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Stability of yield in response to integrated nutrient management practices in rice bean (*Vigna umbellata*)

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ABSTRACT

Eight statistical measures were used to identify the best combination of inorganic fertilizers and two bioinoculants in rice bean tested over eight environments. Four statistical measures namely, coefficient of variance (*CV*), geometric adaptability index (*GAI*), sustainability index (*SI*) and deviation from regression (S_d^2) values were found to be the most appropriate and identical in identifying the best treatment over the locations. Based on the mean seed yield and the three statistical measures, treatment T_{12} [100% recommended dose of fertilizer (RDF) + phosphate-solubilizing bacteria (PSB) + *Rhizobium*] was the best, followed by treatment T_{11} (75% RDF + PSB + *Rhizobium*). Based on the mean seed yield treatment T_2 (100% RDF) was the second best but was not stable over the locations. The inoculants *Rhizobium* and PSB increased and stabilized the yield over locations as compared to control.

Key word: Bio-inoculants, Environment interaction, General adaptability index, Integrated nutrient management, Rice bean, Statistical measures, Sustainability index

Rice bean [*Vigna umbellata* (Thunb.) Ohwi and Ohashi] is an important grain legume having multifarious uses, suitable for cultivation in low to mid-hills and the plains. It is mainly suitable for mid-hills where major pulses like blackgram (*Vigna mungo* L. Hepper) and greengram (*Vigna radiata* L. Wilczek) cannot be grown successfully. Improper use of chemical fertilizers has caused nutritional imbalance in the soil, instability in productivity and hidden hunger, besides depletion of nutritional quality of the pulses (Bairwa *et al.* 2009). The recent concept of integrated nutrient management avoids depletion of soil, organic matter and plant nutrients, besides, suppression of some insect pests and diseases (Gaur 2001). Looking at the availability of the organic manures and existing gap between the demand and supply of pulses, organic farming could not be taken as a complete substitute for inorganic fertilizers and pesticides. Rather, organic sources can be used as a supplement or partial replacement of chemical fertilizer. Alternatively, the use of bioinoculants can help in increasing the efficiency of either full or partial dose of the recommended inorganic fertilizers to get economical yields, attain sustainability and stability in production, maintain soil health and eco-friendly environment. Thus, a strategy for judicious use of nutrient resources is the need of the hour. The improved agronomic practices are developed based on multi-environment trials. A fertilizer dose can be recommended when it gives relatively more stable yield across the environments. The biofertilizers are cost effective, but are greatly influenced by the environment due to their biological nature. Therefore, balanced use of inorganic fertilizers and biofertilizers are important for integrated nutrient management. Stability indices may help in identifying the widely adapted fertilizer dose and biofertilizer. In India, information on biofertilizer-fertilizer-environment interaction is very limited. Keeping this in view, the present investigation was conducted to: (*i*) assess the extent of fertilizer × location interaction in different combinations of inorganic fertilizer doses with bioinoculants, (*ii*) identify the best treatment combination giving stable yield over the locations, and (*iii*) study relationship and similarities among different statistical parameters used to assess the stability.

MATERIALS AND METHODS

Data for the study was obtained from a set of rice bean (RBL 6) yield trials with 12 combinations of inorganic fertilizers and bioinoculants (Table 1) conducted for two years (2007 and 2008) at four different locations in India under All India Coordinated Research Network on Underutilized Crops. The locations were CCS Haryana Agricultural University, Hisar (latitude 29°10' N, longitude 75°46' E, altitude 215m and sandy loamy soil texture);

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University of Agricultural Sciences, Bangalore (latitude $18^0 58'$ N, longitude $77^0 38'$ E, altitude 914m and clay soil texture); Orissa University of Agriculture and Technology, Bhubaneshwar (latitude $21^0 15'$ N, longitude $85^0 15'$ E, altitude 230m and clay soil texture), and GB Pant University of Agriculture and Technology, Ranichauri (latitude $28^0 60'$ N, longitude $77^0 49'$ E, altitude 2000m and silty clay loam soil texture). At each location randomized complete block design was used with three replications. The plot size was 4.0 × 3.6 m^2 with row-to-row distance of 30 cm and plant-to-plant distance of 10 cm at all the locations. Seed yield for each treatment was determined at harvest at each location. For stability analysis, yield data from eight environments (four locations over two years) was considered

Table 1 Treatment and combination of different fertilizer doses

Treatment	Details of fertilizer doses and combination
T_1	Control (no fertilizer and bioinoculant)
T_2	*Recommended dose of fertilizer (RDF)
T_3	Only phosphate-solublizing bacteria (PSB)
T_4	Only *Rhizobium*
T_5	50% RDF + PSB
T_6	50% RDF + *Rhizobium*
T_7	100% RDF + PSB
T_8	100% RDF + *Rhizobium*
T_9	PSB + *Rhizobium*
T_{10}	50% RDF + PSB + *Rhizobium*
T_{11}	75% RDF + PSB + *Rhizobium*
T_{12}	100% RDF + PSB + *Rhizobium*

*RDF in rice bean is N:P:K @ 20:40;20 kg/ha

For original data sets, treatment (*T*), environment (*E*), treatment × environment interaction (*TE*) variances were calculated by combined analysis of the variance (ANOVA). Statistical tests of significance were determined using F-tests.

The interaction sum of squares between treatments and environments was divided into two parts. One part represented the heterogeneity of linear regression coefficient (*bi*) and the second part represented the pooled deviation from individual regression line (S_{di}^2) as per the method proposed by Eberthart and Russell (1966) to assess the cultivar's response to environmental changes. Here the treatment response to environmental changes was estimated as under:

$$b_i = 1 + \frac{\sum_j \left(X_{ij} - \bar{X}i. - \bar{X}.j + \bar{X}..\right)\left(\bar{X}.j - \bar{X}..\right)}{\sum_j \left(\bar{X}.j - \bar{X}..\right)^2}$$

$$S_{di}^2 = \frac{1}{s-2}\left[\sum_j \begin{matrix}\left(X_{ij} - \bar{X}i. - \bar{X}.j + \bar{X}..\right)^2 - \\ (bi-1)^2 \sum_j \left(\bar{X}.j - \bar{X}..\right)^2\end{matrix}\right] - \bar{S}_e^2$$

where, *Xij* is seed yield of rice bean for i^th^ treatment in j^th^ environment, $\bar{X}i$ is the mean seed yield for i^th^ treatment, $\bar{X}ij$ is the mean yield of j^th^ environment, $\bar{X}..$ is the grand mean, $\bar{S}_e^2$ is the error variance and s is the number of environments.

The performance of fertilizer treatments was categorized according to the magnitude of regression coefficient (b_i). The treatments with high yield and regression coefficient (>1) were considered suitable for favourable environments, the treatments with regression coefficient <1 and high yield were considered suitable for unfavourable environments and the treatments with regression coefficient equal to 1 and having high yield were adapted to all environments. The treatments with minimum deviation from regression (S_{di}^2 being almost equal to 0) were most stable.

The environmental variance is one of the major stability measures for the statistical stability concept (Lin *et al.* 1986) and was calculated for each fertilizer treatment across the test environments. A treatment with minimum variance under different environments was considered to be stable. This measure was calculated as follows:

$$S_{ti}^2 = \frac{\sum_j \left(X_{ij} - \bar{X}i.\right)^2}{(s-1)}$$

where *Xij* is the grain seed yield of i^th^ treatment in j^th^ environment, $\bar{X}i$ is the mean seed yield of i^th^ treatment and *s* is the number of environments.

Superiority index (*PI*) is an estimate of treatment adaptability or suitability over a range of environments. It is calculated using the highest seed yield treatment within each environment as a reference point. The treatment with largest yield difference in comparison to the reference treatment would have highest *Pi* value (Lin and Binns 1988), but the stable treatment will have a lower Pi value

$$P_i = \frac{\sum_j \left(X_{ij} - M_e\right)^2}{2s}$$

where, X_{ij} is the seed yield of the i^{th} treatment in j^{th} environment, M_e is the seed yield of the treatment with maximum yield at j^{th} environment and *s* is the number of environments.

The Wricke's (1962) ecovalence is normally used for genotype interaction assessment. However, it was used here for estimating fertilizer treatment × environment interaction as under:

$$W_i^2 = \sum_j \left(X_{ij} - \bar{X}i. - \bar{X}.j + \bar{X}..\right)^2$$

where *Xij* is the observed yield of i^{th} treatment in j^{th} environment (average value across replications), $\bar{X}i.$ and $\bar{X}.j$ correspond to mean of i^{th} treatment j^{th} environment respectively, and $\bar{X}..$ is the grand mean. Greatest stability is when $W_i^2 = 0$.

Coefficient of variance stability parameter, as usual, is measured by use of following formula.

$$CV_i = \frac{\sqrt{\sum(Xij - Xi.)^2 / n}}{\bar{X}i.} \times 100$$

The treatment with low *CV* and high average yields were regarded as most desirable.

In the case of geometric adaptability index, the geometric mean is used to estimate adaptability and suitability of the treatments (Mohammadi and Amri 2008) and is calculated as below:

$$GAI_i = \sqrt[s]{(X_{i1})(X_{i2})..............(X_{is})}$$

where X_{ij} seed yield of i^{th} treatment and j^{th} environment and *s* is number of environments. The treatments with high GAI will be desirable.

The sustainability indices were estimated by using the following formula (Gangwar *et al.* 2004). It signifies that the treatment with high *SI* will be desirable.

$$SI = \frac{\bar{X}i. - \sigma n}{M_e} \times 100$$

where $\bar{X}i.$ is the average performance of i^{th} treatment across the locations, σn is the standard deviation and M_e best performance of the i^{th} treatment across environments.

The relationship among these statistical parameters was estimated using Spearman's rank correlation (Spear 1904). To understand the relationship among these measures, three categories have been proposed. In category I are those measures which are positively and significantly correlated with mean seed yield, in category II are those which are positively and non-significantly correlated with seed yield and in category III are those which are negatively correlated with mean seed yield.

RESULTS AND DISCUSSION

Combined analysis of variance for seed yield across the environments has been presented in Table 2. The variances due to environments, fertilizer treatments and their interactions were highly significant ($P \leq 0.01$). The overall mean seed yield of the treatments at different locations over two years (Table 3) also indicated that there were wide variations in yield over locations and years and thus, the treatment × environment interactions were evident. Under such situations, it becomes difficult to identify the most suitable treatment just based on the mean performance and therefore, estimation of stability parameters becomes essential. However, based on the mean performance (Table 4) treatments T_{12}, T_2, T_{11}, T_{10}, T_8 and T_7 were better than treatments T_1, T_3 and T_4.

As per the statistical parameter b_i, the treatments T_2 and T_9 with high yield and regression coefficient (b_i) higher than 1 were most suitable to favourable environments, whereas

Table 2 Combined analysis of variance for seed yield of 12 fertilizer treatments tested across eight environments

Source	df	Mean sum of square
Fertilizer treatment	11	47.63**
Within fertilizer treatment	84	20.04**
Environment (linear)	1	1590.79**
G × E (linear)	11	4.02**
Pooled deviation	72	0.68*
Pooled error	176	0.28

* $P < 0.05$; ** $P < 0.01$

Table 3 Mean seed yield of 12 treatments at four locations over two years

Location	Year	Mean seed yield (tonnes/ha)
Hisar	2007	1.58
	2008	0.84
Bangalore	2007	0.84
	2008	1.40
Bhubaneswar	2007	0.68
	2008	0.64
Ranichauri	2007	1.78
	2008	1.27

treatment T_{10}, T_{11} and T_{12} with high seed yield and b_i»1.0 could be considered as suitable for all the environments. Treatments T_5, T_6, T_7 and T_8 with $b_i < 1$ and good seed yield were well adapted to poor environments. The treatments T_{11}, T_{10} and T_{12} with higher mean seed yield and regression coefficient being equivalent to 1 had low deviation from regression also. Therefore, these treatments had good combination of yield and stability. This indicated that the combination of PSB and *Rhizobium* either with 50% RDF (T_{10}) or 75% RDF (T_{11}) or 100% RDF (T_{12}) is important to get higher and stable yields in rice bean. The treatment T_2 (100 % RDF) also gave higher average seed yield over locations but because of having higher values of b_i (1.37) and S_{di}^2 (22.05) was not stable in its performance.

According to environmental variance S_{ti}^2, T_1 followed by T_8, T_7, T_5, T_{11} had lower variances across the environments and therefore were considered as stable in performance, whereas T_2 followed by T_9, T_{10}, T_4 showed higher variances (Table 4) and thus were not stable in their performance. Similarly, treatments T_{11}, T_{12}, T_3, T_5, T_6 and T_{10} had lower Wi^2 values and were stable in performance, whereas treatments T_2, T_9, T_1 and T_8 had higher Wi^2 values and were unstable. Based on coefficient variance parameters (*CV*), the treatments T_7, T_8, T_{11}, T_{12} were considered to be stable as they had low values, whereas treatments T_1, T_9, T_3 and T_2 showed higher coefficient of variances and were considered to be unstable.

A per *Pi* values, the treatments T_1, T_7, T_5, T_{11}, T_8 and T_3 were considered stable as they had lower *Pi* values (Table 4).

Table 4 Mean seed yield and stability values as per different statistical measures of 12 fertilizer treatments tested in eight environments in rice bean

Treatment	Mean seed yield (tonnes/ha)	Sti^2	*PI*	Wi^2	*GAI*	*CV*	bi	Sdi^2	*SI*
T_1	0.66	**13.07**	**15.92**	10.09*	5.54	54.83	0.81	5.17*	26.80
T_2	1.43	38.69	38.53	40.06**	**13.06**	43.47	1.37	22.05**	38.73
T_3	0.82	**17.31**	**27.35**	**1.74**	7.21	51.05	**0.95**	1.44	27.63
T_4	0.95	21.58	36.05	4.32*	8.49	48.82	1.05	3.97*	28.97
T_5	1.06	**14.54**	**23.22**	**2.84**	9.98	36.10	0.87	**0.77**	**41.23**
T_6	1.10	17.09	30.15	**2.04**	10.38	37.46	**0.94**	1.68	38.84
T_7	1.24	**13.82**	**22.85**	3.93*	**11.94**	**29.93**	0.85	**1.05**	**47.77**
T_8	1.26	**13.41**	**24.66**	9.42**	**12.17**	**29.04**	0.82	5.13*	**47.74**
T_9	1.01	30.81	49.78	13.05**	8.81	54.74	1.26	3.81*	24.59
T_{10}	1.22	22.37	40.12	**2.79**	**11.38**	38.89	**1.08**	2.02	37.25
T_{11}	1.33	**16.75**	**24.36**	**0.81**	**12.72**	**30.84**	**0.94**	**0.44**	**48.04**
T_{12}	1.47	21.10	30.63	**1.41**	**14.07**	**31.23**	**1.05**	**1.22**	**47.60**
Correlation with mean seed yield	1.00	–0.17	–0.15	0.22	1.00**	0.72**	–0.17	0.20	0.74**

* $P < 0.05$; ** $P < 0.01$; bold values indicate stability of the treatment

As per *GAI* parameters, the treatments T_{12}, T_2, T_{11}, T_8, T_7 and T_{10} were the best for yield stability, whereas the treatments T_1, T_3, T_4 and T_9 were poor in this respect (Table 4). Further, the treatments T_{11}, T_7, T_8 and T_{12} also showed better sustainability as against the treatments T_9, T_1 and T_3 which showed poor sustainability indices (Table 4).

The relationship of different statistical measures with mean seed yields has been indicated in Table 4. The mean seed yield was significantly and positively correlated with *CV, SI* and *GAI* (category I), non-significantly and positively correlated with *PI,* Wi^2, Sdi^2 (category II) and negatively correlated with Sti^2 and b_i (category III). As the parameters under category I are most suitable to find out the best agronomical treatments and therefore, either of these three (*CV, SI* and *GAI)* can suitably be used to find out best stable treatment. As per these parameters, the best stable treatment in the present case is T_{12} (100% RDF + PSB + *Rhizobium*), followed by T_{11} (75% RDF + PSB + *Rhizobium)*, T_8 (100% RDF + *Rhizobium)* and T_7 (100% RDF + PSB). The treatment T_2 (100% RDF), though gave high average seed yield but was not stable over the environments. Hence, it was clear that inoculation of *Rhizobium* and PSB was essential to have higher and stable yield over the environments in rice bean, Similar reports in other pulses have also indicated that inoculation with these two bio-agents increases the seed yield and other growth parameters in chickpea (Saini *et al*. 2004, Rudresh *et al*. 2005) and greengram (Ghosh and Josheph 2008).

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