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EVALUATION OF COTTON BREEDING TEST ENVIRONMENTS IN THE SOUTHEAST UNITED STATES

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Abstract

The selection of breeding and testing locations can have enormous impact on any crop breeding program. The existence of mega-environments is recognized in many crops. Examples include, northern and a southern corn groups, maturity groups of soybeans, and cotton that has at least four groups with Acala, stripper, and two picker groups with early and late maturity. In developing a breeding program with one of its primary goals to develop cotton for the entire US, Phytogen Seed Company, LLC (Phytogen) started with locations in the San Joaquin Valley, CA and in the Mississippi River delta, MS, both previously selected with a history of producing commercial varieties. Tifton, GA was selected as the main site for developing later maturing cotton varieties to expand the breeding program to cover the entire US.

The primary selection criterion for the outlying locations was to have these sites in the middle of important cotton growing areas delineated by lint production on a county by county basis. Phytogen started a MET to determine if there were duplicate locations within the sites in the Southeast or between them and the sites in the MidSouth, and to determine the best main breeding site for the Southeast. After one year of this test, Phytogen decided to close the Southeast breeding program for economic reasons so this Phytogen test data is only from one year. AMMI analysis in Agrobase21 and the GGEbiplot Pattern Explorer were used to analyze the Phytogen data. Both analyses indicated the existence of possible duplicate locations.

GGEbiplot Pattern Explorer was used for additional analysis of data from county yield histories compiled by the United States Department of Agriculture – National Agricultural Statistics Service (USDA-NASS) and data from the National Cotton Variety Trial (NCVT). GGEbiplot analysis of county yield histories may have value in the selection process of test locations. A pattern of related counties in Georgia was revealed but the underlying factors of the relationship require additional research. Data from the NCVT was collapsed into a genotype / environment two-way dataset and into location / year two-way dataset. The GGEbiplots from these datasets were compared and many of the interrelationships among the locations remain between the two analyses but not all. There is value in a location / year analysis when genotype information is not available.

The GGEbiplot Pattern Explorer also has a biplot that shows the most discriminatory and stable locations compared to an ideal location. The 'best' locations for a main research site are shown for all the datasets that were used.

GGEbiplot analysis was also used to find evidence of a location most similar to Stoneville, MS, an area with an excellent reputation in cotton varietal development. Tifton, GA appeared to be the closest environment in this comparison. This supports Phytogen's original decision to place a station near Tifton as well as Delta & Pine Land Company's decision to locate there.

Introduction

The selection of breeding and testing locations can have enormous impact on any crop breeding program. Breeders select phenotypes which are the compilation of genotypic and environmental effects along with the interaction (P = G + E + GEI). Of these components, the genotype can be manipulated by the breeders but much of the environment cannot be so easily controlled. For qualitative traits there is little variance in a desired outcome such as flower color. For quantitative traits there is much more variation in the desired outcome, such as yield, and the environment is directly or indirectly the source of most all of the variance. One of the primary goals of multi-environment variety testing (MET) is to statistically segregate the genotypic, environmental, and interaction components of yield. Making this environmental component a given factor in the equation above results in P = G + GEI for the given environment. In general, one would assume that different varieties do respond differently in different environments (i.e. GEI exists). If GEI doesn't exist then a single location would suffice and P = G which is like a qualitative trait. GEI can also affect the ranking of the varieties (i.e. crossover interactions can exist). In breeding, the change of ranking of any varieties but the best ones is of no consequence. Therefore, if important crossover interactions are repeatable then there is evidence that dividing the cotton belt into mega-environments would allow breeders to exploit GEI. Varieties for each mega-environment could then be developed instead of forcing one variety for the entire production area. This, of course, indicates a strategy of exploiting GEI.

Locating a primary breeding site is sometimes based more on resources, priority, and history than on science. In developing a breeding program with one of its primary goals to develop cotton for the entire US, Phytogen Seed Company, LLC (Phytogen) started with locations in the San Joaquin Valley, CA and in the Mississippi River delta, MS, both previously selected with a history of producing commercial varieties. The existence of at least four mega-environments is recognized in *G. hirsutum* as environments for Acala, stripper, and early and late maturity picker cotton. With the Acala and early maturity picker areas covered, locations to develop stripper and later maturity picker cotton would help Phytogen to expand the program to cover the entire US. Adding the later maturity location in the Southeast instead of further south in the MidSouth covered both the maturity change and items such as soil type and climate that are different in the Southeast. Tifton, GA was selected because it is in the middle of a major cotton growing region that grows later maturing cotton and has highly productive soils. Tifton also had excellent academic/research infrastructure with the Coastal Plain Experiment Station, the Rural Development Center, and Abraham Baldwin Agricultural College.

Ideally, a breeding program would have a stable and very discriminating main site with enough outlying locations to cover each mega-environment. The first problem is to determine the mega-environment and then to find the main site and outlying locations. A MET is used to determine the value of the sites already selected but it can't directly select the sites to be tested. Someone has to select the sites and then evaluate them later with a MET. The Phytogen test was the beginning of a MET. Other METs that are already in existence include the National Cotton Variety Trial (NCVT) and the Official Variety Trials (OVTs) of individual cotton states. These state trials can be coalesced into a larger, more powerful MET that would have more locations to evaluate. Another possible valuable dataset would be the extensive databases of the private breeding concerns such as Delta & Pine Land Company. There is also county yield histories compiled by the United States Department of Agriculture-National Agricultural Statistics Service (USDA-NASS). Unfortunately, this data doesn't have the genotypic component of the earlier equation but it does have location (L) and year (Y) components. The environment component (E) of the equation $P = G + GEI + E$ can be broken into L and Y along with the associated interactions. L can be statistically considered a fixed effect with Y considered a random effect. Although the L for the METs with varieties and the L from the county histories are not exactly the same, analyzing this data for L may be of value in determining possible locations to be tested based on the previous cotton production history of a county.

The two goals of this research was; (1) to determine if there were duplicate locations within the sites in the Southeast or between them and the sites in the MidSouth, and (2) to determine the best breeding site for the Southeast. Costly, superfluous sites were to be eliminated. Also, if this information helped select a better site than Tifton for a main site, knowing that early would provide the opportunity to move with less expense. One possible way of doing this was to find a site that matched the response of that area in MS near Stoneville, Scott, and Leland, MS with its reputation for developing widely adapted productive varieties.

Materials and Methods

Since, as a company, Phytogen is interested in selling seed in all and any mega-environments, primary selection of outlying testing locations would give value if it covered important areas (large acreage). The primary selection criterion was to have these sites in the middle of important cotton growing areas delineated by lint production on a county by county basis. Irrigation and isolation from transgenic cotton were also important along with a progressive grower that understood plot research. These selected Southeast locations covered areas that extended from lower Alabama to just south of the North Carolina/Virginia border. The test was a three replicate randomized complete block design grown at all of the Phytogen sites in the MidSouth and the Southeast (Table 1). The test used conventional varieties that were competitive at the time along with older, previously successful varieties that were diverse in maturities and genetic background (Table 2). Lint yields per acre were reported. After one year of this test, Phytogen decided to close the Southeastern breeding program for economic reasons; so this Phytogen test data is only from one year.

County cotton yields from 1980 to 1999 were retrieved from USDA-NASS web site. Counties with at least 5,000 acres during 1 year of the 5 were selected except for '95 to '99 which the counties had too have at least 10,000 acres. If the counties were selected for more than two sets of five then the data was revisited and the data for the county was completed (unless the last set of five was not selected).

The yield data of the checks (Table 3) of the National Cotton Variety Test from 1990 to 2001 was used to evaluate the locations in this test (Table 4) as well as verify the validity of the analysis of the county yield data from the USDA-NASS.

The Phytogen data was analyzed as an AMMI analysis (Agrobase 21, Agronomix Software Inc., 171 Waterloo Street, Winnipeg, Manitoba, Canada) and with the GGEbiplot Pattern Explorer (Dr. Weikai Yan, 75-252 Stone Road West, Guelph, Ontario, Canada). The rest of the data was analyzed as a GGEbiplot.

Results and Discussion

In the AMMI ANOVA of the Phytogen data, the G and E main effects and the GEI were significant at the 0.01 level as were the first 6 Interaction Principle Component Axes (ICPA) of the GEI (Table 5). The Coefficient of Variation for the test was less than 10%. The first four IPCAs explained 80% of the variance of the GEI (Table 6) with the IPCAs ordered from the largest percent explained by the GEI to the smallest. The IPCA values of each of the locations (Table 7) show a complex relationship that is difficult to easily decipher. Wayside, MS, Leland, MS (dryland), and Crowville, LA show similar patterns of a graph of the IPCAs 1 to 4 (Figure 1). This relationship indicates similarity of the underlying character of the environment being evaluated which in turn suggest duplicate locations. Enfield, NC with Brownsville, TN (Figure 2) and Moultrie, GA with Vienna, GA (Figure 3) are also two pairs of possible duplicates.

This data was analyzed as a GGEbiplot upon the recent development of the GGEbiplot Pattern Explorer software. The AMMI biplot shows the relationship between G and the first IPCA whereas the GGE biplot puts G and GEI together (GGE) and then shows the relationship of the first two principle components. The GGE biplot of the entire dataset obviously shows two groups that follow maturity (Figure 4). The positions of Moultrie and Vienna, GA on the biplot of the later maturity types indicate a very similar environment as was seen in the AMMI analysis (Figure 5). The early maturity set breaks down into two groups (Figure 6). Crowville, LA, Wayside, MS, and Leland, MS (dryland) group together with Leland, MS (irrigated). The first three also group together in the AMMI analysis. The TN and NC locations that grouped in the AMMI analysis also group with the AR, MO, and Florence, SC locations. Crop management could affect where a location is placed. This could be the reason that Florence, SC placed with the early varieties instead of with the later varieties as did the other two SC locations.

County history data consists of non-replicated Location (L) and Year (Y) data. GGEbiplot can be used with any two-way dataset. The data was imported into GGEbiplot Pattern Explorer with the location as the entry and the year as the tester. The ‘which won where’ plot shows that Decatur County was the highest yielding county for 13 years between 1980 and 1999 (Figure 7). Tift County (6 years) and Lee County (1 year) were other top ranking counties during this time. The counties were separated into groups using the information provided in Figure 7 (Figure 8). The gray counties are considered ambiguous because they were too close to the origin of the biplot. Red, yellow and blue are the main groups with the green as an intermediate between the main groups on the map and on the biplot. This biplot does have an apparent pattern based partly on a possible connection with soil type related to prehistoric ocean levels. More research is needed to determine the underlying physical connection with this pattern.

Another aspect of the GGEbiplot Pattern Explorer is a plot that shows an idealized location based on the highest yield and stability. Given the MidSouth and the Southeast together in the one year of Phytogen test data; Florence, SC would be the best site (Figure 9). The ideal location for a main site, however, should be detected using data from a single mega-environment. Given that we have at least two mega-environments, Saint Joseph, LA would be the best site for later maturity testing (Figure 10) and Marianna, AR is the best site for the early maturity testing (Figure 11). Using the entire NASS dataset, Decatur County is the best site for testing in GA (Figure 12) and using the set since the turning point year of 1988, Decatur County is even closer to the ideal site with Baker County an undisputed second (Figure 13). As a reminder, this analysis does assume that G is minor component.

Using the National Cotton Variety Test (NCVT) gave an opportunity to compare a G/L analysis with an L/Y analysis. I am comparing the L of the G/L analysis to the L of the L/Y analysis. The yields of the checks for the test from 1990 to 2001 were pulled and collapsed into two-way tables of variety and location for the G/L analysis and of location and year for the L/Y analysis. The G/L analysis, which is the same as a G/E analysis with the data pooled over years, is assumed to be the more correct analysis. In this analysis, Tifton, GA was the closest to the ideal site with Auburn, AL, Stoneville, MS, Portageville, MO, and Rocky Mount, NC in a tight pack for second (Figure 14). Discrimination power in this biplot can be shown as the distance of the location from the origin. Tifton showed the greatest discrimination power by a small margin and a study by Geng et al. (1990), using earlier NCVT data, also showed the Tifton environment as the most discriminating environment in that study. Even though the GGE biplot for the L/Y analysis (Figure 15) did not show tight similarity to the G/L GGE-biplot, there are location relationships that are essentially the same; for example, University Park, NM, Maricopa, AZ, Altus, OK, College Station, TX, and Saint Joseph, LA. There are locations like West Side Field Station, CA (positive) and Portageville, MO (negative) that changed dramatically. This shows that there is value in L/Y analysis but one must be aware that a given location may be misplaced. For the NCVT, the best analysis would be if the GGEbiplot Pattern Explorer could remove the Y effect and then produce a biplot of the adjusted G and L components. More effort needs to be placed on understanding the L and Y components to get a more consistent value for L.

A secondary goal was to find a location that is most like Stoneville, MS. The previous data from the NCVT was broken into 3 time periods; 90-95, 96-98, and 99-01 and analyzed both as G/L and L/Y (Figures 16 to 21). Over all of these GGEbiplots, Tifton, GA was closer to Stoneville, MS than any other location. The G/L analysis for 1990-1995 was the only one that showed a dramatic difference between these locations.

References

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Randall McPherson, Phytogen, who ran the AMMI analysis with Agrobase21 Software.
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Dr. Peng Chee, University of Georgia, who allowed me time to complete this presentation.

Table 1. Locations used in the Phytogen location evaluation test in 2000.

Location code	Community name
NCE	Enfield, NC
SCB	Bennettsville, SC
SCF	Florence, SC
SCE	Elko, SC
GAB	Brooklet, GA
GAV	Vienna, GA
GAM	Moultrie, GA
ALF	Fairhope, AL
LAJ	St. Joseph, LA
LAC	Crowville, LA
MSW	Wayside, MS
MSL	Leland, MS - Irrigated
MSD	Leland, MS - Dry
ARM	Marianna, AR
TNB	Brownsville, TN
MOH	Hornersville, MO

Table 2. Varieties used in the Phytogen location evaluation test in 2000.

Variety names	
D&PL DP 388	PhytoGen PSC 952
PhytoGen PSC 355	Bayer CropScience FM 966
D&PL SG 747	PhytoGen HS12
Stoneville ST 474	D&PL DP 675
PhytoGen GA161	D&PL DP 5415
D&PL SG 501	D&PL DP 5690
Bayer CropScience FM 958	D&PL DeltaPEARL

Table 3. Check Varieties of the National Cotton Variety Trial from 1990 to 2001.

Year		Varieties
1990 – 1995	Stripper	D&PL Paymaster HS 26
	Picker – early	D&PL DP 50
	Picker – late	D&PL DP 90
	Acala	Acala 1517-88
1996 – 1998	Stripper	D&PL Paymaster HS 26
	Picker – early	D&PL SG 125
	Picker – late	D&PL LA887
	Acala	CPCSD Acala Maxxa
1999 – 2001	Stripper	All-Tex Atlas
	Picker – early	D&PL SG747
	Picker – late	D&PL NuCOTN 33B
	Acala	CPCSD Acala Maxxa

Table 4. Selected Locations of the National Cotton Variety Trial from 1960 to 2001.

Location Code	Location
AlOK	Altus, OK
ArNM	Artesia, NM
AuAL	Auburn, AL
BCLA	Bossier City, LA
BeTX	Beeville, TX
BMAL	Belle Mina, AL
ChOK	Chickasha, OK – dryland
ChTX	Chillicothe, TX
CkOK	Chickasha, OK - irrigated
ClAR	Clarkedale, AR
CSTX	College Station, TX
DaTX	Dallas, TX
EPTX	El Paso, TX
FlSC	Florence, SC
KeAR	Keiser, AR
LMTX	Lamesa, TX
LuTX	Lubbock, TX
MaAZ	Maricopa, AZ
PeTX	Pecos, TX
PoMO	Portageville, MO
RMNC	Rocky Mount, NC
ShCA	Shafter, CA
SJLA	Saint Joseph, LA
StMS	Stoneville, MS
ThTX	Thrall, TX
TiGA	Tifton, GA
TiOK	Tipton, OK
UPNM	University Park, NM
WeTX	Weslaco, TX
WSCA	West Side Field Sta., CA

Table 5. AMMI ANOVA of the Phytogen 2000 MET.

Source	df	SS	MS	F-value	Pr> F
Total	895	76893347.140			
Environments	15	54359383.831	3623958.922	275.13	0
Reps within Env.	48	632239.506	13171.656		
Genotype	13	6142683.601	472514.123	9.26	0
Genotype x Env.	195	9949531.212	51023.237	5.48	0
IPCA 1	27	3358537.229	124390.268	13.36	0
IPCA 2	25	2189520.751	87580.830	9.41	0
IPCA 3	23	1557189.368	67703.886	7.27	0
IPCA 4	21	849038.810	40430.420	4.34	0
IPCA 5	19	670495.272	35289.225	3.79	0
IPCA 6	17	515035.423	30296.201	3.25	0
IPCA 7	15	286600.479	19106.699	2.05	0.0107
IPCA 8	13	193101.088	14853.930	1.60	0.0816
IPCA 9	11	130805.513	11891.410	1.28	0.2333
IPCA10	9	104356.186	11595.132	1.25	0.2641
IPCA11	7	55162.912	7880.416	0.85	0.5490
IPCA12	5	31106.633	6221.327	0.67	0.6477
IPCA13	3	8581.549	2860.516	0.31	0.8202
Residual	624	5809508.991	9310.111		

C.V. = 9.98%

Table 6. Amount of GEI Explained for each Interactive Principle Component Axis and Cumulative Total.

IPCA Axis	% GxE Explained	Cumulative %
1	33.76	33.76
2	22.01	55.76
3	15.65	71.41
4	8.53	79.95
5	6.74	86.69
6	5.18	91.86
7	2.88	94.74
8	1.94	96.68
9	1.31	98.00
10	1.05	99.05
11	0.55	99.60
12	0.31	99.91
13	0.09	100.00

Table 7. The values of the first four Interactive Principle Component Axes

	IPCA1	IPCA2	IPCA3	IPCA4
Marianna, AR	-17.5967	-1.0982	-2.7442	-5.9388
Florence, SC	-15.3805	13.4829	-3.6911	5.6505
Leland, MS	-5.3010	-5.1773	7.0459	-0.2042
Wayside, MS	-3.6227	-11.1958	1.9583	0.7985
Hornersville, MO	-0.6961	-3.7460	-6.8646	-8.0927
Crowville, LA	0.0949	-7.8123	10.2548	3.2919
Brownsville, TN	0.4169	-3.6765	-7.1691	4.2009
Enfield, NC	0.6850	-7.0892	-11.5456	-1.0528
Bennetsville, SC	0.7080	11.1053	7.2252	-6.3944
St. Joseph, LA	0.7584	3.2652	6.6326	8.4523
Leland dry, MS	2.6548	-6.2727	3.1756	3.9096
Brooklet, GA	4.1115	4.7469	6.4732	-8.7410
Elko, SC	5.0723	1.6403	-0.6056	5.7794
Vienna, GA	7.7134	2.0849	0.6165	-3.7494
Fairhope, AL	7.9780	7.6553	-7.0369	5.7404
Moultrie, GA	12.4036	2.0871	-3.7250	-3.6503

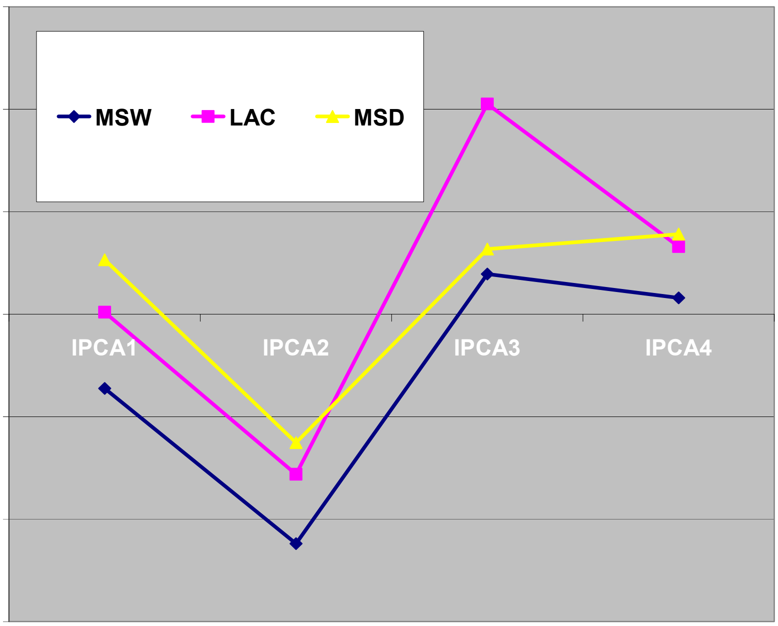

Figure 1. Line graph of the first four Interactive Principle Component Axes of an Additive Main Effect - Multiplicative Interaction Analysis for three Mississippi delta locations; Wayside, MS (MSW), Crowville, LA (LAC), and Leland, MS – dryland (MSD).

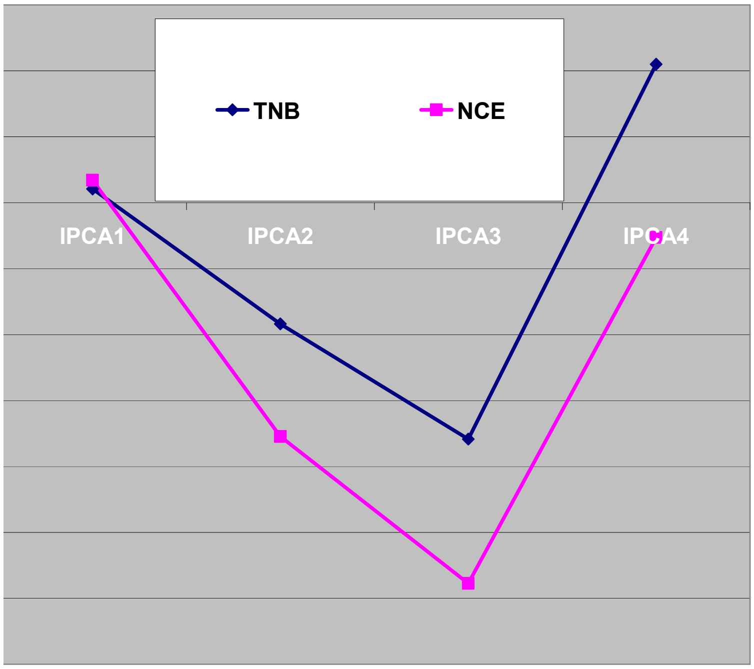

Figure 2. Line graph of the first four Interactive Principle Component Axes of an Additive Main Effect - Multiplicative Interaction Analysis for two Northern Cotton Belt locations; Brownsville, TN (TNB), and Enfield, NC (NCE).

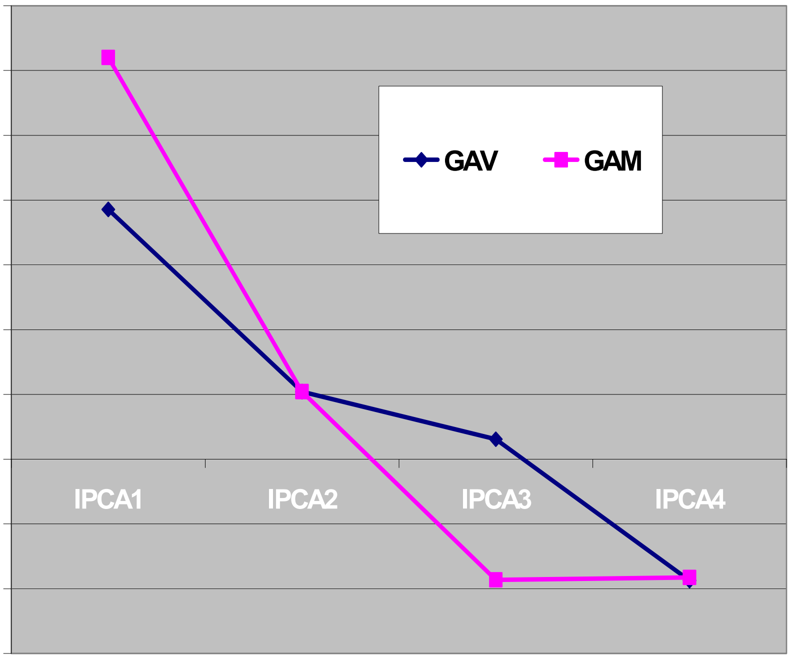

Figure 3. Line graph of the first four Interactive Principle Component Axes of an Additive Main Effect - Multiplicative Interaction Analysis for two South Georgia locations; Vienna, GA (GAV) and Moultrie, GA (GAM).

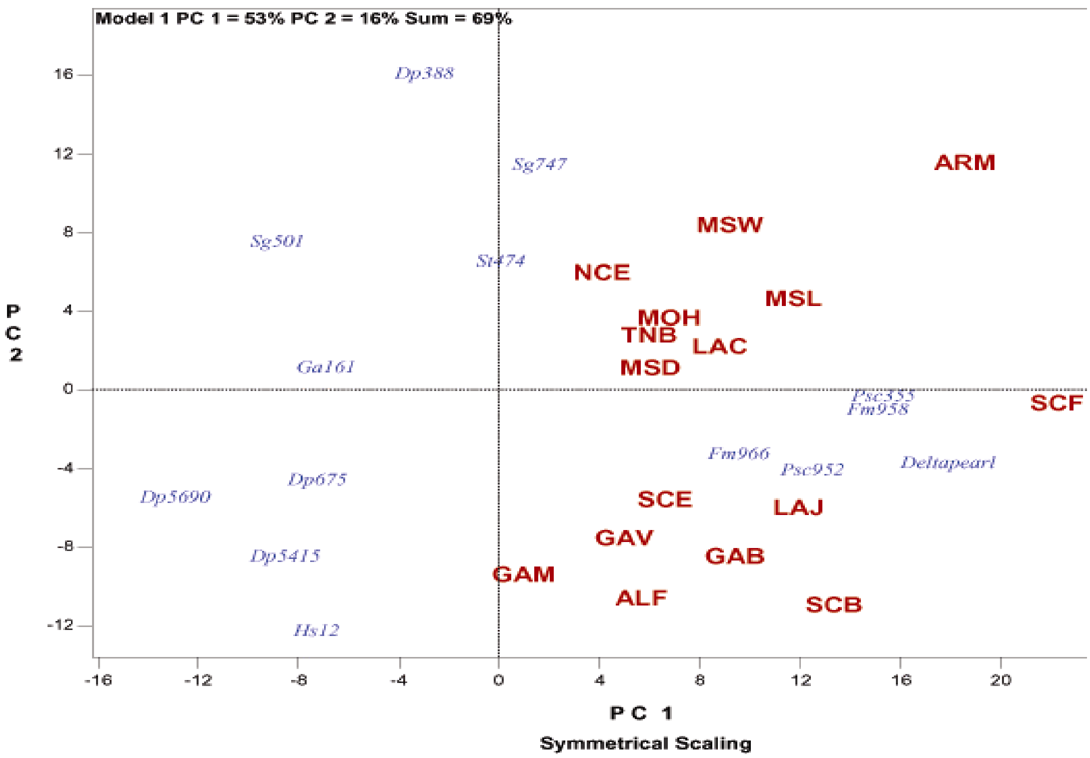

Figure 4. Genotype / Environment GGEbiplot of the Phytogen 2000 MET.

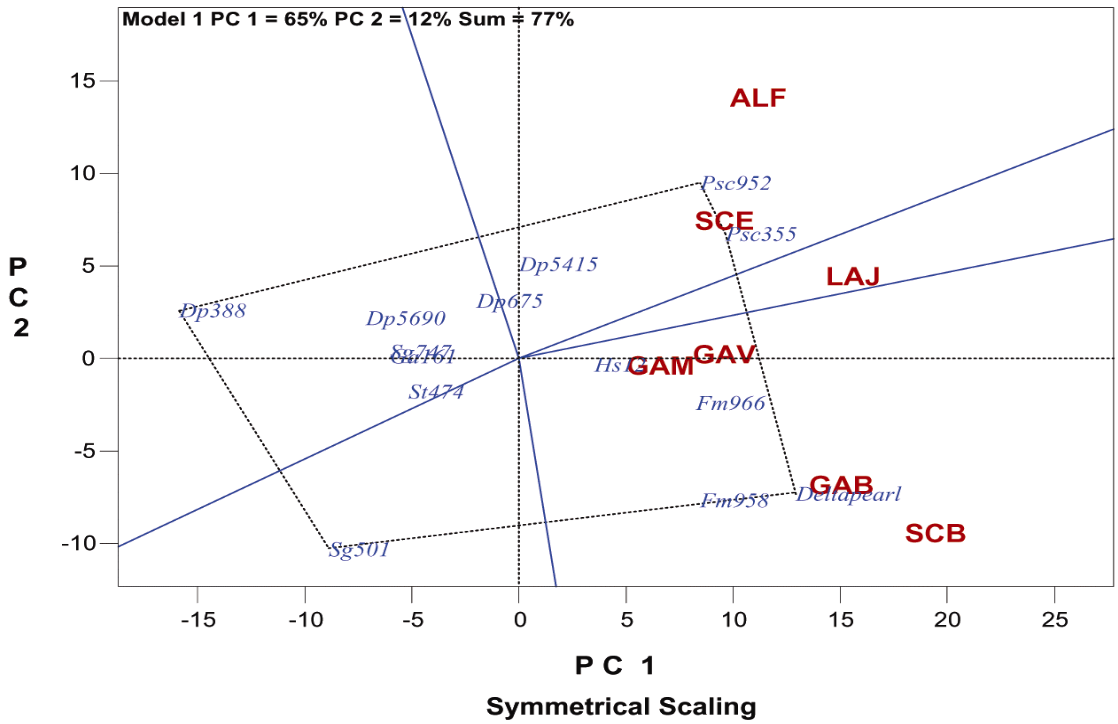

Figure 5. Genotype / Environment GGEbiplot of the later maturity portion of the Phytogen 2000 MET.

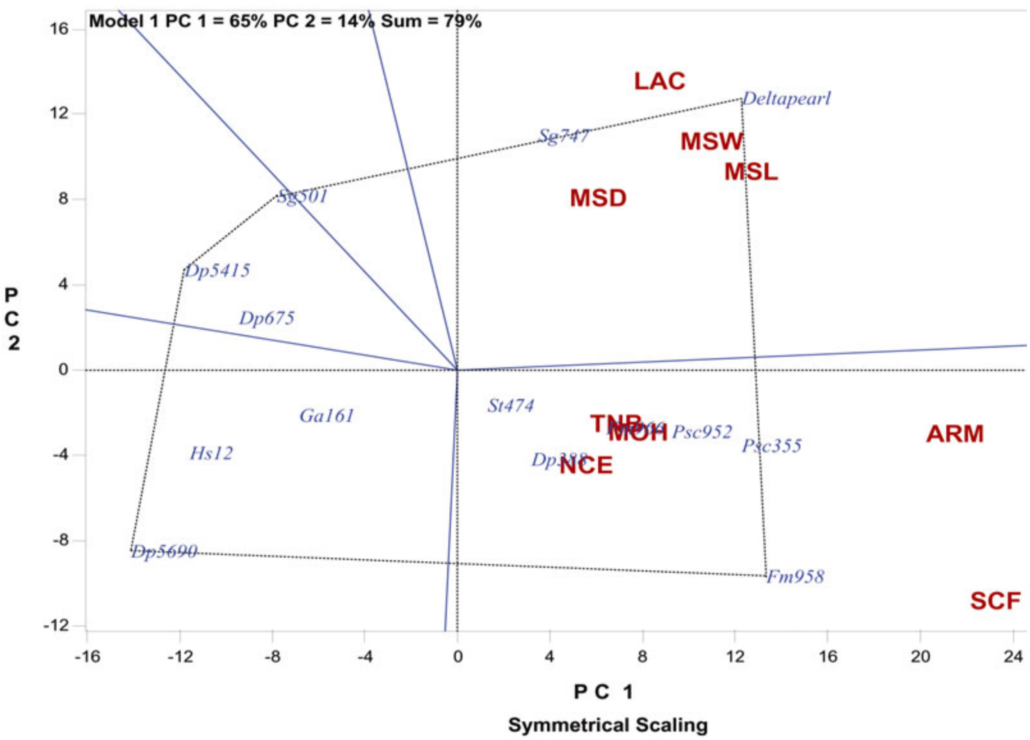

Figure 6. Genotype / Environment GGEbiplot of the early maturity portion of the Phytogen 2000 MET.

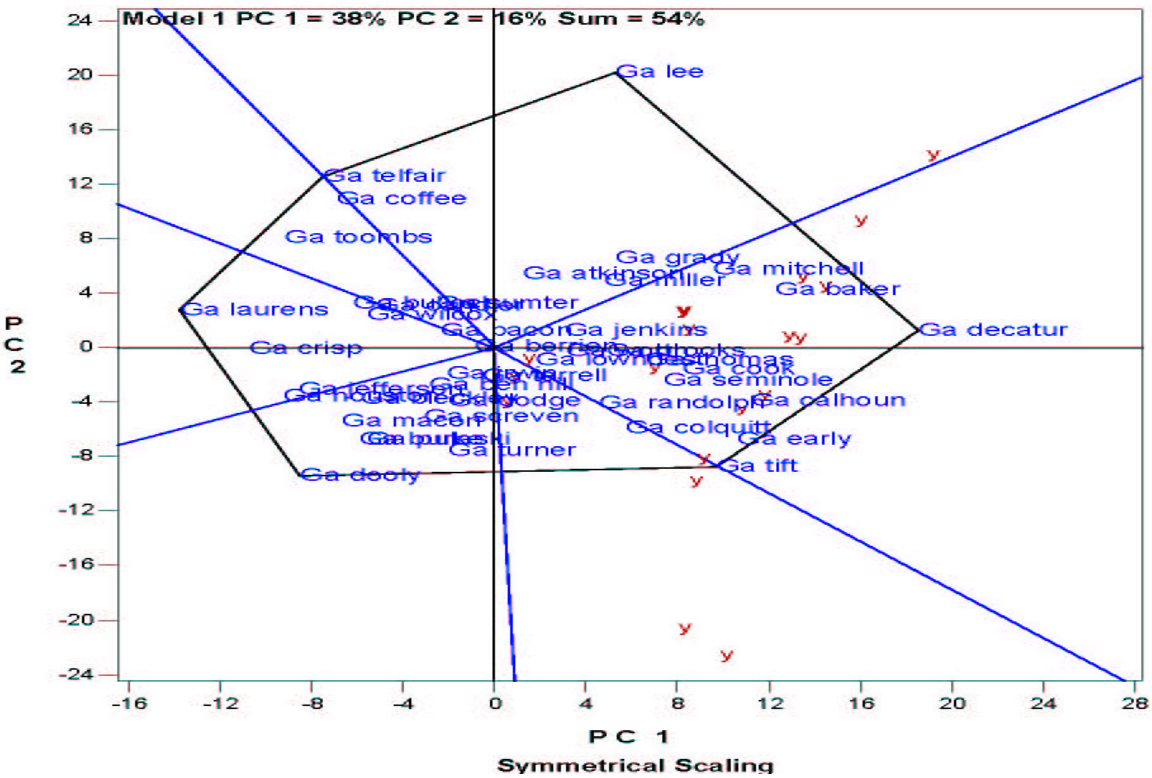

Figure 7. Location / Year GGEbiplot of the USDA-NASS County Yields from 1980 to 1999.

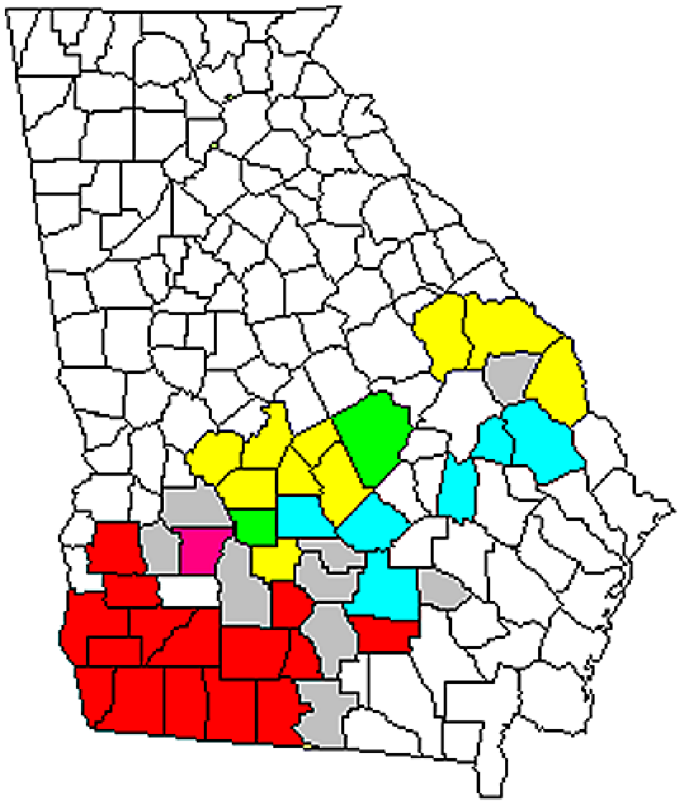

Figure 8. A grouping of Georgia Counties using Location / Year GGEbiplot of the USDA-NASS County Yields from 1980 to 1999. The red, yellow, and blue indicate main areas with green indicating an intermediate area between the yellow and blue groups. The gray counties indicate ambiguous areas that were not clear to which group they belonged.

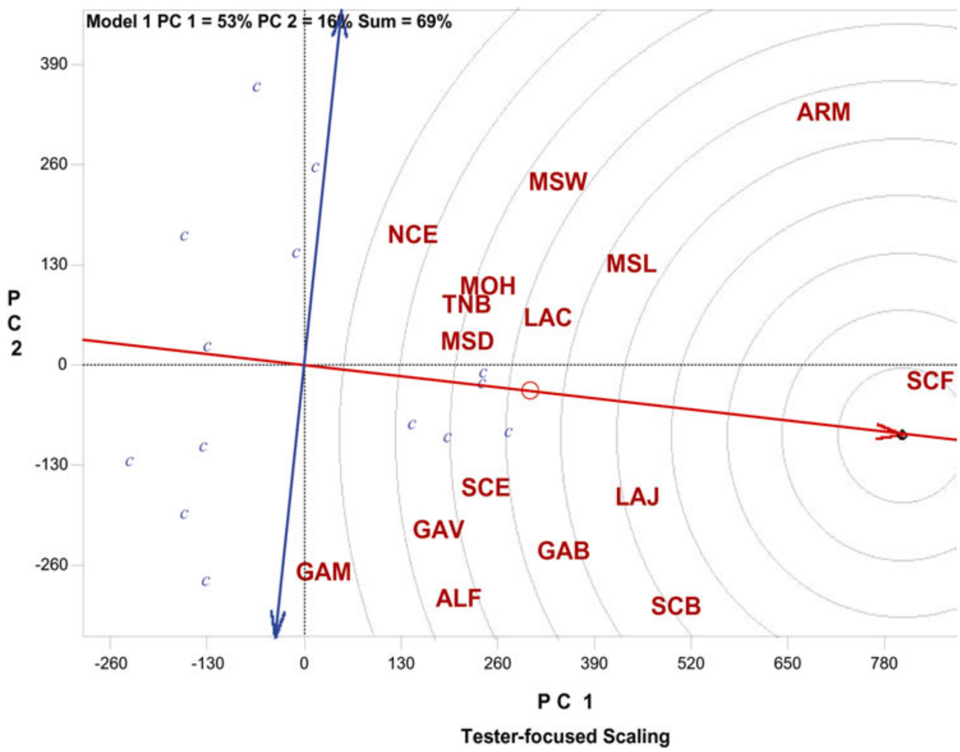

Figure 9. Genotype / Environment GGEbiplot comparison of all the locations in the Phytogen test to the ideal location. The ideal location, represented by the point with an arrow pointing to it, is the most discriminating of genotypes and representative of the other locations.

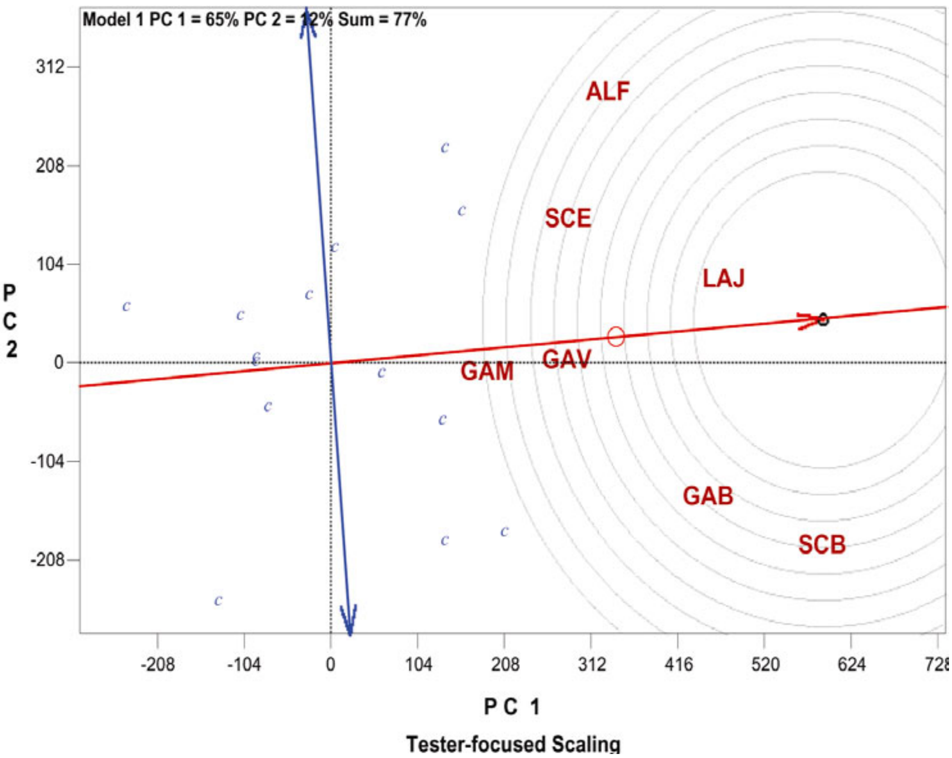

Figure 10. Genotype / Environment GGEbiplot comparison of the later maturing locations in the Phytogen test to the ideal location of that mega-environment. The ideal location, represented by the point with an arrow pointing to it, is the most discriminating of genotypes and representative of the other locations.

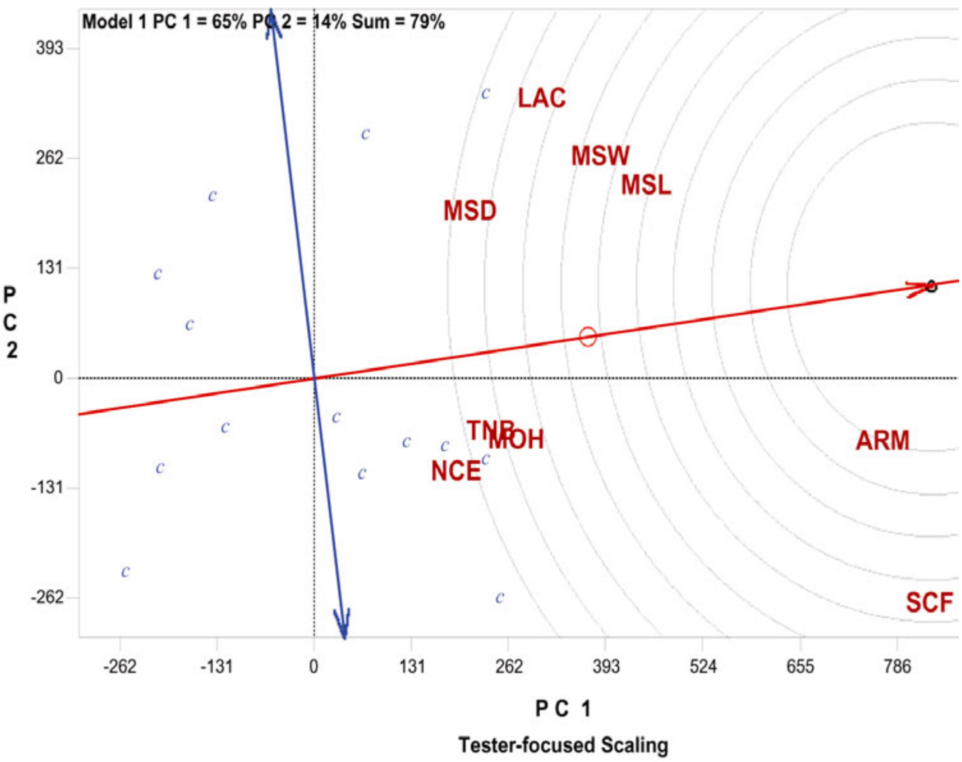

Figure 11. Genotype / Environment GGEbiplot comparison of the earlier maturing locations in the Phytogen test to the ideal location of that mega-environment. The ideal location, represented by the point shown with an arrow, is the most discriminating of genotypes and representative of the other locations.

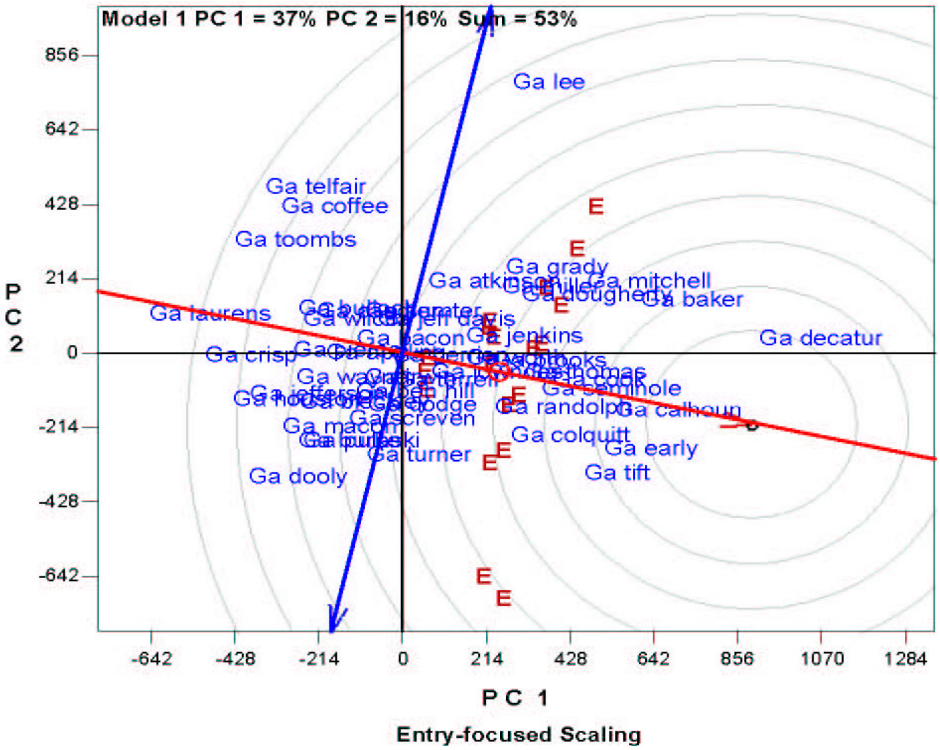

Figure 12. Location / Year GGEbiplot comparison of Georgia counties to the ideal location of Georgia using USDA-NASS county yield histories from 1980 to 1999. The ideal location, represented by the point shown with an arrow, is the most discriminating of genotypes and representative of the other locations.

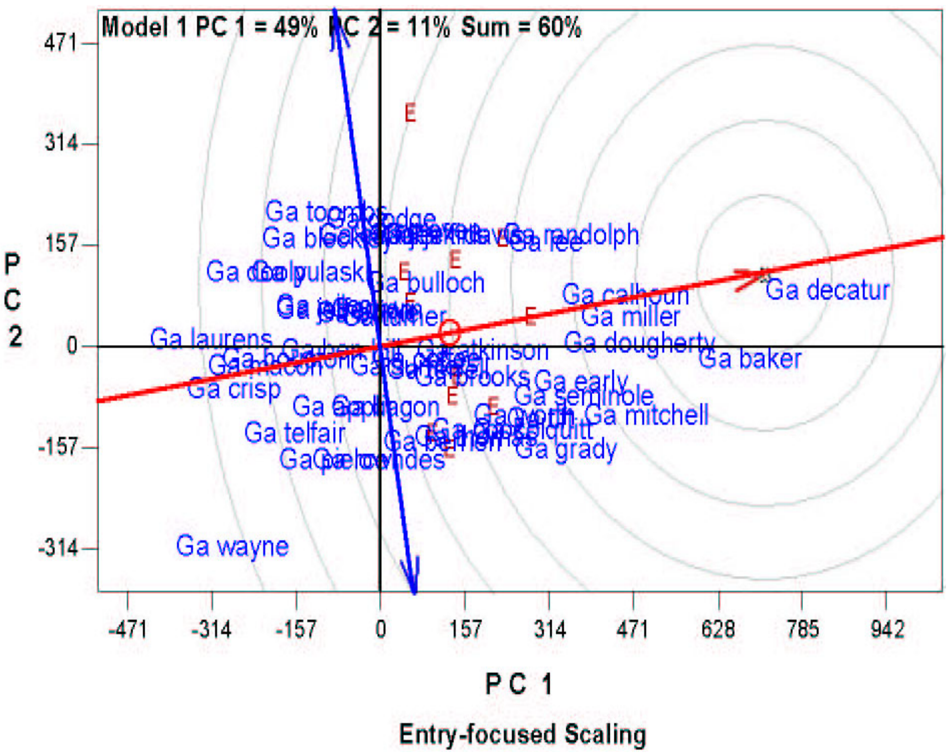

Figure 13. Location / Year GGEbiplot comparison of Georgia counties to the ideal location of Georgia using USDA-NASS County yield histories from 1988 to 1999. The ideal location, represented by the point shown with an arrow, is the most discriminating of genotypes and representative of the other locations.

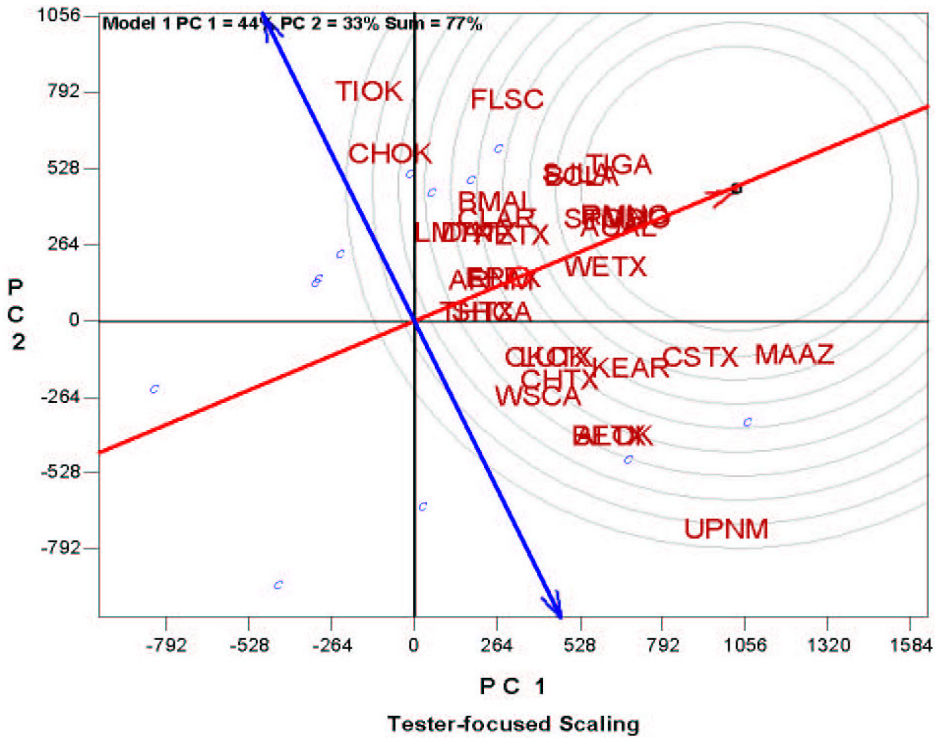

Figure 14. Genotype / Environment GGEbiplot comparison of the locations of the NCVT test to the ideal location using the check varieties. The ideal location, represented by the point shown with an arrow, is the most discriminating of genotypes and representative of the other locations.

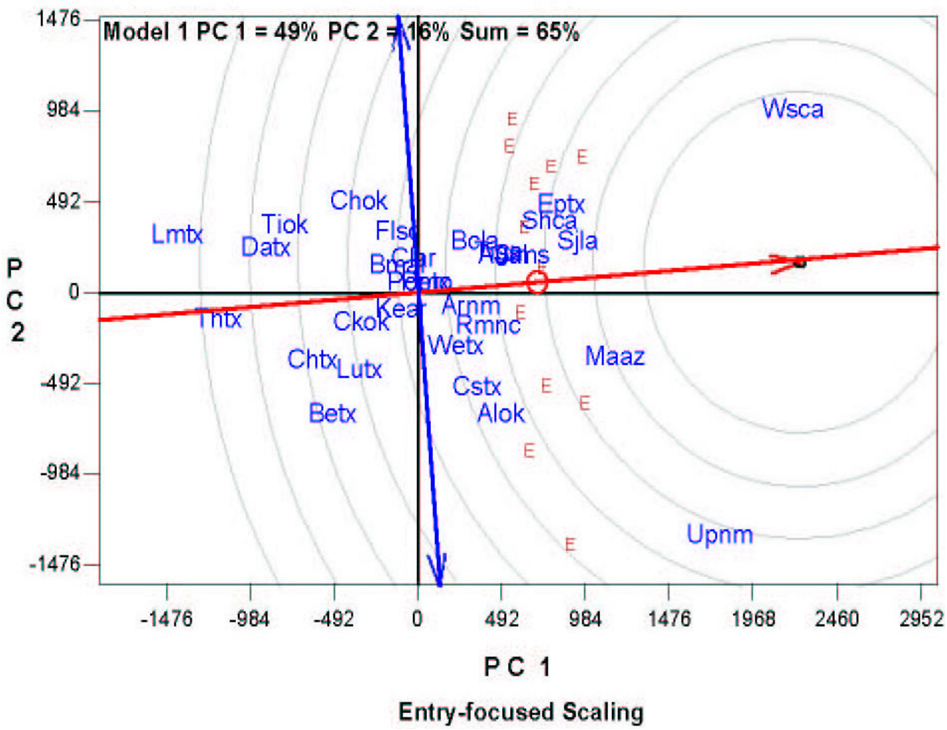

Figure 15. Location / Year GGEbiplot comparison of the locations of the NCVT test to the ideal location using the check varieties. The ideal location, represented by the point shown with an arrow, is the most discriminating of genotypes and representative of the other locations.

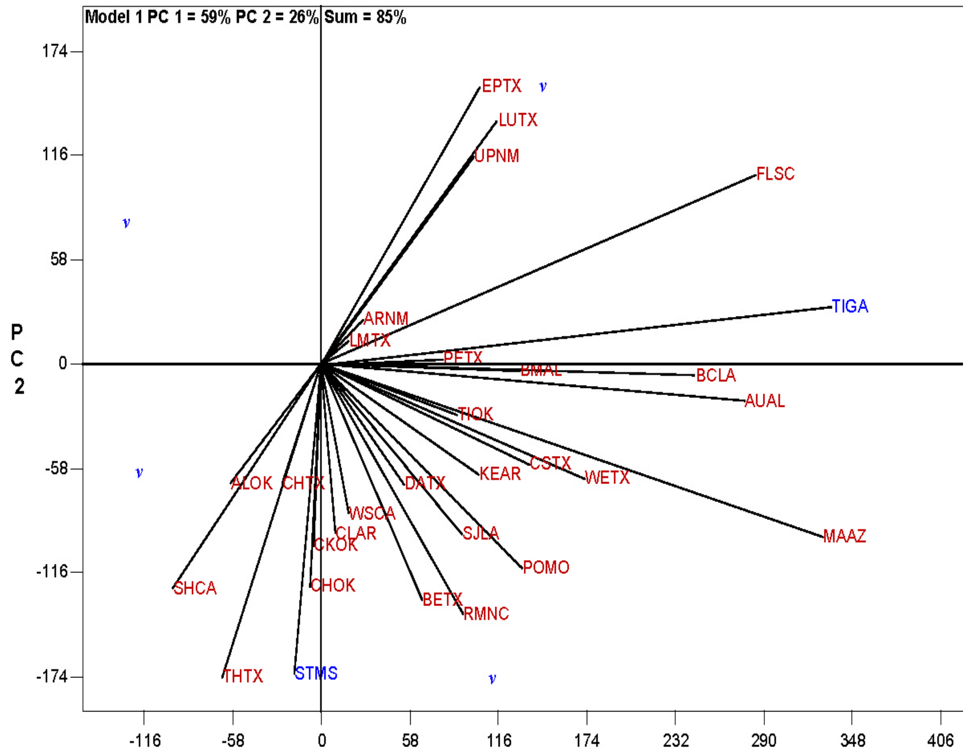

Figure 16. Genotype / Location GGEbiplot analysis using the check varieties showing the interrelationships of the locations of the NCVT from 1990 to 1995.

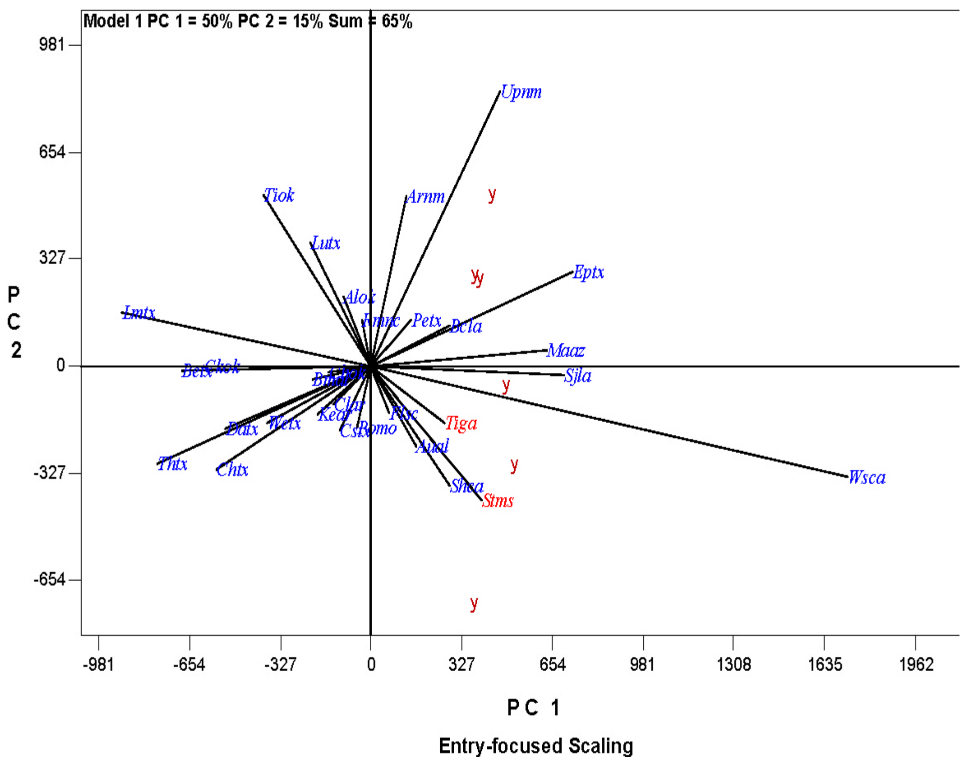

Figure 17. Location / Year GGEbiplot analysis using the check varieties showing the interrelationships of the locations of the NCVT from 1990 to 1995.

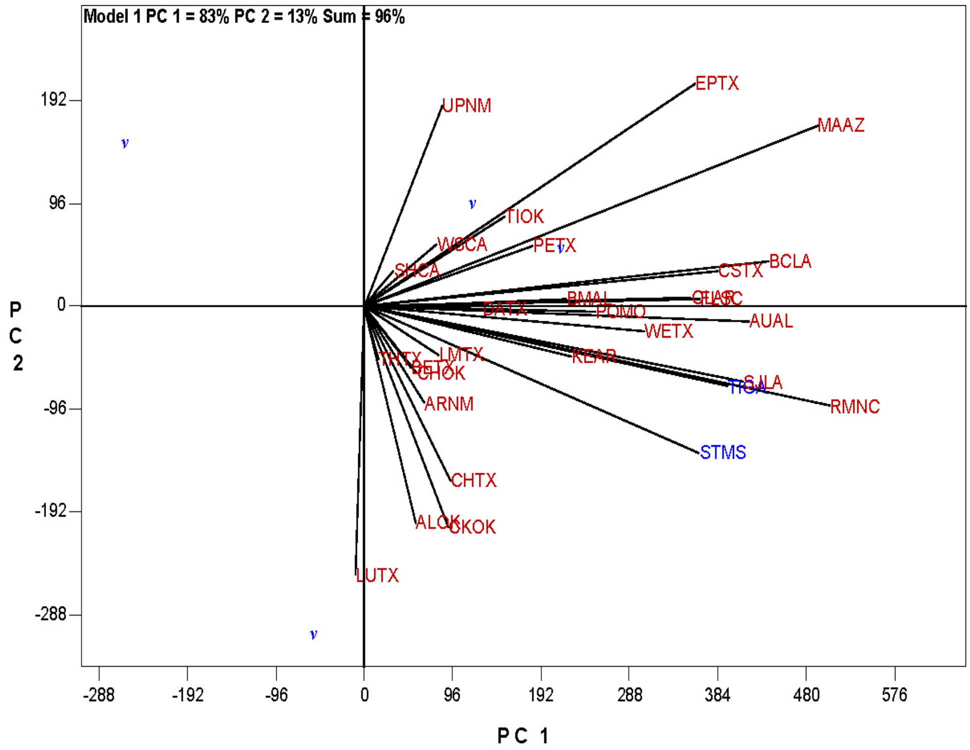

Figure 18. Genotype / Location GGEbiplot analysis using the check varieties showing the interrelationships of the locations of the NCVT from 1996 to 1998.

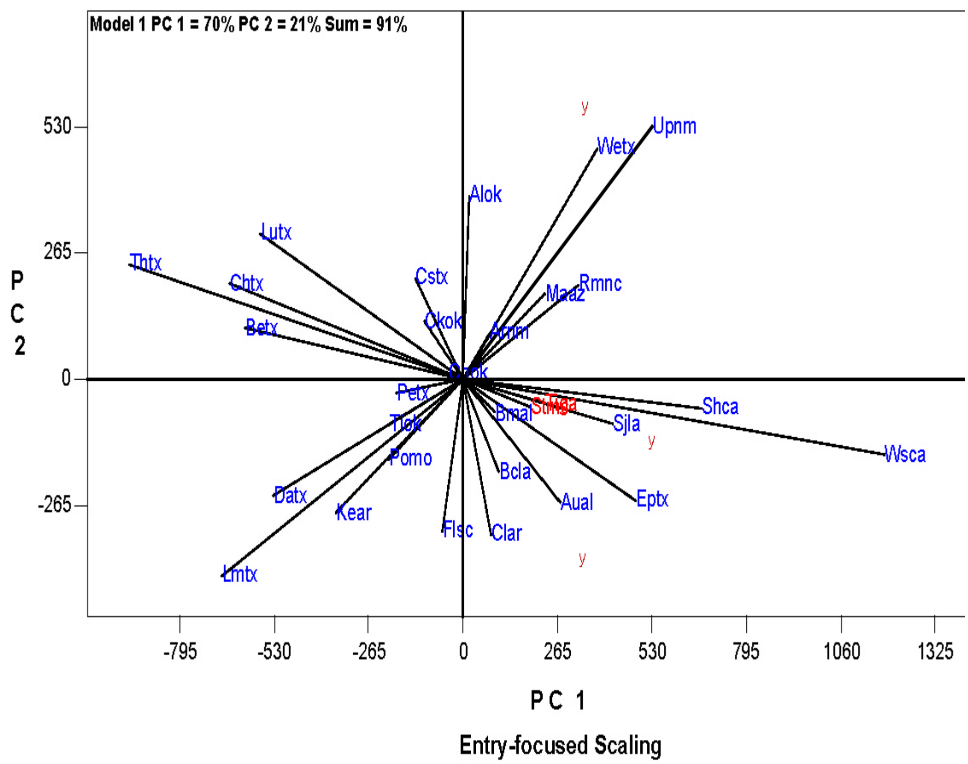

Figure 19. Location / Year GGEbiplot analysis using the check varieties showing the interrelationships of the locations of the NCVT from 1996 to 1998.

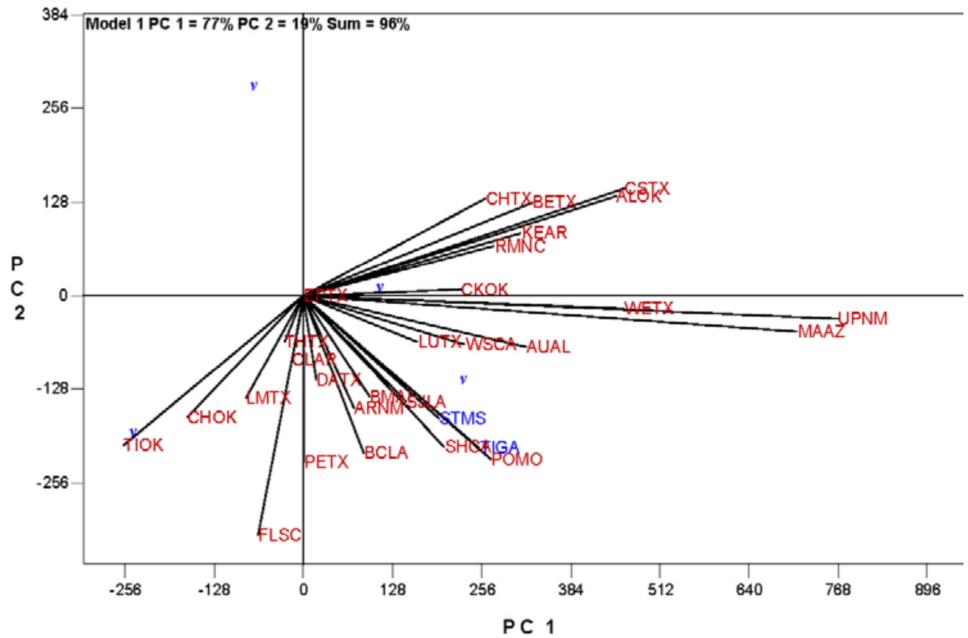

Figure 20. Genotype / Location GGEbiplot analysis using the check varieties showing the interrelationships of the locations of the NCVT from 1999 to 2001.

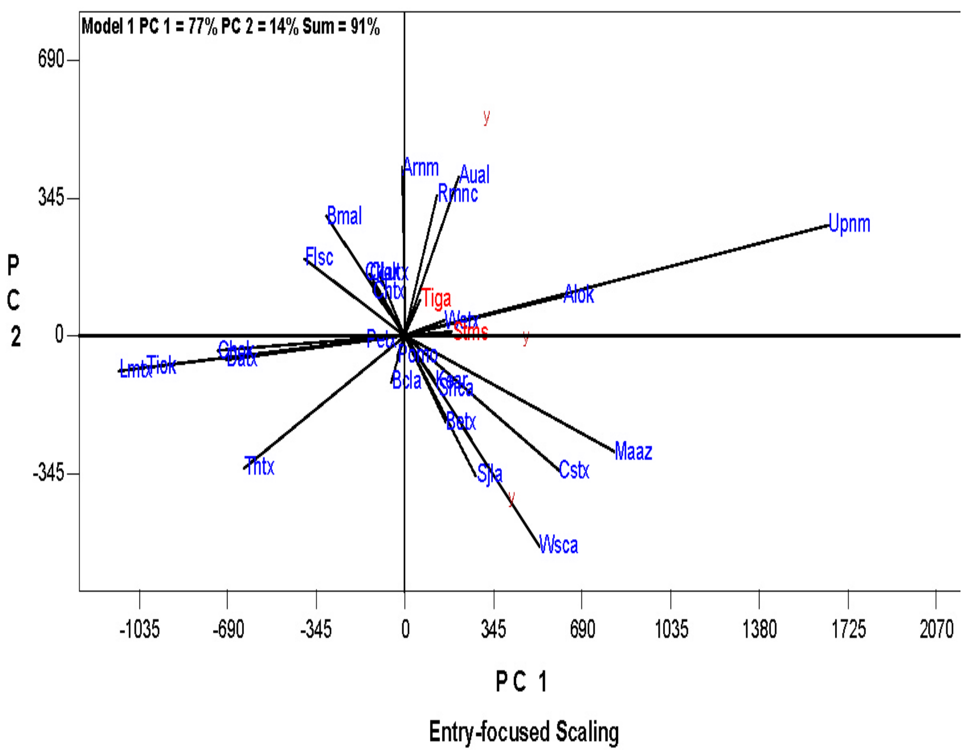

Figure 21. Location / Year GGEbiplot analysis using the check varieties showing the interrelationships of the locations of the NCVT from 1999 to 2001.