Comparison of Stability Statistics as Criteria for Cultivar Development in Peanut[1]

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ABSTRACT

Means of yield and qualitative traits are assessed in multi-location tests in the final stages of breeding line evaluation. Due to large environmental variation and genotype x environment interactions, it is often desirable to compare stability of lines over a range of environments. The objective of this study was to use various stability parameters to try and determine the stability of experimental breeding lines. Using data from regional advanced peanut (*Arachis hypogaea* L.) breeding line yield trials conducted over 3 years and four locations in Virginia and North Carolina, the stability of peanut cultivars and breeding lines was compared. Stability variance was found to be highly correlated (0.91-1.00) with covariate adjusted stability variance. In many instances, the stability-variance parameters produced similar results to pairwise regressions and dissimilarity measures when compared with standard cultivars. However, the distance parameters and regressions provided more precise information on relative responses in varying environments of two advanced breeding lines being considered for release. This allowed for direct comparison to cultivars targetted for replacement. NC 18411 had equal mean yields and qualitative traits but better stability than breeding line NC 18423. Regression analysis indicated that NC 18423 performed best in good environments but worse than most other cultivars in poor environments. Means and stability of value per kilogram and value per hectare were highly correlated with percentage of sound mature kernels and yield (0.92-0.99), respectively. A comparison of means and stability parameters was effective in discerning superiority of peanut breeding lines for potential release and use by growers.

Key Words: Genotype x environment interaction, regression, cultivar release, dissimilarity, groundnut, *Arachis hypogaea* L.

Stability parameters can be useful in assessing crop cultivars for potential release, especially when means of yield and quality traits over environments are very similar. Different concepts of stability have been proposed (1,2,3,7,10,11,12) and compared for various crops (6,7,8,9). Statistics have been developed corresponding to the basic concepts. Lin *et al.* (8) classified basic stability parameters into three main groups. Type 1 stability is analogous to homeostasis where a cultivar is stable if its among-environment variance is small. Statistics for type 1 are based on deviations from the average cultivar effect. A cultivar or line is considered stable by type 2 stability if its response to environments is parallel to the mean response of all lines included in the trial. Statistical procedures for measurement of response stability vary among authors (2,10,12). Both types of stability can be expressed in terms of regression of line performance on the environmental index (2). The type 3 stability parameters are generated from regressions on the environmental index and are measured by the residual mean squares from the regression model (2).

All three concepts have problems in interpretation and usefulness to breeders looking for appropriate stability in lines being considered for release. Homeostasis (type 1) is often associated with poor performance over a wide range of environments. Relative response to good or bad environments (type 2) is highly dependent on cultivars involved in the test and subsequently used as the environmental index. The inference that deviations from regressions (type 3) measure stability due only to unpredictable or uncontrollable irregularities may not be valid.

The interpretations and statistics of Eberhart and Russell (2) which involve both type 2 and type 3 parameters are commonly used in studies of stability in peanut (*Arachis hypogaea* L.). Singh *et al.* (13) found significant differences in the linear component of the genotype x environment interactions but nonsignificant deviations from regression among eight cultivars for yield. Similar results were found by Yadava and Kumar (14) for yield. Both linear regressions and deviations were significant for maturity and fruit characteristics (15).

If the objective is to find a cultivar that has close correlation over environments to a check or adapted genotype, then specific cultivar on cultivar regressions may be useful. Lin *et al.* (8) concluded that genotypic or environmental clustering procedures are effective in determining the relative distance test lines are from standard cultivars in genotypic response.

The objective of this paper was to evaluate stability of peanut breeding lines for yield and quality traits by using various stability statistics. Correlations of stability between traits were investigated to determine whether selection for stability for more than one trait would be possible.

Materials and Methods

Seven peanut genotypes were evaluated for the stability study by using data accumulated over 3 years (1985-87) and four locations (Martin and Northampton counties, North Carolina; City of Suffolk and Sussex County, Virginia) from the Virginia/North Carolina Peanut Variety and Quality Evaluation tests. The cultivars Florigiant, NC 7, NC 9, and NC 10C were used as checks. NC 18411, NC 18413, and NC 18423 were advanced breeding lines undergoing regional evaluation for potential release. The seven genotypes were among the 31, 30, and 32 genotypes evaluated in 1985, 1986, and 1987, respectively. Conventional harvesting was performed at an early and late harvest date approximately 2 weeks apart. The two harvest dates, four locations, and three years resulted in 24 different environmental conditions (Table 1). Experiments at each environment were conducted in a randomized complete block design with three replicates. Plots consisted of two rows 12.8 m in length spaced 91 cm apart with about 10 cm between plants within rows. Experiments were maintained in accordance with recommended cultural practices.

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Table 1. Soil types, precipitation, planting, and digging dates of environments.

	North Carolina		Virginia	
	Martin Co.	Northampton Co.	Sussex Co.	Suffolk
Soil type	Wagram SL	Norfolk LFS	Suffolk SL	Eunola LFS
		1985		
Planting date	5/6	5/1	5/13	5/7
Digging dates	9/18 & 10/1	9/18 & 10/1	9/24 & 10/8	9/19 & 10/2
Precipitation (cm.)	68.66	56.59	65.35	59.74
		1986		
Planting date	5/1	4/29	5/5	5/7
Digging dates	9/23 & 10/6	9/17 & 10/1	9/24 & 10/9	9/25 & 10/9
Precipitation (cm.)	53.54	42.93	52.98[a]	48.64
		1987		
Planting date	5/12	5/7	5/6	5/14
Digging dates	10/2 & 10/16	9/24 & 10/8	9/24 & 10/9	10/1 & 10/15
Precipitation (cm.)	56.01	46.13	41.15[a]	49.68

[a]Includes irrigation during July.

The following characteristics were evaluated after harvest and proper drying:

% fancy (FP): In-shell peanuts that ride the 13.5-mm spacing set on the presizer.

% extra large kernels (ELK): Kernels which ride an 8.5 x 25.4-mm screen.

% sound mature kernels (SMK): The whole undamaged kernels which ride a 6.0 x 25.4-mm slotted screen. Splits which ride this screen are put with the splits, either sound or damaged as may be the case.

Support price, dollars 100 kg^{-1} (DCWT): Taken from a standard price sheet for Virginia or runner-type peanuts (depending upon the percentage of fancy pods) taking the various grade factors into consideration.

Yield, kg ha^{-1}: Plot weights were obtained for each plot and converted to a hectare basis. All yields are net, adjusted to a standard 7% moisture with foreign material deducted.

Value, dollars ha^{-1}(DOLH): Computed by the following formula:

Value = [Yield - (% LSK) (Yield)] [Support price kg^{-1}]
+ Yield (% LSK) (\$.15 kg^{-1} LSK)

where % LSK = percent loose shelled kernels.

An analysis of variance over years, locations, and harvest dates was computed assuming replications, years, and locations were random effects while genotypes and harvest dates were fixed. The genotype x environment (GE) sum of squares was partitioned and all effects were tested versus appropriate error terms. Approximate error terms were constructed for testing harvest dates, genotypes, and harvest date x genotype interaction effects.

Stability-variance parameters ($\hat{\sigma}_i^2$ and $\hat{S}_i^2$) for each cultivar were estimated using the STABGEN program (5). The original parameters were as follows (12):

$$\hat{\sigma}_i^2 = [1/(s-1)(t-1)(t-2)] \times [t(t-1)\sum_{j=1}^{s}(\mu_{ij}-\bar{\mu}_{i.})^2 - \sum_{i=1}^{t}\sum_{j=1}^{s}(\mu_{ij}-\bar{\mu}_{i.})^2]$$

$$\hat{S}_i^2 = t/(t-2)(s-2)[S_i - \Sigma S_i/t(t-1)]$$

where $\mu_{ij} = Y_{ij} - \bar{Y}_{.j}$, $\bar{\mu}_{i.} = \sum_{j=1}^{s} \mu_{ij}/s$, s = number of environments, t = number of cultivars, Y_{ij} is trait value of the i^{th} cultivar in the j^{th} environment, $\bar{Y}_{.j}$ is mean of all cultivars in j^{th} environment, $S_i = \sum_{j=1}^{s}(\mu_{ij}-\bar{\mu}_{i.}-b_iZ_j)^2$ with b_i as a regression coefficient for the i^{th} cultivar, and $Z_j = \bar{Y}_{.j} - \bar{Y}_{..}$ with $\bar{Y}_{..}$ as the overall mean for all cultivars and all environments.

Simple correlation coefficients were determined between means, $\hat{\sigma}_i^2$ and $\hat{S}_i^2$ of trait 1 and 2 in all pairwise combinations. Correlation coefficients were also computed for means, $\hat{\sigma}_i^2$ and $\hat{S}_i^2$ within traits.

Pairwise dissimilarity measures were calculated on the basis of Euclidean distance of both genetic effects and GE interaction (4):

$$d^2(A)_{ii'} = \sum_{j=1}^{s}(Y_{ij}-Y_{i'j})^2,$$

and on GE interaction alone (1):

$$d^2(B)_{ii'} = \sum_{j=1}^{s}[(Y_{ij}-\bar{Y}_{i.}) - (Y_{i'j}-\bar{Y}_{i'.})]^2$$

where i and i' are the test and check cultivars, respectively.

Linear regression coefficients (b_i) and corresponding coefficients of determination (r_i^2) for all traits were computed by regressing test genotypes on individual check cultivar means and on environmental means for all seven genotypes.

Results and Discussion

An ANOVA table can give an initial indication of the importance of genetic and environmental factors, and GE interactions to specific traits (Table 2). Main effects for location were significant only for fancy pods. Year effects were significant only for fancy pods (FP) and sound mature kernels (SMK). The interactions of location x year and location x year x genotype were highly significant for all traits indicating the need for stability analysis on these traits. There were significant harvest date effects on SMK, extra large kernels (ELK), and dollars per kilogram weight (DCWT). Genotype main effects were significant for all traits except yield and dollars per hectare (DOLH). The mean squares of genotype for FP and ELK are larger than any other mean squares for these traits indicating that genetics plays a dominant role in the expression of these traits. Good stability in the form of homeostasis within and among locations suggested that heritabilities for these traits would be significant. The partitioning of GE effects indicates significant first and second-order interactions for all traits. Yield and subsequently DOLH were influenced by GE interactions (L x G, L x Y x G, L x Y x H x G). The significance of the second-order interaction (L x Y x H) and third-order interaction (L x Y x H x G) for yield and DCWT warrant using digging dates within location-year as separate environments. Maturity and pod loss can be different over years and locations depending on temperature and rainfall.

Table 2. Split plot analysis of variance for percentage of six traits with environments as main plots and genotypes as subplot treatments for Virginia/North Carolina Peanut Variety and Quality Evaluation tests.

Source	df	Mean squares[a]					
		FP	ELK	SMK	Yield (x 10^3)	DCWT	DOLH (x 10^2)
Location (L)	3	662*	590	149	12468	52.4	16425
Year (Y)	2	1581**	814	1883**	9694	12.3	9107
L * Y	6	116**	835**	181**	9318**	43.8**	10266**
Harvest date (H)	1	357	4959**	387*	2435	110.5**	7489
L * H	3	88	546	61	1654	8.8	2746
Y * H	2	350	104	74*	3451	15.9*	4166
L * Y * H	6	100**	137**	13*	989**	2.9	1035**
Error a	48	31	29	5	223	1.7	275
Genotype (G)	6	6827**	6314**	47**	679	16.0**	1057
L * G	18	42	51	6	544*	2.1*	642**
Y * G	12	237**	271**	16**	347	3.5**	548*
H * G	6	31	36	7	99	1.6	150
L * Y * G	36	39**	31**	5**	240**	1.0**	249**
L * H * G	18	19	16	2	39	0.5	42
Y * H * G	12	22	18	4	97	1.3	147
L * Y * H * G	36	22**	11	2	126**	0.6*	132**
Error b	240	11	9	2	35	0.4	47

[a]FP = fancy pods, ELK = extra large kernels, SMK = sound mature kernels, yield in kg ha^{-1}, DCWT = support price in \$ 100 kg^{-1}, and DOLH = value in \$ ha^{-1}.

*,** Significant at the 5 and 1% probability levels, respectively.

NC 7 had the greatest mean percentage of fancy pods, extra large kernels, and sound mature kernels (Table 3). No significant differences for yield and dollars per hectare were obtained by ANOVA (Table 2). However, the greatest values were exhibited by two of the advanced breeding lines NC 18411 and NC 18423. A consistent 3 to 4% yield increase and 5 to 6% increase in DOLH on average over numerous environments is often enough to consider release of a cultivar. NC 18423 was the most unstable for FP, SMK, and DCWT for both stability parameters and the most unstable for yield and DOLH under the stability variance ($\hat{\sigma}_i^2$). NC 10C showed the greatest variability over environments for ELK, while NC 18413 was most unstable for yield and DOLH via the covariant-adjusted stability parameter ($\hat{S}_i^2$).

Table 3. Mean, stability variance (σ_i^2), and covariant-adjusted stability variance (S_i^2) for six traits over 24 environments.[1]

Cultivar	$\bar{x}$	σ_i^2	S_i^2	$\bar{x}$	σ_i^2	S_i^2	$\bar{x}$	σ_i^2	S_i^2
		% FP			% ELK			% SMK	
Florigiant	77.3c	25.8**	23.2**	31.6d	10.8	9.3	66.3d	1.95	1.37
NC 7	89.2a	52.5**	16.5	53.0a	70.1**	47.0**	68.6a	4.06**	4.31**
NC 9	86.3b	21.9**	24.2**	36.4c	31.3**	22.9**	67.6bc	3.35*	3.29*
NC 18411	69.7d	35.0**	36.7**	38.2b	21.6**	23.5**	68.3ab	3.36*	3.33*
NC 18413	85.6b	16.8	18.9*	35.0c	44.9**	37.3**	67.1c	4.88**	5.16**
NC 10C	78.9c	34.4**	37.1**	21.4e	78.1**	73.7**	67.0c	5.51**	4.87**
NC 18423	62.2e	147.3**	143.8**	36.1c	66.6**	70.8**	68.0ab	11.65**	11.42**
σ_e^2		10.5			8.7			2.00	
		Yield, kg ha^{-1}			DCWT, \$ 100 kg^{-1}			DOLH, \$ ha^{-1}	
Florigiant	4702[2]	103174**	76943**	64.7d	0.40	0.41	3033[2]	11189**	7787*
NC 7	4637	138801**	143034**	67.6a	0.99**	1.04**	3082	15082**	15458**
NC 9	4752	113013**	123532**	60.0c	0.57*	0.60*	3116	11111**	12112**
NC 18411	4868	116596**	126635**	66.7bc	1.16**	1.22**	3225	17151**	18587**
NC 18413	4751	373519**	390989**	65.8cd	1.10**	1.10**	3109	50203**	52943**
NC 10C	4538	186665**	165959**	65.2d	1.05**	1.09**	2955	21249**	19144**
NC 18423	4803	406155**	265767**	67.1b	3.38**	3.53**	3200	52972**	38072**
σ_e^2		35443			0.36			4739	

[1]Refer to Table 2 for definition of traits. Duncan's New Multiple Range Test at the 0.05 level. Means showing the same letter(s) are not statistically different.

[2]Duncan's New Multiple Range Test was not used due to nonsignificance from analysis of variance.

Correlations of stability parameters indicate that assessment of stability of SMK or FP could approximate stability of DCWT (Table 4). Percentage of SMK has a large influence on determining the value of peanuts as was shown by the correlation of SMK and DCWT means. The relationship of means and stability between yield and dollar value per hectare was also noteworthy. In assessment of elite material often seed quality for shellers (SMK, ELK) has been achieved through previous selection so that yields play a much greater role in net value.

Table 4. Simple correlation coefficients (r_s) between means ($\bar{x}$), estimated stability-variance statistics (σ_i^2), and estimated stability-variance statistics following a covariate correction (S_i^2) of pairwise combinations of traits.[a]

Statistics correlated	Trait	ELK	SMK	Yield	DCWT	DOLH
$\bar{x}$ vs. $\bar{x}$	FP	0.28	-0.09	-0.49	-0.12	-0.49
σ_i^2 vs. σ_i^2		0.46	0.91**	0.58	0.95**	0.56
S_i^2 vs. S_i^2		0.57	0.90**	0.27	0.96**	0.36
$\bar{x}$ vs. $\bar{x}$	ELK		0.74	0.27	0.80*	0.49
σ_i^2 vs. σ_i^2			0.61	0.44	0.47	0.38
S_i^2 vs. S_i^2			0.76*	0.40	0.66	0.39
$\bar{x}$ vs. $\bar{x}$	SMK			0.32	0.96**	0.64
σ_i^2 vs. σ_i^2				0.81*	0.97**	0.78*
S_i^2 vs. S_i^2				0.57	0.97**	0.62
$\bar{x}$ vs. $\bar{x}$	Yield				0.35	0.92**
σ_i^2 vs. σ_i^2					0.76*	0.99**
S_i^2 vs. S_i^2					0.45	0.99**
$\bar{x}$ vs. $\bar{x}$	DCWT					0.68
σ_i^2 vs. σ_i^2						0.75*
S_i^2 vs. S_i^2						0.52

[a]Refer to Table 2 for definition of traits.

*,** Significant at the 5 and 1% probability levels, respectively.

The two stability parameters ($\hat{\sigma}_i^2$) and ($\hat{S}_i^2$) were highly correlated for all traits (Table 5) indicating that heterogeneity of responses within environment were minimal. Yield had the lowest correlation (0.91) of stability parameters among the traits, thus was more conducive to differential response among cultivars within environment. This is understandable considering the amount of influence the environment and GE interactions have on yields.

Table 5. Simple correlation coefficients (r_s) between means ($\bar{x}$), estimated stability-variance (σ_i^2), and estimated stability-variance following a covariate correction (S_i^2) within six traits.[a]

Statistics correlated	FP	ELK	SMK	Yield	DCWT	DOLH
$\bar{x}$ vs. σ_i^2	-0.70	0.03	0.28	0.20	0.52	0.33
$\bar{x}$ vs. S_i^2	-0.82*	-0.20	0.35	0.16	0.53	0.30
σ_i^2 vs. S_i^2	0.95**	0.94**	0.99**	0.91**	1.00**	0.95**

[a]Refer to Table 2 for definition of traits.

*,** Significant at the 5 and 1% probability levels, respectively.

Comparisons with standard cultivars are necessary when lines are considered for release. In some instances a specific cultivar may be the target for replacement. Besides assessing means of traits, it is useful to compare responses to different environments. Genotype on genotype regressions (3) or distance parameters (1,4) may be appropriate. It is necessary to acknowledge differences in distance parameter techniques. If $d^2(A)_{ii'}$ and $d^2(B)_{ii'}$ are compared for the same trait, large differences in rank may occur. Distance due to response over environments [$d^2(B)_{ii'}$] is included with genotypic differences in $d^2(A)_{ii'}$. One example in the major discrepancy between measures can be shown by comparing distance measures of NC 10C from NC 7 for ELK (Table 6). Though NC 10C is the farthest removed from NC 7 via $d^2(A)_{ii'}$ they are the most similar in response over environments [$d^2(B)_{ii'}$]. As one would expect, the mean differences for ELK between NC 10C and NC 7 was extremely large (Table 3). The two distance parameters were comparable for yield where GE effects comprised a much greater proportion of the variation.

The choice of distance parameter is directly related to the purpose of comparisons. If a breeder is looking for a line to replace NC 7 which has a high ELK, one may wish to have both genetic similarity and parallel response over environments. One would thus choose NC 18411 based on $d^2(A)_{i\ NC\ 7}$ rather than NC 10C which is closest to NC 7 in response over environments [$d^2(B)_{i\ NC\ 7}$]. On the other hand, a breeder would want genetic dissimilarity for yield (*i.e.*, greater means) but similarity of response to a genotype in question and $d^2(B)_{ii'}$ would be the most useful together with a means comparison.

Regression coefficients may be useful in determining the relative response of a line. Coefficients of less than one indicate relative homeostatic response and values greater than one are attributed to more extreme responses to environments. Genotypes in this category

Table 6. Distance parameters of peanut genotypes measured from three standard cultivars.

Trait[a]	Genotype	Florigiant $d^2(A)_{ii'}$	Florigiant $d^2(B)_{ii'}$	NC 7 $d^2(A)_{ii'}$	NC 7 $d^2(B)_{ii'}$	NC 9 $d^2(A)_{ii'}$	NC 9 $d^2(B)_{ii'}$
FP	Florigiant	--	--	4008.5(4)	626.6(4)	2285.1(4)	363.3(2)
	NC 7	4008.5(5)[b]	626.6(5)	--	--	845.3(2)	637.1(5)
	NC 9	2285.1(4)	363.3(1)	845.3(1)	637.1(5)	--	--
	NC 18411	1941.2(2)	413.8(3)	9685.3(5)	559.0(3)	7475.4(5)	499.8(3)
	NC 18413	2094.7(3)	471.5(4)	851.5(2)	528.5(2)	294.1(1)	282.6(1)
	NC 10C	437.8(1)	383.2(2)	2994.0(3)	462.4(1)	1818.3(3)	512.9(4)
	NC 18423	6737.7(6)	1271.6(6)	19239.5(6)	1700.7(6)	14388.1(6)	1088.1(6)
ELK	Florigiant	--	--	11607.7(5)	590.5(3)	889.6(4)	330.4(2)
	NC 7	11607.7(6)	590.5(5)	--	--	7639.9(6)	1038.0(6)
	NC 9	889.6(2)	330.4(2)	7639.9(3)	1038.0(4)	--	--
	NC 18411	1305.6(4)	268.5(1)	5777.9(1)	546.1(2)	509.8(2)	432.1(3)
	NC 18413	767.5(1)	478.0(3)	8824.8(4)	1150.5(5)	329.1(1)	284.9(1)
	NC 10C	3149.0(5)	679.9(6)	24373.1(6)	461.4(1)	6387.6(5)	1005.7(5)
	NC 18423	1027.4(3)	541.1(4)	7587.3(2)	1305.4(6)	537.6(3)	534.8(4)
SMK	Florigiant	--	--	182.2(6)	49.7(1)	79.9(4)	38.6(1)
	NC 7	182.2(6)	49.7(3)	--	--	92.8(5)	62.0(5)
	NC 9	79.9(3)	38.6(2)	92.8(2)	62.0(3)	--	--
	NC 18411	159.6(4)	59.2(4)	55.2(1)	52.4(2)	60.3(1)	50.8(2)
	NC 18413	75.6(2)	63.4(5)	119.6(4)	72.5(4)	65.7(2)	58.7(3)
	NC 10C	54.9(1)	32.0(1)	143.3(5)	84.6(5)	65.8(3)	60.4(4)
	NC 18423	178.6(5)	102.7(6)	112.6(3)	109.3(6)	130.5(6)	126.9(6)
Yield	Florigiant	--	--	1720.3(1)	1638.3(2)	1970.4(2)	1922.6(3)
	NC 7	1720.3(1)	1638.3(2)	--	--	1822.3(1)	1599.0(1)
	NC 9	1970.4(3)	1922.6(4)	1822.3(2)	1599.0(1)	--	--
	NC 18411	2061.2(4)	1678.1(3)	3054.5(4)	2191.6(4)	2117.2(3)	1861.8(2)
	NC 18413	4384.6(5)	4343.7(5)	3814.8(5)	3438.3(5)	3508.5(4)	3513.8(5)
	NC 10C	1884.8(2)	1370.4(1)	2284.3(3)	2174.5(3)	4056.0(6)	3180.6(4)
	NC 18423	4902.0(6)	4704.2(6)	5957.5(6)	5413.7(6)	3831.5(5)	3785.2(6)
DCWT	Florigiant	--	--	NC	12.7(2)	NC	10.8(5)
	NC 7	NC	12.7(4)	--	--	NC	10.0(2)
	NC 9	NC	10.8(2)	NC	10.0(1)	--	--
	NC 18411	NC	17.8(5)	NC	16.4(5)	NC	12.4(4)
	NC 18413	NC	12.1(3)	NC	16.4(4)	NC	8.7(1)
	NC 10C	NC	10.2(1)	NC	13.1(3)	NC	11.2(3)
	NC 18423	NC	33.0(6)	NC	27.9(6)	NC	32.8(6)
DOLH	Florigiant	--	--	NC	171.7(1)	NC	200.2(2)
	NC 7	NC	171.7(2)	--	--	NC	193.2(1)
	NC 9	NC	200.2(3)	NC	193.2(2)	--	--
	NC 18411	NC	202.9(4)	NC	286.7(4)	NC	213.3(3)
	NC 18413	NC	464.3(5)	NC	428.4(5)	NC	383.2(5)
	NC 10C	NC	141.6(1)	NC	244.7(3)	NC	360.8(4)
	NC 18423	NC	605.4(6)	NC	618.7(6)	NC	439.6(6)

[a]Refer to Table 2 for definition of traits.

[b]Number in parentheses is ranking in order of closest to furthest distance.
NC = not computed.

Table 7. Linear regression coefficients (b_{YX}) and coefficients of determination (r^2) of genotype on genotype responses over environments.

Trait[a]	Genotype	Florigiant b_i	Florigiant r^2	NC 7 b_i	NC 7 r^2	NC 9 b_i	NC 9 r^2	Mean b_i	Mean r^2
FP	Florigiant	--	--	0.19	0.18	0.85	0.52	1.27	0.78
	NC 7	0.93	0.18	--	--	0.06	0.01	0.25	0.15
	NC 9	0.61	0.52	0.21	0.01	--	--	1.01	0.69
	NC 18411	0.71	0.51	0.76	0.21	0.64	0.37	1.13	0.66
	NC 18413	0.64	0.41	0.81	0.04	0.92	0.53	0.98	0.71
	NC 10C	0.72	0.52	0.86	0.24	0.44	0.29	0.95	0.58
	NC 18423	0.47	0.22	0.44	0.01	0.75	0.29	1.40	0.48
ELK	Florigiant	--	--	0.99	0.47	0.78	0.77	1.15	0.92
	NC 7	0.47	0.47	--	--	0.30	0.25	0.56	0.46
	NC 9	0.99	0.77	0.81	0.25	--	--	1.28	0.89
	NC 18411	0.87	0.57	0.76	0.37	0.64	0.70	0.94	0.80
	NC 18413	0.95	0.68	0.81	0.23	0.92	0.81	1.28	0.84
	NC 10C	0.58	0.43	0.86	0.47	0.44	0.33	0.74	0.50
	NC 18423	0.82	0.60	0.44	0.08	0.75	0.64	1.04	0.67
SMK	Florigiant	--	--	1.01	0.87	1.11	0.91	1.12	0.97
	NC 7	0.86	0.87	--	--	0.96	0.80	1.00	0.91
	NC 9	0.81	0.91	0.83	0.80	--	--	0.93	0.92
	NC 18411	0.79	0.85	0.85	0.84	0.91	0.82	0.93	0.92
	NC 18413	0.87	0.85	0.92	0.80	1.00	0.82	1.02	0.90
	NC 10C	0.99	0.91	1.00	0.79	1.13	0.86	1.13	0.92
	NC 18423	0.75	0.73	0.79	0.68	0.80	0.57	0.88	0.77
Yield	Florigiant	--	--	0.76	0.74	0.70	0.75	0.82	0.88
	NC 7	0.97	0.74	--	--	0.81	0.79	0.92	0.85
	NC 9	1.06	0.75	0.97	0.79	--	--	1.02	0.89
	NC 18411	1.04	0.77	0.87	0.70	0.83	0.76	0.97	0.87
	NC 18413	1.04	0.55	1.00	0.65	0.91	0.64	1.05	0.72
	NC 10C	0.91	0.76	0.76	0.67	0.65	0.58	0.83	0.80
	NC 18423	1.39	0.71	1.14	0.61	1.15	0.73	1.37	0.88
DCWT	Florigiant	--	--	0.80	0.72	0.85	0.78	0.98	0.89
	NC 7	0.90	0.72	--	--	0.83	0.65	0.99	0.81
	NC 9	0.91	0.78	0.79	0.65	--	--	1.00	0.87
	NC 18411	0.83	0.59	0.79	0.60	0.86	0.68	0.99	0.79
	NC 18413	0.99	0.74	0.86	0.63	0.98	0.77	1.09	0.83
	NC 10C	0.83	0.66	0.76	0.62	0.75	0.59	0.91	0.75
	NC 18423	0.88	0.47	0.81	0.47	0.78	0.40	1.01	0.61
DOLH	Florigiant	--	--	0.35	0.46	0.71	0.78	0.82	0.89
	NC 7	1.33	0.46	--	--	1.05	0.45	1.13	0.43
	NC 9	1.10	0.78	0.43	0.45	--	--	1.03	0.90
	NC 18411	1.08	0.77	0.46	0.53	0.87	0.77	1.00	0.86
	NC 18413	1.06	0.58	0.26	0.14	0.91	0.66	1.04	0.73
	NC 10C	0.94	0.77	0.29	0.29	0.67	0.60	0.84	0.81
	NC 18423	1.37	0.68	0.57	0.45	1.15	0.74	1.35	0.86

[a]Refer to Table 2 for definition of traits.

may do extremely well in good environments but very poorly in bad environments with similar overall means. Given the unpredictable nature of rainfall, temperature, and pest damage, coefficients of one or less would be desirable for insuring crop success. Evaluation of regression coefficients are not always effective if deviations from regression are large (low r^2). Traits such as percentage of fancy pods and ELK are examples where linear regressions poorly represent the GE response (Table 7). However, linear regression accounted for most of the GE variation for percent SMK, yield, DCWT, and DOLH except for regressions involving NC 7. Regression coefficients of NC 18423 for yield and DOLH were greater than one (except $b_{i\ NC\ 7}$ for DOLH), indicating good performance in good environments but poor performance in poor environments.

In previous studies, linear regression explained most of the genotype x environment interaction in yield (14,15). The major problem with using the standard stability measures (b_i and $S^2_{d_i}$) of Eberhart and Russell (2) is the high dependency on the cultivars used in the test. This study used seven genotypes and in most cases only a few test genotypes will survive varietal testing over a number of years. Test genotype on check cultivar regression may thus be more useful. However, the distance parameters have an advantage of taking into account all components of the G x E interaction into one measure rather than two components of linear regression (b_{ij} and $S^2_{d_i}$).

NC 18411 was consistently more stable than NC 18423 on the basis of consistent response over environments (Table 3) and compared to the check cultivars (Table 6). Inspection of the data and regression coefficients (Table 7) indicates that NC 18423 generally outyielded other entries in good environments but responded negatively to poor environments resulting in a mean yield close to the more stable NC 18411. The relative stability of NC 18411 to NC 18423 is not due to pedigrees. Both have similar coefficients of parentage to Florigiant (Table 8). Florigiant was the most stable genotype over environments (Table 3) for all traits except for fancy pods. Based on genetic relatedness, NC 7 would be expected to be the most dissimilar to Florigiant. Predictions hold only for ELK and SMK [$d^2(A)_{i\ Flor}$] (Table 6). There is no case where NC 7 is the most distant from Florigiant based on GE only [$d^2(B)_{ii'}$]. In fact, for ELK the most closely related line (NC 10C) is the most distant in performance. Thus stability cannot be attributed to genetic relatedness in this study.

Table 8. Pedigree and coefficients of parentage (θ) with Florigiant of entries.

Cultivar or line	Pedigree	θ x 100 Florigiant
Florigiant	(Jenkins Jumbo x F 230) x F 334	100
NC 7	NC 5 x Fla 393	22
NC 9	NC 2 x Florigiant	53
NC 18411	(Florigiant x NC 5) x (Florigiant x Valencia)	50
NC 18413	(Florigiant x Florunner) x (Ac 3139 x Florigiant)	61
NC 10C	(Ac 3139 x Florigiant) x Florigiant	75
NC 18423	(Florigiant x Florunner) x Early Bunch	52

In summary, stability parameters indicated differences in responses of genotypes over environments for all traits. However, Shulka's (12) statistics ($\hat{\sigma}^2$and $\hat{S}^2$) are highly dependent on genotypes involved and inferences are thus restricted. Stability of DCWT was highly correlated with stability of percentage of SMK and FP, while stabilities of yield and DOLH were also highly correlated. Pairwise distance measures $[d^2(B)_{ii'}]$ combine all components of genotypes x environment interaction between cultivars into one value and would be an appropriate measure of stability for most purposes. Genotype on genotype regression coefficients are limited in usefulness by the fit to the linear regression model (r^2). NC 18423 is considered the most unstable over environments when comparing stability statistics and comparing against standard cultivars $[d^2(B)_{ii'}]$. Using the information on means and stability, NC 18411 would be the most favorable breeding line for release. NC 18423 would be useful only to growers who are prepared to insure excellent growing conditions with high inputs such as irrigation and pest control.

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