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REGULAR ARTICLE

Stability and adaptability analysis of rice cultivars using environment-centered yield in two-way ANOVA model

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ABSTRACT

Identification of rice varieties with wider adaptability and stability are the important aspects in varietal recommendation to achieve better economic benefits for farmers. Multi locational trails are conducted in different locations / seasons to test and identify the consistently performing varieties in wider environments and location specific high performing varieties. The interaction aspect of varieties with environment is complex and highly variable across locations. Thus, the identifying varieties under these circumstances are difficult for varietal recommendations. However, several methods have been proposed in the recent past with the complex computation requirements. But, the aid of statistical software and other programs capabilities ease the complexity to a large extent. In this study, we employed one of the established techniques called variance component analysis (VCA) to make the varietal recommendation for wider adaptability for many varying environments and the location specific recommendations. In this method variety × environment interaction is portioned into components for individual varieties using yield deviation approach. The average effect of variety (environment centered yield deviation - D_k) and the stability measure of each variety (variety interaction variance -s_k^2) are used make the recommendations. The rice yield data of cultivars of three month maturity duration, cultivated across diverse environments during the 2002/03 wet–season in Sri Lanka was analyzed for making recommendations. Based on the results the variety At581 gave the highest D_k value with wide adaptability selected for general recommendation. Varieties Bg305 and At303 also had relatively higher D_k and thus these two can also be selected for general cultivation purpose.

Key Words: *adaptability; rice varieties; stability; variance components; yield deviation.*

INTRODUCTION

Adaptability of a crop cultivar commonly understood as its wide adaptation or local (specific) adaptation is a consequence of cultivar's relatively high mean productivity (measured usually by yield) and yield stability across environments either in locations or seasons or both. Yield stability of a cultivar is defined as a similarity (consistency) degree of its yield response function across environments to mean of all studied cultivar yield response function (Abeysiriwardena et al. 1991, Annicchiarico 2002). When genotype × environment (GE) interactions are present, it is important to analyze them and utilize the results in evaluating wide adaptability of crop cultivars (Kang, 1998). Recommendation of crop cultivars with wide adaptability is essential for countries with diverse environments or agro-ecological regions and seasons. Under such situations, it is important to account for the differential response of different crop varieties to different environments; i.e. GE interaction has to be studied to evaluate yield stability and adaptability of crop varieties over diverse environments and seasons (Simmonds, 1991).

Several advancement have made in the recent past in analyzing the varietal performance in diverse environment and their selection. The regression approach (Eberhart and Russell, 1966; Tai 1971),Variance component methods (Shukla, 1972,), additive main effects and multiplicative Interaction (AMMI) analysis (Gauch, 1992), Yield stability statistic approach (Kang, 1993) and Biplot analysis (Yan, 2001) are major techniques in analyzing multi environmental trails. The AMMI model and Biplot analysis are more frequently used method in recent years (Gauch et.al., 2008).

The AMMI analysis was designed to address the "which – won-where" pattern. It uses analysis of variance and singular value decomposition for additive parameters and multiplicative parameters respectively and uses and graphical method to identify the varieties. However, the "which won where" patterns are not usually easy for visualization with the larger number of varieties and the environments. If more than one interaction principal component is required, it will be complex in AMMI analysis (Yan et.al., 2007). The biplot analysis displays yield trait relations in individual environments and addresses whether and how the genotype by environment interactions (GE) for yield can be explored by indirect selection for other traits (Yan, 2005). The traits considered as explanatory variables influenced by GE interaction itself. Thus, using these traits, as explanatory variable is subject to debate. Moreover, the another problem is genetic values of the explanatory traits is that traits with larger genotype by environment may be regarded as irrelevant even if they are important (Gauch, et.al., 2008). Kang, et.al., (2006) used yield stability statistics, cultivar's stability variance (Shukla, 1972) and Biplot analysis (Yan, 2001; Yan and Kang, 2003). The environment centered yield variation is the important part in these methods. Abeysiriwardena et.al. (1991) used the variance component analysis to identify the rice varieties for wider adaptability and stability using yield deviation (environment centered yield deviation) approach.

The aim of the paper is to evaluate of cultivars in terms their stability and adaptability including both wide and local (specific) adaptation using environment-centered yield in two-way mixed ANOVA model for data obtained in Multi Environmental Trails (MET). These evaluation principles are also illustrated by real example regarding rice cultivar trial. The method could be powerful to recommendation of cultivars.

MATERIALS AND METHODS

The statistical approach and the parameter estimates used for analysis are explained here. Further, the description of the data used also provided in this section.

STATISTICAL METHODOLOGY

Large numbers of univariate techniques are currently used for varietal selection. Each method has its advantages and disadvantages (Abeysiriwardena et.al., 1991). Adaptability is termed as the ability of a crop variety to perform well over diverse environments. As a mean of assessment, adaptability of a crop variety is defined as a function of both mean productivity and production stability is further defined as a function of yield variation due to changing environment (Abeysiriwardena et.al., 1991). In this paper an efficient methodology for evaluating adaptability and stability of cultivars over diverse environments is used and illustrated by a yield rice trial. This methodology is originated from Abeysiriwardena et.al. (1991), who proposed partitioning GE interaction variance into components one corresponding to each variety. Here, the methodology is based on the model of classical form, but environment is assumed to be a random factor. Then, the mixed two-way ANOVA model for yield data obtained in METs is the following:

$$y_{ijk} = \mu + E_i + B(E)_{ij} + G_k + (GE)_{ik} + \varepsilon_{ijk}, \quad (1.1)$$

where y_{ijk} is the yield of the kth variety from the jth block at the ith environment, E_i is the random main effect of the ith environment, $B(E)_{ij}$ is the fixed effect of the jth block within the ith environment, G_k is the fixed main effect of the kth variety, $(GE)_{ik}$ is the random GE interaction effect of the kth variety with the ith environment, ε_{ijk} is the random error component of the kth variety in the jth block within the ith environment and i=1..n, j=1...q, and k=1...p.

From the model (Equ.1.1), the model for environmental or locational mean can be obtained as

$$\bar{y}_{i\bullet\bullet} = \mu + E_i + \in_{i\bullet\bullet}, \quad (1.2)$$

where $\bar{y}_{i\bullet\bullet}$ is the mean yield at the ith environment, E_i is the main effect of ith environment, $\in_{i\bullet\bullet}$ is the mean random error component at ith environment.

In the method, yield deviations from the mean yield at the ith environment, d_{ijk}, (environment-centered yield deviations) are used for this analysis. The d_{ijk} is obtained by subtracting the mean yield of a particular location from the yield of a variety for each block at that location, i.e.

$$d_{ijk} = y_{ijk} - \bar{y}_{i\bullet\bullet}, \quad (2.1)$$

where d_{ijk} is the yield deviation of kth variety from the jth block at the ith environment.

Thus, d_{ijk} can be expressed of the form (by subtracting the Equ. 1.2 from Equ. 1.1)

$$d_{ijk} = G_k + B(E)_{ij} + (GE)_{ik} + e_{ijk} - \in_{i\bullet\bullet} \quad (2.2)$$

Therefore, d_{ijk} can be called environmental yield deviation and i=1...n, j=1...q, and k=1...p.

In each environment, the variety with highest deviation is the one with the highest yield and the best in that environment. Thus, any variety having highest deviations in all environments would be the best or the most adaptable variety in the test since it has given the highest yield across all environments. The mean yield deviation across environments for each variety would estimate the average superiority of that variety.

It is assumed y_{ijk} and d_{ijk} to be distributed normally and ε_{ijk} and $e_{ijk} \sim N(0, \sigma_\varepsilon^2)$ and the environmental means were assumed to represent a hypothetical variety in a variety by environment data set, the distribution of the variance of the varietal deviations from the environmental means approximated to chi-square distribution. Hence, the stability parameter (s_k^2), which is simply a variance of varietal deviations across environments, has a chi-square distribution. Thus, the distribution of the variance ratio and the random error term would have a F-distribution. The genotypic, genotype by environment interaction and the variance of varietal deviations across environments for each variety are tested against pooled error by a F-test for significance (Table 1). The merit in this method is that though the environment is assumed to be random, in the environmental centered yield deviation model, it is not required to account the environmental effect and thus, no test is required for environmental effect.

Table 1. ANOVA table of environmental yield deviations

Source	df	SS	MS
Total	n(pq-1)	$\sum_{k=1}^{p}\sum_{i=1}^{n}\sum_{j=1}^{q} d_{ijk}^{2}$	
Blocks / Environment(E)	n(q-1)	$\sum_{i=1}^{n}\sum_{j=1}^{q} d_{ij\bullet}^{2} / p$	
Genotype (G)	p-1	$\sum_{k=1}^{p} d_{\bullet\bullet k}^{2} / nq$	MS(G)*
GE	(p-1) (q-1)	$\sum_{k=1}^{p}\sum_{i=1}^{n} d_{i\bullet k}^{2} / q - \sum_{k=1}^{p} d_{\bullet\bullet k}^{2} / nq$	MS(GE)*
GE_1	(n-1)	$\left(\sum_{i=1}^{n} d_{i\bullet 1}^{2} - \frac{(\sum_{i=1}^{n} d_{i\bullet 1})^2}{n} \right) / q$	$MS(GE_1)$*
…			
…			
GE_p	(n-1)	$\left(\sum_{i=1}^{n} d_{i\bullet p}^{2} - \frac{(\sum_{i=1}^{n} d_{i\bullet p})^2}{n} \right) / q$	$MS(GE_p)$*
Pooled error	n(q-1) (p-1)	$\sum_{k=1}^{p}\sum_{i=1}^{n}\sum_{j=1}^{q} d_{ijk}^{2} - \sum_{i=1}^{n}\sum_{j=1}^{q} d_{ij\bullet}^{2} / p - \sum_{k=1}^{p}\sum_{i=1}^{n} d_{i\bullet k}^{2} / q$	MS(e)

In order to evaluate cultivars for both yield mean and stability, two parameters are defined on the basis of variety environmental yield deviations. d_{ijk}. The first parameter is mean deviation across locations for each variety, D_k. calculated as:

$$D_k = \frac{d_{\bullet\bullet k}}{nq},$$

where n is number of environment or locations, q is number of blocks, $d_{\bullet\bullet k}$ is sum of yield deviation over blocks and locations for k^{th} variety. The D_k would estimate the average effect of a variety and be either positive, negative or zero. The second parameter is stability measure for each variety, s_k^2 called also cultivar interaction variance. It can be computed as:

$$s_k^2 = \left[\sum_{i=1}^{n} d_{i.p}{}^{2} - \frac{\sum_{i=1}^{n} (d_{i.p})^2}{n} \right] / q(n-1),$$

where s_k^2 is stability measure (variance in variety environmental yield deviation across environments), $d_{i\bullet k}$ is mean of environmental yield deviation over blocks for kth variety in ith environment, n is number of environments or locations, q is number of blocks.

With above estimates of parameters selection of varieties for recommendation is made as follows:

(i) Select for non significant s_k^2 in a case of recommending cultivars for yield stability only. This would identify most stable varieties in the test (s_k^2 value close to zero for stability indicates that the variety does not interact with the environment in an unpredictable manner and thus as the environment improves the performance of the variety improves in a predictable manner).

(ii) Select simultaneously for higher D_k and less (rather non significant) s_k^2 in a case of recommending cultivars for wide adaptation (cultivars indicating compromisely both belonging to those highest D_k and least or non significant s_k^2 for yield show high level of wide adaptation).

(iii) A variety with the highest $d_{i.k}$ in a particular location is the most adaptable one for that location regardless of its D_k and s_k^2 and this cultivar shows the local (wide) adaptation to this particular location (according to the rule of "which won where" - Yan and Kang 2003; Kang, et.al., 2006).

The variance component analysis and the computation of s_k^2 and D_k were performed using a Pascal program to analyze multi-locational trials (Anputhas et al., 1997).

VARIABLE SELECTION AND DATA USAGE

Data from the multi locational rice varietal testing program during the 2002/03 wet season conducted by the Rice Research and Development Institute in Sri Lanka was used in this study. The test locations were Ambalantota, Ampara, Batalagoda, Bombuwela, Murunkan and Vavuniya, and they represented different agro-ecological regions of Sri Lanka. The varieties included in the test were At303, At576, At581, Bg300, Bg305 and Bg3835 of the 3-month (90 day) maturity group. At each location the varieties had been evaluated using randomized complete block design with four replications. The output of analysis of variance, the adaptability and stability parameters are presented and discussed.

RESULTS AND DISCUSSION

The mean yield of the varieties, mean yield deviation and the mean environment centered yield are presented in Table 2. The variety At581 produced the highest yield across all the location and the highest yield by this variety is produced in Murungan (Table 2).

Moreover, the highest environmental centered yield and the highest yield deviation are also recorded in the same location while the lowest yield was produced by BG2835 in Batalagoda. The lowest environment centered mean yield is recorded in Batalagoda but the lowest mean yield deviation was found in Ampara region (Table 2). The ANOVA analysis and interaction component of each rice varieties are obtained. The blocks are nested within the environment and variance of environment is not calculated as explained in the model (Equ. 2.2). The genotypic and the genotype by environment interactions are significant at P = 0.05. This indicates the fact that yields of varieties are different significantly across locations they are interacting with the environment unpredictably.

Table 2: Mean yield of varieties, mean yield deviation and mean environmental yield

	Ambalantota		Ampara		Batalagoda		Bombuwela		Murungan		Vavuniya	
Variety	MY*	YD**	MY	YD	MY	YD	MY	YD	MY	YD	MY	YD
Bg300	5.79	0.26	4.38	-0.40	3.49	-0.22	4.00	-0.24	5.39	-0.23	4.26	-0.33
Bg305	5.64	0.12	4.99	0.22	3.62	-0.08	4.57	0.33	5.95	0.32	4.70	0.10
Bg2835	5.03	-0.49	3.48	-1.30	3.27	-0.43	3.86	-0.38	5.53	-0.10	3.89	-0.71
At576	5.07	-0.46	4.97	0.20	3.33	-0.37	3.76	-0.48	5.05	-0.57	4.56	-0.03
At581	6.12	0.59	5.67	0.89	4.60	0.9	4.87	0.63	6.66	1.04	5.45	0.85
At303	5.51	-0.02	5.16	0.39	3.90	0.2	4.39	0.15	5.17	-0.46	4.72	0.12
MEY	5.53		4.78		3.7		4.24		5.63		4.6	

MY* - Mean yield,
YD** - Mean yield deviation
MEY*** - Mean environmental yield

Table 3. Mean grain yield and corresponding adaptability parameters estimated based for six varieties tested in six locations.

		Adaptability Parameters	
Variety	Yield (t / ha)	Individual interaction variance – stability measure -	Average effect of genotype (D_k)
Bg300	4.55	0.22***	–0.19
Bg305	4.91	0.10***	0.17
Bg2835	4.18	0.66**	–0.57
At576	4.46	0.36***	–0.29
At581	5.56	0.12***	0.82
At303	4.81	0.33***	0.06

*, **,*** – s_k^2 not significantly different from zero ($P > 0.001$, $P > 0.01$, $P > 0.05$ respectively).

The estimated adaptability parameters or the interaction effects (s_k^2) and the average effects (D_k) of varieties from the univariate analysis based on yield only (y_{ijk}) are presented in Table 3. All other varieties except Bg2835 were highly adaptable and Bg2835 was moderately adaptable. Variety At581 gave the highest D_k and thus it can be selected for general recommendation. Varieties Bg305 and At303 also had relatively high D_k and thus these two can also be selected for general cultivation purpose (Table 3). Further, the variety Bg300 which gave a high $d_{i.k}$ value (0.26, the second highest among all varieties) at Ambalantota, can be recommended for that particular location based on its specific adaptability.

CONCLUSIONS

This study demonstrated that VCA could effectively be used for varietal selection for recommendation. The need for nested approach in varietal recommendation was clearly illustrated and the proposed method provided an appealing solution to the need. The importance of the proposed method is that it paves the way of taking account of genotype by environment interaction with a proper statistical basis. The additional information obtained in the proposed method by portioning by genotype by environment into components provides useful adoptability and stability parameters. The proposed method can be executed through standard statistical software with the help of macros in the respective program though we used already written program.

REFERENCES

Abeysiriwardena, D.S.de.Z., Buss, G.R., Reese Jr., P.F. (1991). Analysis of multi environmental yield trails for testing adaptability of crop genotypes, *Tropical Agriculturist* 147, 85–97.

Annicchiarico, P. (2002). Genotype × environment interactions: Challenges and opportunities for plant breeding and cultivar recommendations.. Available at http://www.iao.florence.it/ training/adaptation/references.php. *FAO Plant Production and Protection Paper* No. 174, FAO, Rome, 85–86.

Anputhas, M., Thattil, R.O., Abeysiriwardena, D.S.de.Z. (1997). *A Pascal program to analyze multi locational trails* – undergraduate research thesis, Faculty of Agriculture, university of Peradeniya, Sri Lanka.

Eberhart, S.A., Russell, W.A. (1966). Stability parameters for comparing varieties. *Crop Science*. 6, 36–40.

Gauch, H.G. 1992. *Statistical analysis of regional yield trials: AMMI analysis of factorial designs*. Elsevier, Amsterdam.

Gauch, H.G., Piepho, H.P., Annicchiarico, P. (2008). Statistical analysis of yield trials by AMMI and GGE: Further considerations. *Crop Science* 48, 866–889

Kang, M.S. (1993). Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. *Agronomy Journal* 85, 754–757.

Kang, M.S. (1998). Using genotype-by environment interaction for crop cultivar development. *Advances in Agronomy* 62,199–253.

Kang, M.S., Aggarwal, V.D., Chirwa, R.M. (2006). Adaptability and stability of bean cultivars as determined via yield-stability statistic and GGE biplot analysis. *Journal of Crop Improvement* 15, 97–120

Shukla, G.K. (1972). Some statistical aspects of partitioning genotype-environmental components of variability. *Heredity* 29, 237–245.

Simmonds, N.W. (1991). Selection for local adaptation in a plant breeding programme. *Theoretical and Applied Genetics* 82, 363–367.

Tai, G.C.C. (1971). Genotypic stability analysis and its application to potato regional trials. *Crop Science* 11, 184–190.

Yan, W. (2001). GGEBiplot—A Windows application for graphical analysis of multi-environment trial data and other types of two-way data. *Agronomy Journal* 93,1111–1118.

Yan, W., Kang, M.S. (2003). *GGE biplot analysis: a graphical tool for breeders, geneticists, and agronomists*. Boca Raton, FL, CRC Press

Yan, W., Tinker, N.A. (2005). An integrated system of biplot analysis for displaying, interpreting, and exploring genotype-by-environment interactions. *Crop Science* 45, 1004–1016.

Yan, W., Kang, M.S., Ma, B., Woods, S., Cornelius, P.L. (2007). GGE biplot vs. AMMI analysis of genotype-by-environment data. *Crop Science* 47, 643–655.