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Research Note

Studies on Genotype x Environment interaction and stability for yield in soybean (*Glycine max* (L.) Merrill)

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Abstract
The present investigation was carried out to study stability performance over three environments for yield and its components in seven elite pipeline soybean genotypes using a randomized complete block design. The mean sum of squares due to genotype and environments (linear) differed significantly. However, higher magnitude of mean squares due to environments indicated considerable differences between environments for all traits. Similarly, the MSS for Genotype x Environment was found to be significant for all the traits expect for number of pods per plant. Based on the stability parameters the genotype Dsb-21 was found to be widely adapated whereas Dsb-19 and JSS-335 a popular variety among the farmers performed better under favorable conditions.

Keywords
Soybean, G X E interaction, stability analysis, regression, yield.

Soybean (*Glycine max* (L.) Merrill) is an important grain legume crop in the world and known as "miracle bean". It contains 40% high quality protein and 20 % oil and contributes to about 58 % of the global oil seed production. It is a source of raw material for manufacturing antibiotics, paints, adhesives and lubricants etc.

Soybean occupies an area of 113.10 m ha producing 283.79 mt with the productivity of 2509 kg ha^{-1} in the world. In India, it occupies an area of 12.03 m ha with the production of 12.45 mt and productivity of 1035 kg ha^{-1}. Whereas, in Karnataka, soybean is grown over an area of 0.25 m ha with a production of 0.30 mt and productivity of about 1215 kg ha^{-1} (Anon., 2013).

The productivity of soybean of soybean in India is low compared to the global productivity level mainly due to short growing periods, limited varietal stability, and narrow genetic base (Singh and Hymowitz, 2001). Increasing yields is a challenge that needs to be resolved through promotion of high yielding varieties, tolerant to biotic (Asian rust) and abiotic stress. These improved varieties should have stable yield levels and widely adaptability to be adopted by farmers. It is a known fact that the genotypes performing well under a particular environment may not perform well over other environments due to genotype-environment interactions (GEI). A proper understanding of the magnitude and nature of G x E interaction and stability of the complex traits like yield and yield components in soybean would be of great help in identifying stable varieties.

Various techniques have been developed to reveal patterns of G x E interaction such as joint regression (Finlay and Wilkinson, 1963; Perkins and Jinks, 1968), sum of squared deviations from regression (Eberhart and Russel, 1966), stability variance (Shukla, 1972), coefficient. These methods are commonly used to analyze multi-location environment trials data to reveal patterns of G x E interaction. In view of the above facts, an attempt was made to evaluate soybean genotypes for yield and its components characters under different environments to identify genotypes with stable performance in variable environments.

The present experiment was carried out during *Kharif* season at Agriculture Research Station, Arabhavi during the year 2010, 2011 and 2012. Arabhavi is located in Northern dry zone (Zone III) of Karnataka. Geographically it lies at 16°12' N latitude and 74°57' E longitude with an altitude of 640 m above sea level. The soils are sandy loam type with pH of 7.2. In all the three years the trial was sown during the first fortnight of June month. Totally there were seven test entries in the trial with six elite soybean genotypes which were in the process of identification for release along with JS-335 a popular variety with farmers was used as check. Each entry was raised in six rows of 4 m length with spacing of 30 cm X 10 cm in three replications under irrigation. The entire recommended package was followed to raise a healthy crop.

Meteorological data on Temperature (Min/Max), Relative Humidity (%) and Rainfall (mm) was also collected (Table. 1) from the weather monitoring system in the station during the crop growth period from all the three years to know the influence weather parameters on growth and yield of soybean. Observations were recorded on ten randomly selected plants for plant height (cm), and No of pods per plant. Whereas, 100 seed wt (g), and plot yield (kg) were taken after harvest and sun drying from each entry and replication wise and the yield per plot was converted into grain yield (q/ha).

The data was compiled for all the three years and combined analysis of variance (ANOVA) was used to determine the effects of genotype (G), environment (E) and genotype by environment (GE) interaction using the SPAR-2 statistical package and the genotypes were assessed for their stability of performance across environments following the method described by Eberhart and Russell (1966).

Among the stability methods in multivariate statistics, the additive main effects and multiplicative interaction (AMMI) analysis is widely used for GEI investigation as it clearly separates main and interaction effects and often provides meaningful interpretation of data(Bose *et al.,* 2014).The AMMI analysis is as below

$$Y_{ij} = \mu + g_i + e_j + \sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij}$$

where Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment, g_i is the i^{th} genotype mean deviation, e_j is the j^{th} environment mean deviation, λ_k is the square root of the eigen value of the PCA axis k, α_{ik} a and λ_{jk} are the principal component scores for PCA axis k of the i^{th} genotype and the j^{th} environment, respectively and ε_{ij} e is the residual (Zobel *et al*., 1988).

Sustainability index (SI) was calculated by the following the formula suggested by Babarmanzoor et al., 2009. SI= [(Y-σn)/YM] X100 where Y is the mean performance of a genotype, σn is the standard deviation**,** and YM is the best performance of a genotype in any year. This index is used to select stable genotypes by various authors (Singh and Agarwal, 2003; Gangawar *et al.,* 2004 and Tuteza, 2006)

The metrological data from the Research station indicates that the Min and Max temperature were slightly on the higher side compared to normal (Table-1) which favoured better germination and establishment during all the three seasons. Similarly higher RH% and higher rainfall during July month was influential in putting up higher vegetative growth and increased test weight due to development of bold seeds.

The mean performance of the genotypes across environments indicated that Dsb-21 recorded highest per plot yield of 2.57 kg followed by Dsb-19 with 2.36 kg. Whereas, JS-335 the check entry recorded 2.07 kg only (Table. 2). The test entry Dsb-20 recorded highest no of pods/plot with 72.9 pods and the check entry JS-335 recorded only 39.24 pods/plant. 100 seed weight was highest in Dsb-22 at 18.11 g followed by Dsb-19 (17.88) and JS-335 recorded 16.55 g whereas Dsb-12 recorded the lowest 100 seed wt with 13.55 g. Higher test weight in these trials may be due to high relative humidity and temperature coupled with irrigation. The performance of these genotypes is looked across the environments, the highest plant height was observed in E1 environment (2010) and the mean plot yield was highest across genotypes during 2011 i.e. E2 environment as compared to 2010 and 2012 (Table. 3). This may be attributed to the even distribution of rainfall during 2011, lower pan evapouration and higher RH %.

From the combined analysis of variance (ANOVA) to know the Genotype x Environment interaction, the mean sum of squares was found to be significant for Genotypes and environments for all the traits (Table. 4). However, higher magnitude of mean squares due to environments indicates considerable differences between environments for all traits indicating that these characters were greatly influenced by environments. These results are in agreement with the earlier findings of Dillion *et al.* (2009). Similarly, the MSS for Genotype x Environment was found to be significant for all the traits expect for number of pods per plant indicating that genotypes perform differentially in different environments. The presence of genotype x environment interaction indicates that the phenotypic expression of one genotype might be superior to another genotype in one environment but inferior in different environment which further complicates the selection of superior genotypes for a target population. The presence of significant genotype x environment interaction is justified from the principal component analysis (PCA) wherein, nearly 90.0% of the interaction could be explained by first PCA and second PCA (Table-5). This is in accordance with Gauch and Zobel (1996) who suggested that first two IPCA's cumulatively explain > 90 % of the variation then there is presence of significant G x E interaction.

Stability analysis was carried out for plot yield trait by employing the linear regression model proposed by Eberhart and Russell (1966) to identify stable genotype. An ideal stable genotype is defined as the one possessing high mean performance, with regression coefficient around unity (bi=1) and deviation from regression to be as close to zero as possible. The linear regression is regarded as the measure of linear response of a particular genotype to the changing environment. If the regression coefficient (bi) is greater than unity, the genotypes is said to be highly sensitive to environmental changes but adapted to high yielding environments. If bi is equal to unity, it indicates average sensitivity to environmental changes and adaptable to all environments. If bi is less than unity, it indicates less sensitivity to environmental changes and if this is accomplished by a high mean value, then the genotype is said to be better adapted to unfavorable conditions.

In the present study stability parameters such as mean (x), regression co-efficient (bi=1) and deviation from regression (S^2d_i = 0), as suggested by Eberhart and Russell (1966) were considered to explain and discuss the stability of different genotypes for various characters under consideration. The mean values for plot yield and grand mean, regression co-efficient (bi) and deviation from regression (S^2d_i) and Stability Index (%) were worked out for the seven genotypes (Table. 6). Among all the genotypes, the test genotype Dsb-21 was found to be highly stable and widely adapted under all environments with a mean plot yield of 2.57 kg as compared to the overall mean of all genotypes (grand mean) 2.11 kg with Regression co-efficient (bi) of 0.98 indicating that the genotype responds consistently well to the varying conditions and non-significant deviation from linearity (S^2d_i = 0.28) which also reveals that the genotype shows less fluctuations to the changes in the environment conditions. The Stability Index was 70.53 % which is classified as highly stable as per Babarmanzoor *et al.* (2009).

On the other hand Dsb-19 and JS-335 were found to be suitable for favourable situation with predictable performance as they recorded per plot yield of 2.36 and 2.07 kg with below average responsiveness b_i > 1.0 i.e., b_i =1.26 and 1.18 respectively and non-significant deviation from regression. The SI % was at 48.36 and 43.87 per cent which is considered as moderate. Similarly, Dsb-20 was found to suitable for poor environments whereas Dsb-12 was found to be least stable among all the genotypes.

From the above study showed presence of significant G x E interactions among the seven soybean genotypes and for yield and other components. High-yielding genotypes with broad adaptation and some genotypes with specific adaptation were identified. Further investigations on G x E interactions at important crop growth stages for yield components would help to develop strategies that integrate traditional plant breeding with modern molecular marker-based selection for tailoring soybean cultivars for high yield and target environments. Among the cultivars used in this study, Dsb-21 showed high mean seed yield and was found to be stable over the environments and therefore could be used in the breeding programme for the development of high yielding stable genotypes over environments for future use.

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Table 1. Meteorological observations at Agriculture Research Station, Arabhavi during the crop period from 2010 to 2012

Months	Min(Temp)			Min Nor	Max (Temp)			Max Nor	RH%			Rainfall			Normal (15 Yrs)	Evaporation		
	2010	2011	2012		2010	2011	2012		2010	2011	2012	2010	2011	2012		**2010**	**2011**	**2012**
May	22.0	21.64	21.24	19.9	38.4	36.4	36.9	34.4	64.1	63.0	59.9	56.6	85.6	15.9	33.0	6.7	5.73	5.96
June	21.7	21.79	21.87	20.9	33.3	28.9	33.5	29.1	76.3	77.8	65.7	115.2	81.1	14.0	78.9	5.4	3.57	5.26
July	22.0	21.98	21.95	19.9	29.0	29.2	29.9	28.3	83.8	81.7	78.2	73.3	60.2	79.4	55.9	2.7	2.83	4.01
August	22.5	22.15	21.77	19.1	31.1	28.8	29.7	28.5	81.2	81.4	78.6	29.8	89.3	27.1	51.5	3.0	2.74	3.12
September	22.2	24.85	27.54	18.3	31.4	29.8	29.1	29.2	78.8	77.5	75.4	96.2	26.0	23.0	66.9	4.2	3.32	3.37
Mean / Sum	**22.1**	**22.5**	**22.9**	**19.6**	**32.6**	**30.6**	**31.8**	**29.9**	**76.8**	**76.3**	**71.6**	**371.1**	**342.2**	**159.4**	**286.2**			

Table 2. Mean performance of the genotypes for different traits across environments

Genotypes	Plt. Ht (cm)	Plot Yld (kg)	No of pods/plt	100 seed wt (g)	Grain Yld q/ha
DSb-1	73.93	1.88	56.46	14.33	26.23
DSb-12	71.48	1.84	40.97	13.55	25.65
DSb-19	71.75	2.36	53.06	17.88	32.90
DSb-20	82.13	2.12	72.79	17.66	29.52
DSb-21	67.15	2.57	36.86	17.00	35.80
DSb-22	66.88	1.93	53.55	18.11	26.81
JS-335 (C)	59.39	2.07	39.24	16.55	28.81
CV %	9.57	10.35	18.39	11.03	10.35

Table 3. Environmental means for different traits

	E1	E2	E3	Mean
Plt. Ht	79.79	73.76	57.62	70.4
Plot Yld	1.90	2.75	1.68	2.1
No of pods/plt	54.32	56.36	40.59	50.4
100 seed wt	17.23	15.19	16.90	16.4
Grain Yld q/ha	26.47	38.24	23.46	29.4

Table 4. Pooled ANOVA over environments and genotypes

Source	df	MSS				
		Plt. Ht	Plot Yld	No of pods/plt	100 seed wt	Grain Yld q/ha
Treatments	6	445.44 *	0.65*	1428.0*	29.22*	126.45*
Environments	2	2757.22*	6.64*	1545.23*	25.34*	1281.30*
Rep(Env)	6	49.97	0.16	53.76	1.47	31.76
Treat * Env	12	98.48 *	0.14*	70.88	7.68*	27.2*
Error	36	45.38	0.047	283.28	3.29	9.25
Total	62	11303.35	0.34	371.45	445.55	67.29

*Significant at 5 %

Table 5. AMMI ANOVA for interaction for plot yield (kg)

Source	Df	MSS	F
Treat*Envt	12	0.141	2.9*
PCA-1	7	3.84	80.25*
PCA-2	5	0.38	8.00*
PCA-3	3	0.38	7.92*
Error	36	0.047	

Table 6. Stability parameters for plot yield (kg)

Variety	Mean (g_i)	Grand Mean ($\hat{G}$)	P_i= (g_i-$\hat{G}$)	Regression Co-efficient (bi)	S^2_{di}	SD	SI (%)
DSb-1	1.89	2.11	-0.22	0.76	0.00	0.43	55.98
DSb-12	1.84		-0.27	1.75	-0.43	0.66	34.62
DSb-19	2.36		0.25	1.26	-0.59	0.71	48.36
DSb-20	2.12		0.01	0.75	0.01	0.43	62.00
DSb-21	2.57		0.46	0.98	0.28	0.66	70.53
DSb-22	1.93		-0.18	0.91	0.09	0.56	41.20
JS-335(C)	2.07		-0.04	1.18	0.00	0.66	43.87

P_i= Phenotypic stability, **S^2_{di}**: deviation from regression, SI: Sustainability Index (%)