strengths in this data set were generally high in 2010 and 2011 (Table 10). In 2008, the non-irrigated trial at College Station had, on average, weak fiber as did the non-irrigated trial at Corpus Christi in 2009. Curiously, the irrigated trial at College Station in 2009 had relatively weak fiber. That particular test was defoliated or terminated slightly early so the immature bolls may have had weaker than normal fibers. Much of the fiber strength can be attributed to secondary wall formation which occurs after twenty days post-anthesis (Naithani et al., 1982).

Fiber elongation is the amount of stretch a fiber can endure before breaking. The mechanics behind fiber structure are not well understood and neither is the hereditary component nor the environmental influences (Benzini et al., 2007).. Nevertheless, it is considered to be a highly heritable trait. One of the issues surrounding measurement of fiber elongation for many years was the lack of consistency among high volume instrumentation (HVI) fiber testing units. Each machine had a unique calibration. Therefore if samples from the same test were analyzed on different machines, the variation from the machines would often be greater than the variation within the set of test samples. Since 2011, this issue seems to have been resolved with standardized fiber samples used to uniformly calibrate HVI units.

Fortunately in this data set, all samples within a year were analyzed using the same HVI machine, therefore valid comparisons can be made within years and among trials. In 2009, fiber samples from the test at Commerce were high and they were relatively high again in 2011 (Table 11). This is an ideal situation for a plant breeder because differences among genotypes are extended and more readily discernible. Often times in more southern testing locations, elongation tends to be lower (Hague, personal communication, 2014). Perhaps this is a function of warmer planting temperatures or maybe even shorter day lengths during the growing season in comparison to locations at higher latitudes.

Table 10. Fiber strength mean values and coefficients of variation (CV) from 2008 to 2011 at Central and South Texas cotton cultivar testing locations.

	2008		2009		2010		2011		Avg			
Location	Strength (g/tex)	CV	Strength (g/tex)	CV	Strength (g/tex)	CV	Strength (g/tex)	CV	Strength (g/tex)	Rank	Avg CV	Rank
CS-irr	29.5	3.8	26.5	9.4	29.1	4.9	32.3	3.5	29.3	6	5.4	9
CS-dry	25.4	4.4	30.2	7.8	30.0	3.0	-	-	28.5	8	5.1	8
WS-irr	31.3	2.2	-	-	30.8	2.6	31.0	3.5	31.0	3	2.8	1
WS-dry	-	-	-	-	29.9	2.6	30.1	3.5	30.0	5	3.0	3
SP-irr	32.7	2.7	-	-	30.7	3.3	-	-	31.7	1	3.0	2
SP-dry	31.3	3.9	-	-	31.1	2.9	-	-	31.2	2	3.4	4
CC-dry	30.4	3.4	25.6	4.3	-	-	29.9	4.5	28.6	7	4.1	5
CM-irr	-	-	30.4	4.6	-	-	-	-	30.4	4	4.6	7
TH-dry	27.3	3.6	-	-	29.6	4.6	-	-	28.5	9	4.1	6
Mean	29.7	3.4	28.1	6.5	30.2	3.4	30.8	3.8				

Table 11. Fiber elongation mean values and coefficients of variation (CV) from 2008 to 2011 at Central and South Texas cotton cultivar testing locations.

	2008		2009		2010		2011		Avg		Avg	
Location	Elongation (%)	CV	Elongation (%)	CV	Elongation (%)	CV	Elongation (%)	CV	Elongation (%)	Rank	CV	Rank
CS-irr	5.0	4.6	6.5	11.9	7.0	7.2	7.4	4.0	6.5	2	6.9	8
CS-dry	4.6	7.0	5.7	13.9	6.9	5.8	-	-	5.7	1	8.9	9
WS-irr	8.5	3.8	-	-	7.2	4.3	8.1	3.6	7.9	6	3.9	1
WS-dry	-	-	-	-	7.2	3.7	8.4	5.3	7.8	4	4.5	3
SP-irr	8.8	3.8	-	-	7.4	5.8	-	-	8.1	7	4.8	7
SP-dry	8.9	5.0	-	-	7.6	4.2	-	-	8.3	8	4.6	4
CC-dry	8.6	3.9	6.2	6.4	-	-	8.1	3.8	7.6	3	4.7	6
CM-irr	-	-	11.3	4.6	-	-	-	-	11.3	9	4.6	5
TH-dry	8.4	4.3	-	-	7.2	4.4	-	-	7.8	5	4.3	2
Mean	7.6	4.6	7.4	9.2	7.2	5.0	8.0	4.2				

Comparison of Stability Tests for Lint Yield

Three methods, ecovalence, cultivar superiority measure, and stability measure, were used to assess cultivar stability using this data set (Becker and Leon, 1988; Eberhart and Russell, 1966). One issue involved in comparing the cultivars was the non-orthogonal structure of the data set. In none of the years were all five cultivars planted at all locations so there are inherent biases involved with the comparison (Table 12). However, many of the cultivars were tested in uniform locations and those comparisons do offer insight into the validity of the stability measures in question.

In 2008, DP 0935 B2RF was only tested at a single location and therefore the stability analyses were of little value (Table 13). Among the other cultivars in that year, ST 5458 B2RF appeared to be the most stable according to ecovalence and the superiority measure. In general, ecovalence and superiority measure identified similar cultivars as stable, whereas the stability variance was not in agreement.

In 2009, DP 0935 B2RF was the least stable cultivar by all methods and Phy 375WRF and Tamcot 73 were the most stable. Nearly opposite findings occurred in 2010. DP 0935B2RF was the most stable and Phy 375WRF was the least stable. Again in 2011, DP 0935 B2RF was considered stable by all three methods as was Tamcot 73. In 2012, Phy 375 WRF was the most stable across locations.

Interestingly FM 1740 B2RF was never rated as the most nor least stable in any year. Tamcot 73 in general was rated as stable. This is to be expected since this cultivar was developed at many of the same locations in which it was tested. All other cultivars were developed primarily in the Mississippi Delta. This gives credence to the strategy of breeding for local growing environments.

Relationship between Lint Yield and Fiber Quality

As has been demonstrated, the conditions which lead to high yielding cotton trials, primarily abundant soil moisture, also tend to have a positive effect upon most fiber qualities. In an effort to examine this relationship further, regression analyses were conducted which compared lint yield and fiber length, strength, micronaire, and length uniformity index.

Among the four regressions in 2008, fiber length uniformity index had the greatest R-square value at 0.49 and fiber strength had the lowest R-square value at 0.09 (Figure 1). Fiber length had the highest slope of any fiber trait suggesting that stresses that compromised yield, primarily drought stress, most greatly affected fiber length.

Table 12. Lint yield of cultivars tested at ten locations across South and Central Texas (2008-2012).

Cultivar	Year	Trial Locations*									
	2008	cccvt	chcvt	comcvt	cscvt-d	cscvt-i	spcvt-d	spcvt-i	tcvt	wcvt-d	wcvt-i
DP0935B2RF		-	-	-	-	1851	-	-	-	-	-
ST5458B2RF		695	-	-	360	2108	799	1217	643	-	1440
FM1740B2F		570	-	-	344	1943	830	1299	536	-	1508
PHY375WRF		518	-	-	365	1883	959	1202	559	-	1202
Tamcot73		659	-	-	381	1792	832	980	616	-	1179
	2009										
DP0935B2RF		756	-	1614	191	2085	-	1340	356	1282	-
ST5458B2RF		609	-	-	171	2152	-	1222	350	1209	1868
FM1740B2F		692	-	-	136	1732	-	1422	325	1077	2021
PHY375WRF		719	-	1584	143	1721	-	1357	348	1296	1858
Tamcot73		768	-	1155	173	2187	-	1138	450	1380	1758
	2010										
DP0935B2RF		1265	2848	605	1471	1545	1503	1682	598	1689	1302
ST5458B2RF		1374	2362	-	1110	1499	1785	1313	537	1484	1390
FM1740B2F		1325	2128	-	1405	1488	1435	1505	515	1532	1390
PHY375WRF		1136	2565	489	1264	-	1651	1275	685	1799	1611
Tamcot73		1083	3044	623	1290	1827	974	1614	485	1595	1333
	2011										
DP0935B2RF		2100	-	69	-	2712	1061	1237	1714	-	1830
ST5458B2RF		-	-	-	-	2588	-	-	-	-	-
FM1740B2F		-	-	54	-	2365	-	-	-	-	-
PHY375WRF		2214	-	82	-	2606	-	1474	1816	-	2066
Tamcot73		2162	-	59	-	2774	1297	1565	1939	-	2100
	2012										
DP0935B2RF		435	566	-	1737	3050	-	-	295	2031	2914
ST5458B2RF		-	651	-	-	-	-	-	-	-	-
FM1740B2F		509	-	-	-	3070	-	-	202	-	2627
PHY375WRF		713	821	-	2360	3155	-	-	323	1857	2805
Tamcot73		539	1257	-	-	2592	-	-	231	1879	2576

* ‘ccvt’ = Corpus Christi non-irrigated; ‘chcvt’= Chilicothe irrigated; ‘comcvt’= Commerce non-irrigated; ‘cscvt-d’=College Station non-irrigated; ‘cscvt-i’= College Station irrigated; ‘spcvt-d’= San Patricio non-irrigated; ‘spcvt-i’= San Patricio County irrigated; ‘tcvt’ = Thrall irrigated; ‘wcvt-d’= Weslaco non-irrigated; ‘wcvt-i'= Weslaco irrigated.

Table 13. Cultivar stability assessments using ecovalence, stability variance,and cultivar superiority measure techniques with five cultivars tested in Central and South Texas, 2008-2012.

	Lint (kg/ha)	Test Locations	Ecovalence	Stability Variance	Superiority Measure
Year-2008					
DP 0935 B2RF	1851	1	3.0	1120772.3	510626.3
ST 5458B2RF	1037	7	0.6	205641.4	16893.6
FM 1740B2F	1004	7	0.4	153102.4	24425.3
PHY 375 WRF	955	7	0.2	75172.0	38121.2
Tamcot 73	920	7	0.2	63108.5	52893.6
Year – 2009					
DP 0935 B2RF	1089	7	4.0	1948885.7	297425.9
ST 5458B2RF	1083	7	1.5	709465.8	214544.4
FM 1740B2F	1058	7	1.4	651353.2	226718.9
PHY 375 WRF	1128	8	0.4	198025.1	28300.9
Tamcot 73	1126	8	0.3	133851.1	41145.1
Year - 2010					
DP 0935 B2RF	1451	10	0.3	221961.7	136962.3
ST 5458B2RF	1428	9	0.5	420716.1	286515.0
FM 1740B2F	1414	9	0.5	354981.5	309373.4
PHY 375 WRF	1386	9	1.6	1335975.2	348530.1
Tamcot 73	1387	10	0.6	454523.8	169689.7
Year- 2011					
DP 0935 B2RF	1532	7	0.4	436970.7	83070.9
ST 5458B2RF	2588	1	1.7	2052657.2	1576351.7
FM 1740B2F	1210	2	1.4	1727939.9	1593262.1
PHY 375 WRF	1710	6	1.2	1421098.8	168021.0
Tamcot 73	1699	7	0.5	548667.4	33115.6
Year- 2012					
DP 0935 B2RF	1575	7	1.9	1038695.1	156610.4
ST 5458B2RF	651	1	6.4	3717709.6	2592730.5
FM 1740B2F	1602	4	2.7	1530251.8	1110555.7
PHY 375 WRF	1719	7	2.0	1103076.6	65366.3
Tamcot 73	1512	6	2.6	1437244.3	690343.6

In 2009, there was a negative regression response to all fiber traits except for length uniformity index (Figure 2). Moreover, the R-square values for all traits were relatively low. There is no simplistic explanation as to why there was such a poor relationship between lint yield and fiber quality. Perhaps the factors that affected yield either occurred early in the growing season before fiber quality was influenced. Early season factors such as poor stand establishment, weed infestations, or poor soil fertility that were corrected later in the growing season could all lead to such occurrences.

In 2010, there was again a positive response between lint yield and fiber quality (Figure 3). Fiber micronaire had the highest R-square value at 0.44, whereas fiber strength had virtually no relationship with lint yields.

Another positive response was observed in 2011 (Figure 4). Fiber length had the highest R-square value at 0.26 and the highest slope at 1296.8. The results from 2009 were out of the trends observed in the other years. Intuitively, cotton breeders have tended to make fiber quality assessments from high-yielding trials. This set of correlations confirms that paradigm.

Figure 1. Regression of lint yield and fiber traits from cultivar trials in South and Central Texas in 2008.

Fiber trait	y-Intercept	Slope
Micronaire	-1120.7	476.4
Length	-3582.8	1639.6
Uniformity Index	-20456.0	260.6
Strength	-867.0	66.5

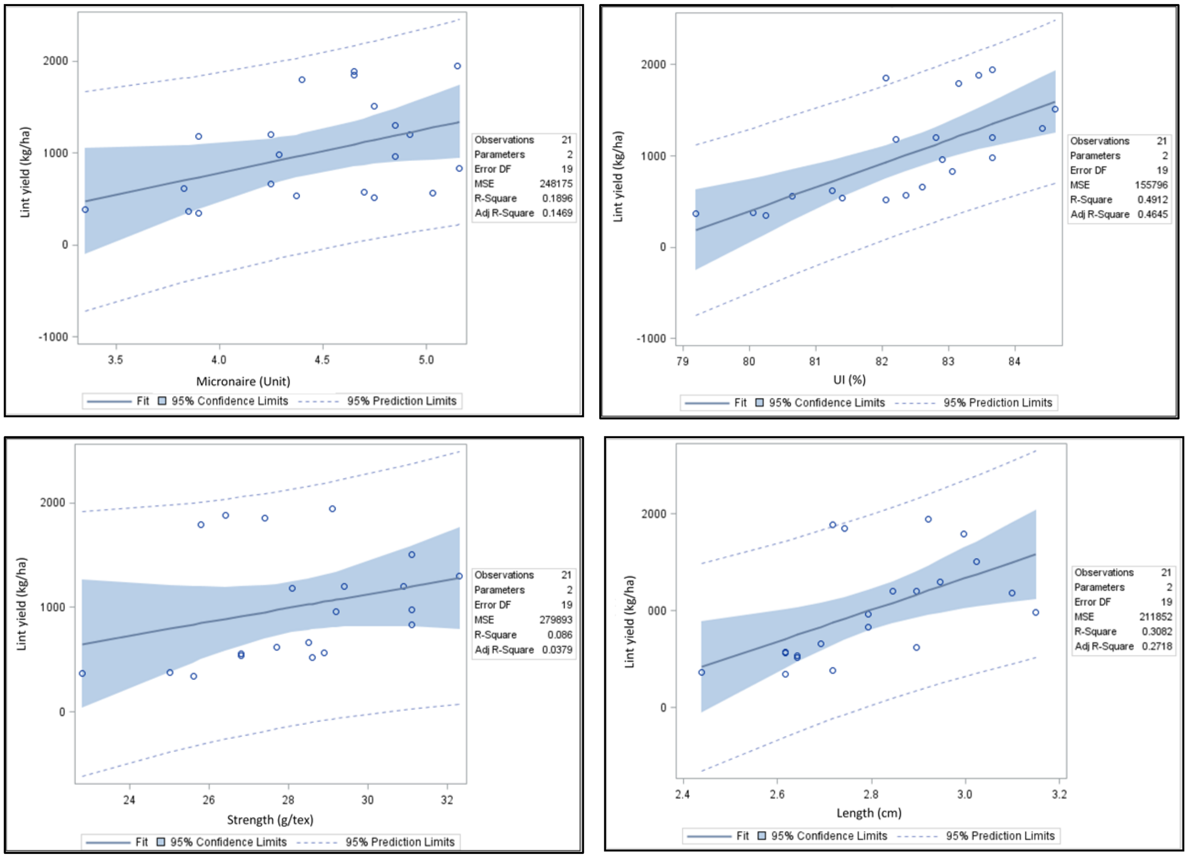


Figure 2. Regression of lint yield and fiber traits from cultivar trials in South and Central Texas in 2009.

Fiber trait	y-Intercept	Slope
Micronaire	5121.0	-905.5
Length	2179.1	-446.6
Uniformity Index	-3198.3	50.9
Strength	1942.7	-35.1

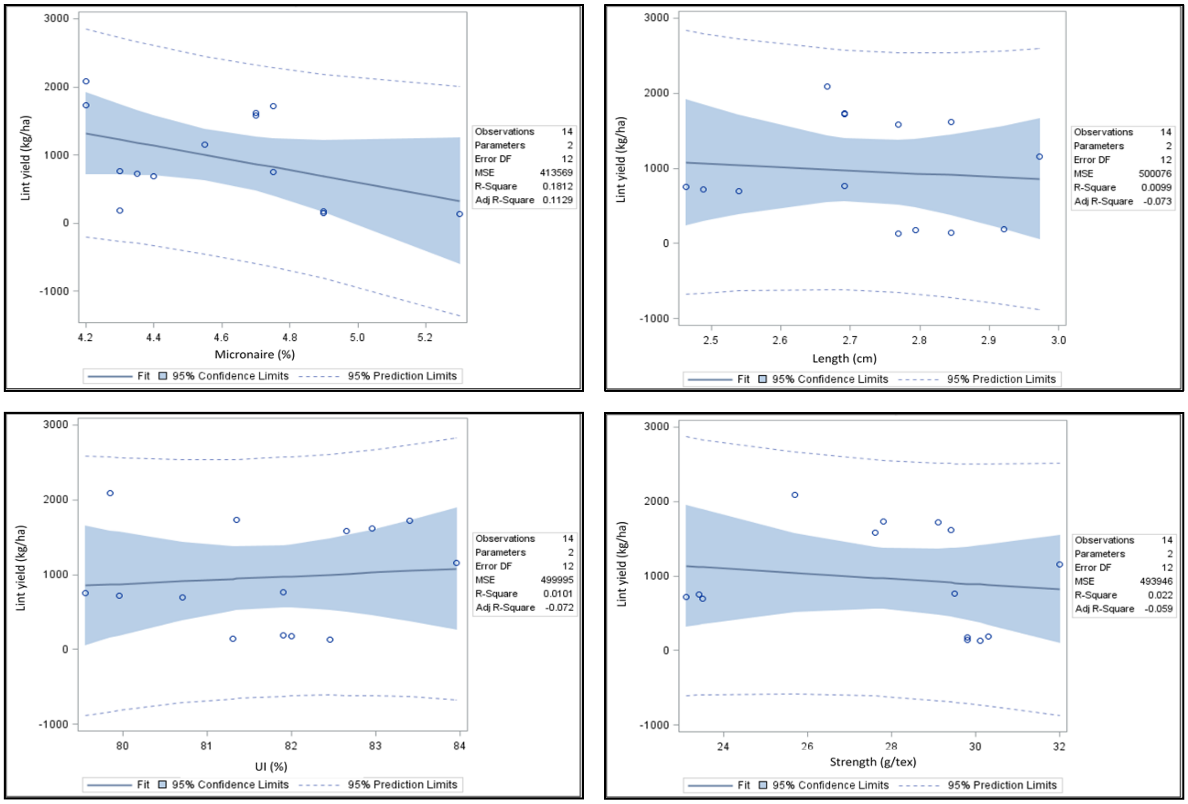


Figure 3. Regression of lint yield and fiber traits from cultivar trials in South and Central Texas in 2010.

Fiber trait	y-Intercept	Slope
Micronaire	-1268.5	550.9
Length	-3129.3	1565.8
Uniformity Index	-10439.0	141.4
Strength	1188.5	5.5

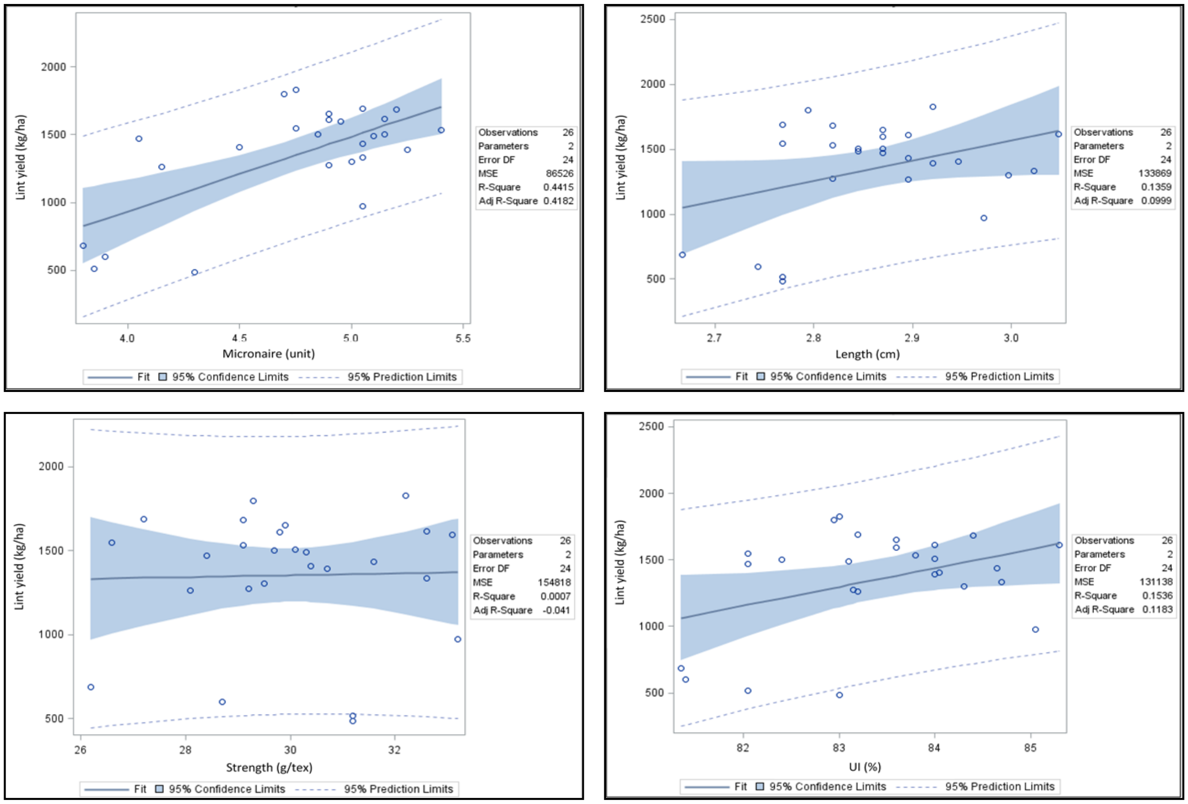
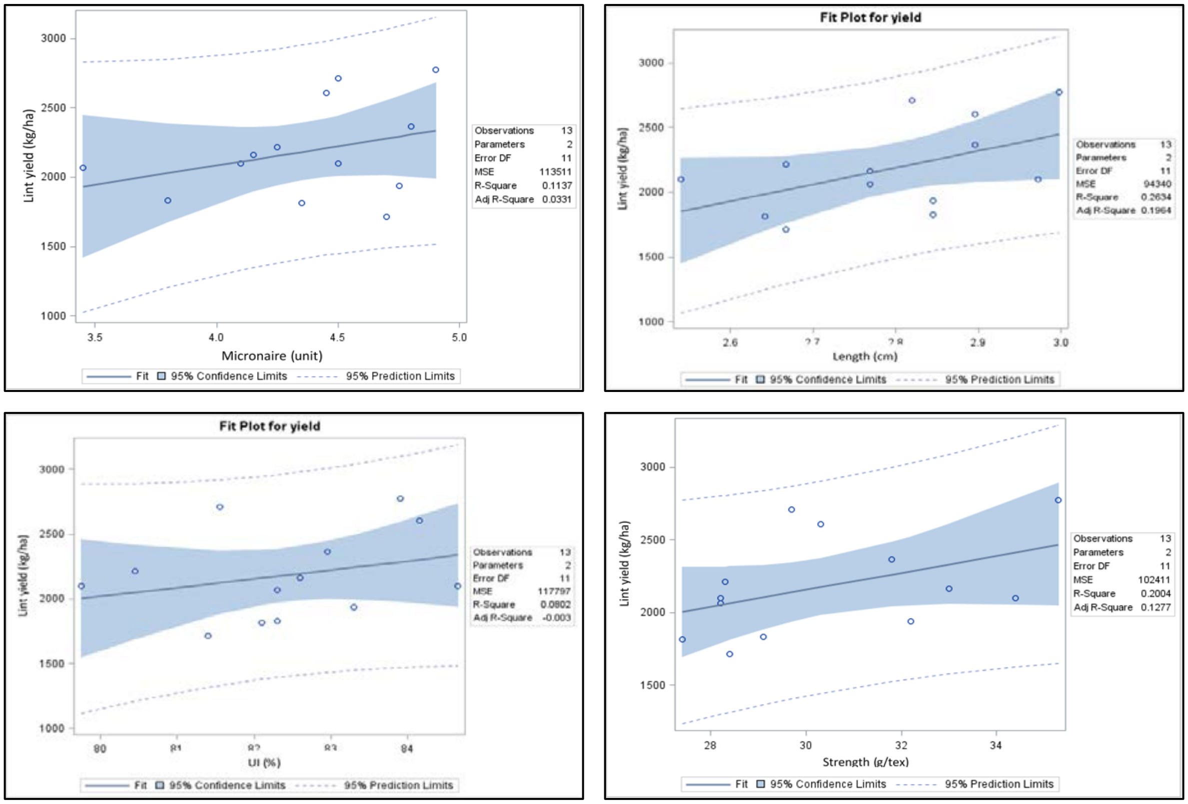


Figure 4. Regression of lint yield and fiber traits from cultivar trials in South and Central Texas in 2011.

Fiber trait	y-Intercept	Slope
Micronaire	970.0	278.4
Length	-1438.7	1296.8
Uniformity Index	-3449.5	68.4
Strength	386.7	59.0



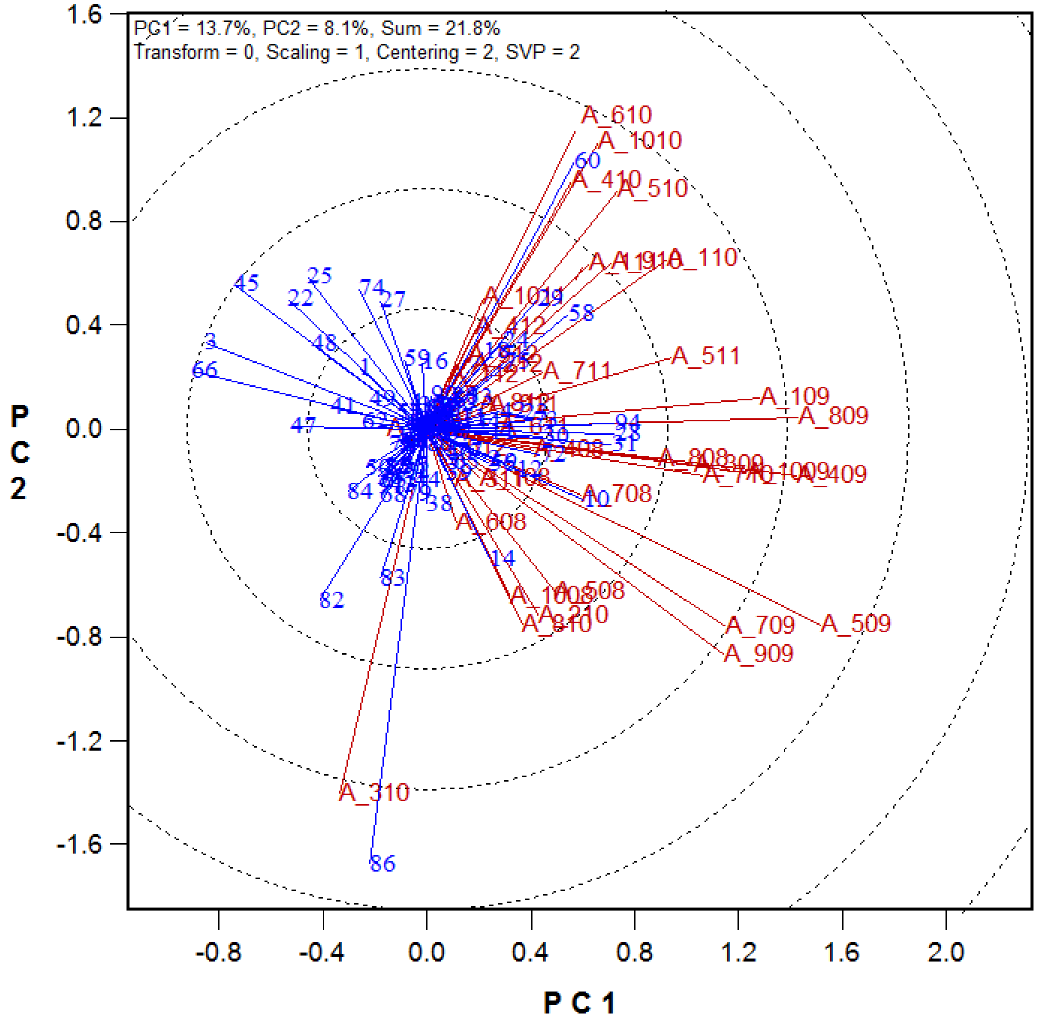
Evaluation of Testing Environments Using Biplot Analysis

Relationship among Testers

The environment- victor view of the GGE biplot results explain 21.8% of total environmental variation – centered genotype by location for lint yield data (Figure 5.). Results are based on an environment center (centering=2) G by E table with a scaling equal to 1 (scaling=1), and it has a environment metric preserving (SVP=2). The axes were drawn to scale based on GGE biplot default feature. Locations were given a numeric code (Table 14)

Environmental vectors are lines connecting test environments (locations) to the biplot origin (W. Yan & Tinker, 2006). The angle between two environment vectors is an estimate of how well they are correlated. Because A-610 is positively correlated with sites like A-1010, there is an acute angle between the points. The obtuse angle indicates the correlation is slightly negative. An example of a negative correlation is if the angle between A-610 and A-409. A-610 and A-909 are not well-correlated because there is a right angle between their respective vectors. The wider the obtuse angle between location vectors, the stronger the supposed GE interaction. Hence, an angle that is slightly larger than 90□ indicates a moderate GE interaction (i.e. A-610 and A-210) and location with a wide obtuse angle between corresponding vectors is a strongly suggests a GE interaction.

Figure 5. Similarities among test environments for discriminating among cultivars.



Relationship among testers

Table 14. Location codes used in the biplot analysis of cotton cultivar yield trials in Central and South Texas (2008-2012).

Code	Test site location
Year 2008	
a_108	Corpus Christi (non-irrigated)
a_408	College Station (non-irrigated)
a_508	College Station (irrigated)
a_608	San Patricio County (non-irrigated)
a_708	San Patricio County (irrigated)
a_808	Thrall (non-irrigated)
a_1008	-Weslaco (irrigated)
Year 2009	
a_109	Corpus Christi (non-irrigated)
a_309	Commerce (non-irrigated)
a_409	College Station (non-irrigated)
a_509	College Station (irrigated)
a_709	San Patricio County (irrigated)
a_809	Thrall (non-irrigated)
a_909	Weslaco (non-irrigated)
a_1009	Weslaco (irrigated)
Year 2010	
a_110	Corpus Christi (non-irrigated)
a_210	Chillicothe (irrigated)
a_310	Commerce (non-irrigated)
a_410	College Station (non-irrigated)
a_510	College Station (irrigated)
a_610	San Patricio County (non-irrigated)
a_710	San Patricio County (irrigated)
a_810	Thrall (non-irrigated)
a_910	Weslaco (non-irrigated)
a_1010	Weslaco (irrigated)
Year 2011	
a_111	Corpus Christi (non-irrigated)
a_311	Commerce (non-irrigated)
a_511	College Station (irrigated)
a_611	San Patricio County (non-irrigated)
a_711	San Patricio County (irrigated)
a_811	Thrall (non-irrigated)
a_1011	Weslaco (irrigated)
Year 2012	
a_112	Corpus Christi (non-irrigated)
a_212	Chillicothe (irrigated)
a_412	College Station (non-irrigated)
a_512	College Station (irrigated)
a_812	Thrall (non-irrigated)
a_912	Weslaco (non-irrigated)
a_1012	Weslaco (irrigated)

Locations are positively correlated, the genotype performed similarly in both test locations, therefore, excluding one of the locations can reduce the costs without losing the ability to discriminate among cultivars within a breeding program.

To assess the discrimination ability of test locations, vectors provide valuable insight when vectors are equivalent to the standard deviation within the respective locations. This, in effect, can measure the ability of a location to accurately determine differences among cultivars in trials. The concentric circles in Figure 5 helps to visualize the length of the location vectors. Longer vectors indicate that a location is more informative (more discriminating) than a location with a shorter vector. Locations such asA-409, and A-909 are more discriminating and therefore provide more information about cultivars in contrast to locations with the shorter vector lengths like A-812. Hence, such locations should not be included in cultivar trials because they would provide little information about cultivar performance on a broader scale.

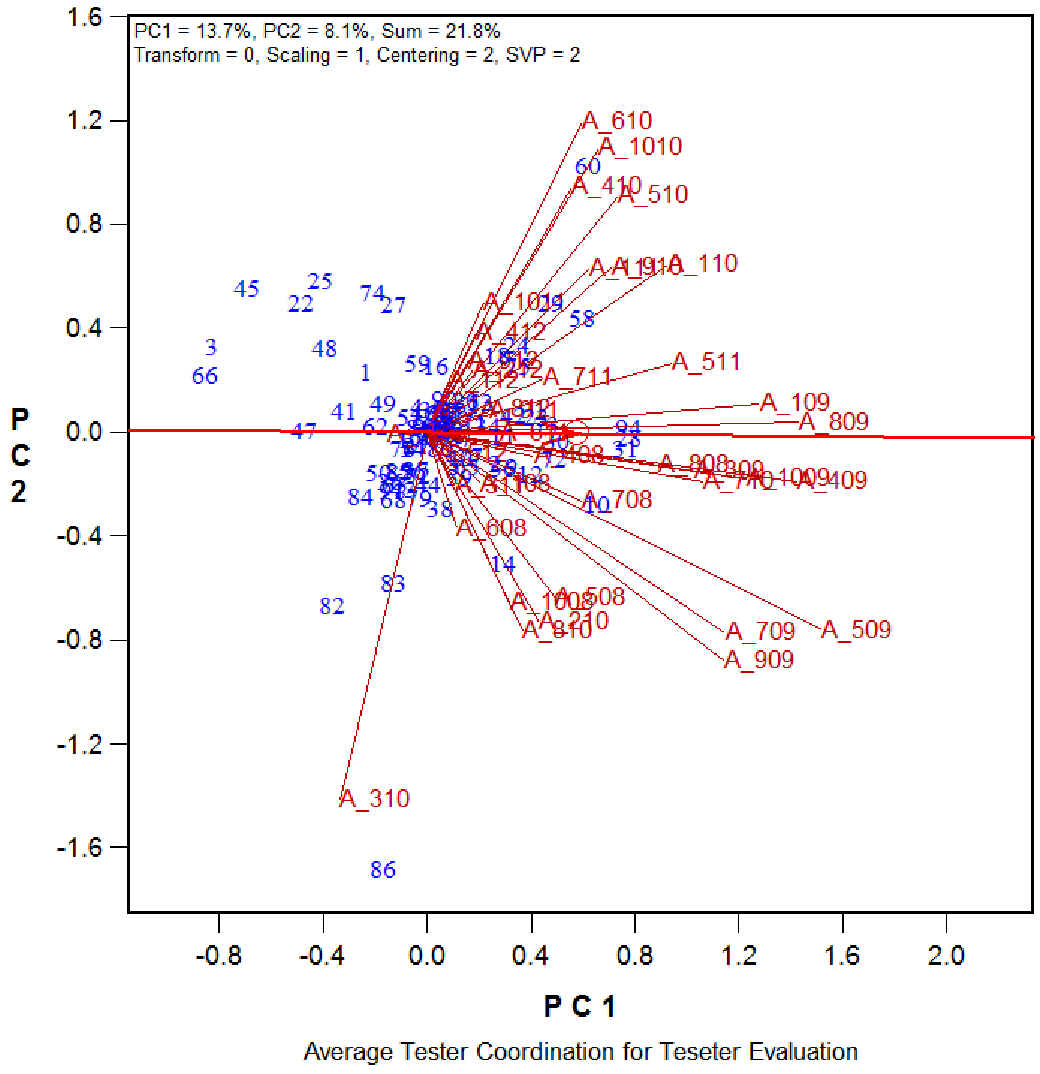
Representativeness of Test Environments

Biplot Figure 6 is similar to the biplot depicted in figure 5, but with the addition of an Average Environment Axis AEA, or average-tester-axis (W. Yan & Tinker, 2006; W. K. Yan, 2001). The small circle at the point of the arrow represents the average environment which has the average coordinates of all test location, and AEA is the line that passes through the average environment (W. Yan & Tinker, 2006).

A test location with a smaller angle with the AEA is more representative of other test environments. Accordingly, A-809 is more representative than the other locations; however, A-310 is the least representative because it is represented with the largest angle with the AEA.

Finding a discriminating and representative environment such as A-409 is essential when selection for a well adapted genotypes (E. L. Lubbers, 2003), while a location that only discriminates but non-representative of other locations like A-310 (Commerce,TX, in 2010) are good sites to select genotypes specifically adapted to that specific location. In such case, a split can be made into mega-environments (Yan et al., 2000). A location described as discriminating but non-representative like A-610 (San Patricio County non-irrigated in 2010) is beneficial for identifying unstable cultivars when the target location is a single mega-environment. Finally, non-discriminating test locations such as A-812 are less informative about cultivars because of the short vector.

Figure 6. Discriminating ability and representativeness of the test locations.



Usually, in a single location is it important to assess the cultivars mean performance and stability. The Biplot depicted in Figure 7 is similar to those in Figures 5 and 6 except that SVP= 1, which means it is a genotype-metric preserving. Therefore it provides cultivar mean performance and stability information. In order to condense information conveyed in a biplot, cultivar names were given a numeric code (Table 15). The single- arrowed line is the average Environment coordination AEC abscissa (or AEA) it always points to the higher mean yields across locations. Therefore cultivar 94 had the highest mean followed by 28 and 31. Cultivar 81 had a mean similar to the grand mean. Cultivar 66 had the lowest yield mean of all genotypes.

The double arrowed line in the middle points to cultivars with low stability, which in turn equates to greater variability, in both directions. Accordingly, cultivar 86 was highly unstable compared to other cultivars, while cultivar 23 was highly stable and therefore had low variability across testing locations. It is worth pointing out that GGE biplot explained only 21.8% of the total variation observed in this data set.Consequently, cultivars that may appear stable based on biplot information, may not be stable because of variation not captured in the biplot (Yan and Tinker, 2006).

Figure 7. The mean performance and stability of the cultivars depicted by the average environment coordination (AEC) view.

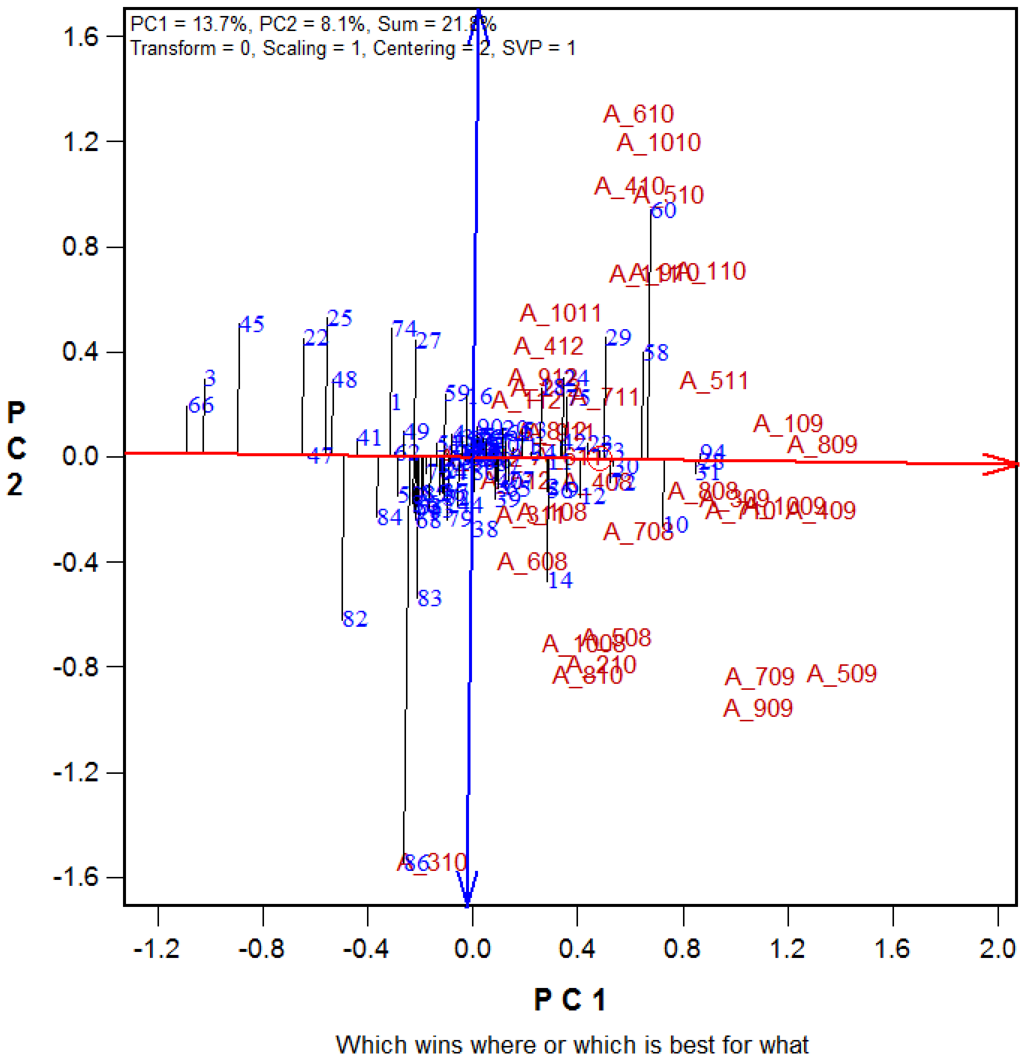


Table 15. Cultivar names and corresponding numeric cods used in biplot analysis.

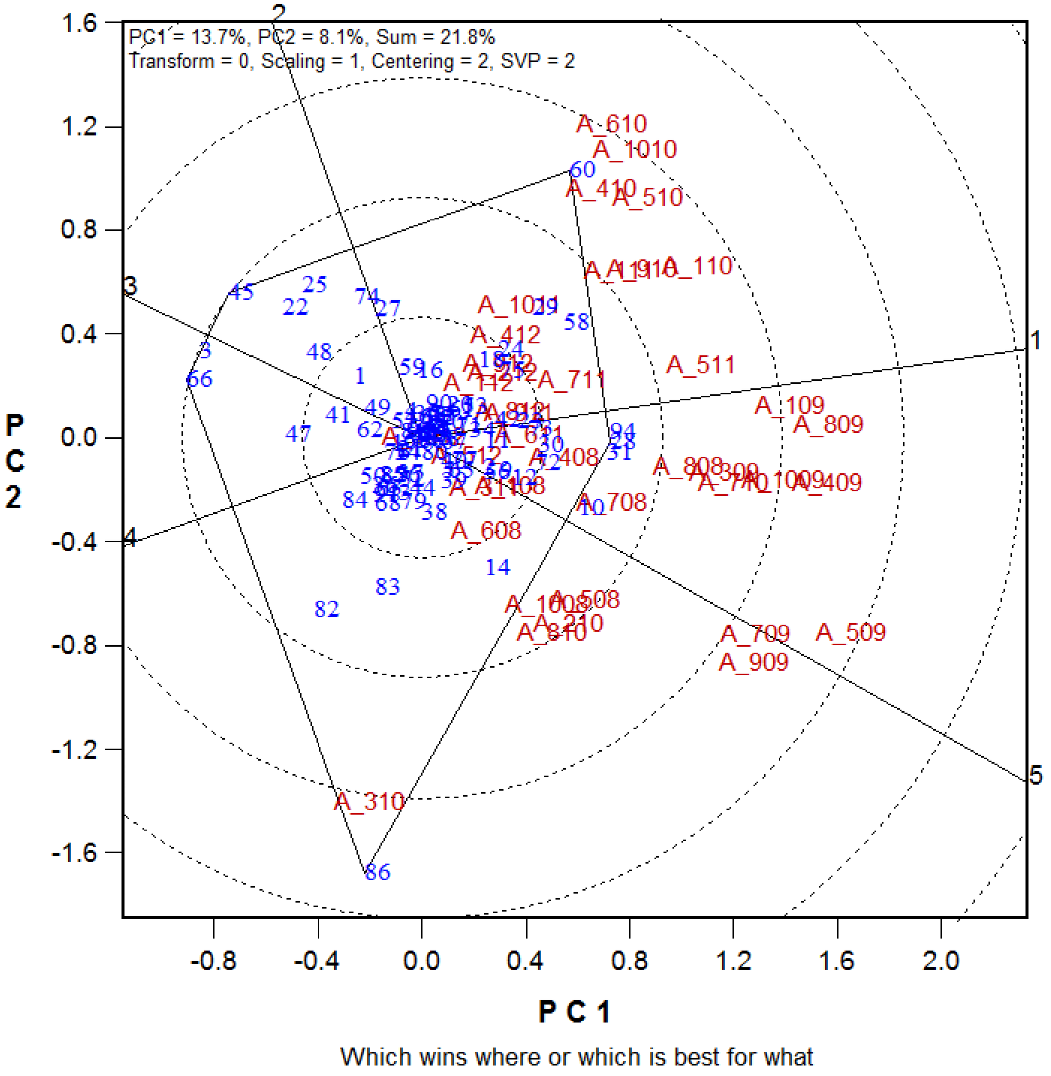
Cultivar	Code in biplot	Cultivar	Code in biplot	Cultivar	Code in biplot
04 N-49	1	DP 1044 B2RF	34	SSG HQ 210 CT	67
04 WD-9s	2	DP 1048 B2RF	35	SSG HQ 212 CT	68
04 WE-27s	3	DP 1050 B2RF	36	ST 4288B2F	69
04 WG-66s	4	DP 1133 B2RF	37	ST 4427B2RF	70
04 WH-66	5	DP 141 B2RF	38	ST 4498B2RF	71
04 WH-7	6	DP 161 B2RF	39	ST 5288B2F	72
09R303B2R2	7	DP 555 BG/RR	40	ST 5458B2RF	73
09R549B2R2	8	FM 1735LLB2	41	STV 4554B2RF	74
09R550B2R2	9	FM 1740B2F	42	STV 5327 B2RF	75
09R615B2R2	10	FM 1773 LLB2	43	TAM 02 WK-11L	76
09R619B2R2	11	FM 1845 LLB2	44	TAM 04 WA-24	77
09R796B2R2	12	FM 1880B2F	45	TAM 04 WD-9	78
10R013B2R2	13	FM 832LL	46	TAM 04 WH-66	79
All-Tex 7A21	14	FM 835LLB2	47	TAM 04 WH-7	80
All-Tex 81144 B2RF	15	FM 840B2F	48	TAM 05 A-46	81
All-Tex Apex	16	FM 9058F	49	TAM 05 A-52s	82
AM 1532 B2F	17	FM 9160B2F	50	TAM 05 B-15	83
AM 1550 B2RF	18	FM 9170B2F	51	TAM 05 -WJ-07	84
Ark 0114-53	19	FM 955LLB2	52	TAM 05 -WK-31Ls	85
Ark 0222-12	20	NexGen 1511 B2RF	53	TAM 05 WL-27	86
Ark 9803-23-04	21	NG 4010 B2RF	54	TAM 06 A-61	87
CG 3020B2RF	22	NG 4012 B2RF	55	TAM 06 A-71	88
CG 3035RF	23	PHY 315 RF	56	TAM 06 B-69	89
CG 3220 B2RF	24	PHY 370 WR	57	TAM 06 C-79	90
CG 3520B2RF	25	PHY 375 WRF	58	TAM 06 E-37	91
CG 3787 B2RF	26	PHY 485 WRF	59	TAM 06 WE-14	92
CG 4020B2RF	27	PHY 499 WRF	60	TAM 06 WE-39	93
DP 0912 B2RF	28	PHY 519 WRF	61	Tamcot 73	94
DP 0920 B2RF	29	PHY 525 RF	62	UA48	95
DP 0924 B2RF	30	PHY 565 WRF	63		
DP 0935 B2RF	31	PHY 569 WRF	64		
DP 0949 B2RF	32	PHY 5922 WRF	65		
DP 1032 B2RF	33	PHY 72	66		

This feature in biplot considers an important feature for its ability to show the which-won-where pattern of a genotype by environment dataset, and it is favored by many researchers because it graphically tackles major concepts like GE interaction, mega-environment differentiation, adaptation etc. (W. Yan & Tinker, 2006).

This biplot configuration contains a polygon drawn to connect cultivars that are furthest from the biplot origin and all the other cultivars are contained within the polygon (Figure 8). The vertical lines start from the biplot origin to each side of the polygon.

Cultivars that lie on each vertices of the polygon preformed either the worst or the best at one or more locations. The vertical lines, called equality lines, between adjacent cultivars provides a visual comparison among cultivars. Based on that assumption, cultivar 60 performed better at testing locations A-610, A-1010, A-410 etc., and the cultivar 94 performed better at testing locations A-310 A-109, A-809. Finally, cultivar 68 performed well in at testing location A-509. Those cultivars were considered winners in those locations. Conversely, cultivars 86, 66, and 45 performed the poorest in all locations.

Figure 8. Biplot of cultivars describing the best performances in specific environments.



CHAPTER IV

CONCLUSIONS

The objectives of this project were to compare the statistical tools we have at our disposal in describing stability performance in terms of lint yield, and fiber quality. The other goal was to identify the best locations, years, and cultivars. In this way, we can most effectively use resources in testing not only cultivars, but also early generation material in breeding programs.

So in answering the most pertinent questions of what were the best location, year, and cultivar:

1- The best locations were irrigated trials at Weslaco and College Station. While Chillicothe is a good location it could be describing another mega-environment.

2- Rainfall patterns varied greatly from year-to-year. Non-irrigated trials were especially vulnerable to these differences and therefore less inherently stable testing locations.

3- Finally, the most stable cultivars as identified by this study suggest that cultivars that have a lengthy history of successful cultivation and/or developed in this growing region tend to be more stable such as Tamcot 73 and PHY 375 WRF.

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