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Genotype x Environment Interaction and Yield-Stability Analyses of Rice Grown in Tropical Inland Swamp

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Abstract

Twelve rice varieties were cultivated in inland hydromorphic lowland over a four year-season period in tropical rainforest ecology to study the genotype x environment (GxE) interaction and yield stability and to determine the agronomic and environmental factors responsible for the interaction. Data on yield and agronomic characters and environmental variables were analyzed using the Additive Main Effect and Multiplicative Interaction (AMMI), Genotype and Genotype x Environment Interaction, GGE and the yield stability using the modified rank-sum statistic (YSi). AMMI analysis revealed environmental differences as accounting for 47.6% of the total variation. The genotype and GxE interaction accounted for 28.5% and 24% respectively. The first and second interaction axes captured 57% and 30% of the total variation due to GXE interaction. The analysis identified 'TOX 3107' as having a combination of stable and average yield. The GGE captured 85.8%of the total GxE. 'TOX 3226-53-2-2-2' and 'ITA 230' were high yielding but adjudged unstable by AMMI. These two varieties along with 'WITA 1' and 'TOX 3180-32-2-1-3-5' were identified with good inland swamp environment, which is essentially moisture based. The two varieties ('TOX 3226-53-2-2-2' and 'ITA 230'), which were equally considered unstable in yield by the stability variance, $\hat{\sigma}^2_i$, were selected by YSi in addition to 'TOX 3107', 'WITA 1', 'IR 8' and 'M 55'. The statistic may positively complement AMMI and GGE in selecting varieties suited to specific locations with peculiar fluctuations in environmental indices. Correlation of PC scores with environmental and agronomic variables identified total rainfall up to the reproductive stage, variation in tillering ability and plant height as the most important factors underlying the GxE interaction. Additional information from the models can be positively utilized in varietal development for different ecologies.

Keywords: AMMI, GGE, grain yield, *Oryza sativa*, swamp rice

Introduction

Genotype x environment (GxE) interaction and yield-stability analysis has continued to be important in measuring varietal stability and suitability for cultivation across seasons and ecological zones. Genotype x environment interaction analysis in rice, especially inland swamp-based cultivation has not received adequate attention comparable to the crops importance. Although McLaren and Chaudhary (1994) reported an extensive study on GxE in rice, the international focus of the study obscured some detailed genotypic and environmental intricacies specific to the ecologies where the crop is cultivated.

The analyses of genotype x environment has focused on the identification of stable genotypes for cultivation. The Additive Main Effects and Multiplicative Interaction (AMMI) model has found more use recently since it incorporates both the classical additive main effects model for GxE interaction and the multiplicative components into an integrated least square analysis and thus becomes more effective in selection of stable genotypes (Crossa *et al.,* 1991; McLaren and Chaudhary, 1994; Ariyo, 1998; De Cauwer and Ortiz, 1998; Haji and Hunt, 1999; Ariyo and Ayo-Vaughan, 2000; Taye *et al.*, 200; Yan and Hunt, 2001; Yan and Hunt, 2001). In order to further improve the quality of interpretation of results from AMMI analysis, correlation studies have been conducted between significant principal components and underlying environment and agronomic variables (Alvarez and Ruiz de Galaretta, 1999; Haji and Hunt, 1999; Yan and Hunt, 2001). The procedure identifies the particular component of the environment and the genotypic variables contributing most of the observed GxE interaction. Although the Genotype main effect and Genotype by Environment Interaction GGE has been reported to be versatile in selecting appropriate genotypes for locations (Samonte *et al.*, 2005; Gauch, 2006). The superiority of AMMI, compared to other models, was however espoused by Gauch (2006) thus affirming its importance in environment based selection for genotype breeding and selection for optimum performance. In addition, it was observed that AMMI uniquely separates G, E, and GE as required for most agricultural research purposes, and also separates structural variation from noise as well as any other method for the purpose of gaining accuracy. Nonetheless, the relative versatility of the GGE, especially in mega-environment delineation and genotype selection, is worthy of being exploited for selection of genotypes for specific location. More importantly, it would assist in guiding the direction of varietal development for stable ecology based selections.

The use of the unbiased estimator ($\hat{\sigma}^2$) (Shukla, 1972) has also been advantageously used to select genotypes for environment based research especially when it is integrated with yield (or any other trait) for simultaneous selection of high yielding and stable genotypes (Kang, 1991; Kang and Pham, 1991; Kang and Magari, 1995). A yield-stability (YSi) statistic was consequently developed by Kang and Magari (1995) to be used as a selection criterion when GXE interaction is significant.

The objective of this study, therefore, are (a) to conduct a G x E interaction and yield-stability analyses and explore the use and relative importance of the techniques to improve selection in rice and (b) to identify the genotype and environmental components associated with the GxE interaction in the inland swamp ecology so as to inform better management of the crop.

Materials and methods

A total of twelve genotypes were used for this study. The genotypes comprised 'TOX 3107', 'TOX 2336-53-2-2-2', 'TOX 3180-32-2-1-3-5' and 'WITA 1' which are conventional lowland varieties, 'IRAT 169', 'ITA 150', 'ITA 128', 'OS 6' and 'M 55' which are frequently cultivated in both the upland and swampy regions of the study area, 'ITA 230' and 'SIPI 692033' which are recommended for shallow swamps and 'IR 8' which is recommended for both conventional lowland and shallow ecologies.

This study was carried out over a four-year season period (season I-IV) from 1997 to 2000 at the rice paddy of Olabisi Onabanjo University Teaching and Research Farm, Ago Iwoye, in South West Nigeria (6.5°N, 10°E). The soil was a sandy loam with high organic matter from previous cultivations. The temperature, rainfall and relative humidity for the study months and seasons are in Tab. 1. For each planting, soil preparation was done by ploughing, harrowing and leveling. In each season, three-to four-week old seedlings were transplanted into well bunded plots as the soil moisture became adequate. In all cases, the experimental design was the randomized complete block design with three replicates. Plots had a dimension of 4 x 2 m and were spaced 20 cm apart (Gomez, 1972). Plants were weeded manually at 3 and 6 weeks after transplanting (WAT) and fertilized at 2WAT with NPK 20-10-10 at 100 kgNitrogen/hectare. Urea at 20 kg Nitrogen/hectare was applied at the boot stage. Insect control was done at 2-weekly intervals from 4 WAP with foliar sprays of Karate at 2 ml/l of water. Diseases, particularly blast, brown spot and sheath rot were controlled with foliar sprays of 0.2% suspension of Benomyl at two weekly intervals from two WAT. Birds and rodents were controlled by scaring and setting traps respectively.

Data collection and analysis

In each season, agronomic and yield data were collected on ten competitive plants in each plot as described by Gomez (1972) and Anon (1988). The sample plants were obtained from the two innermost rows within each plot. Grain yield (tones/ha) was estimated form the weight of threshed grains from all panicles in a plot, excluding border rows.

Plot means for each character and yield were subjected to analysis of variance using the SAS 2000 package. Yield data were also subjected to the Additive Main Effect and Multiplicative Interaction (AMMI) analysis using the MATMODEL version 2.0 (Gauch, 1986). The AMMI biplots were obtained from the graphical ordination of mean grain yield and the interaction principal component axes (Kempton, 1984). The GGE biplot was constructed from the environment centred yield data following the method described by Yan *et al*. (2001) and Yan *et al*. (2007).

Coefficients of linear correlation were obtained between PC scores and some environmental indices to identify the special feature of the environment influencing the GxE interaction (Haji and Hunt, 1999). Similarly genotype PC scores were correlated with the means of agronomic and yield characters (Yan and Hunt, 2001).

Tab.1. Mean monthly temperature, (°C), rainfall, R (mm) and relative humidity, RH (%) for the study months and seasons

Months	Season I			Season II			Season III			Season IV		
	T	RH	R	T	RH	R	T	RH	R	T	RH	R
April	27.5	83	222.1	30.4	77	56.4	28.3	95	121.3	29.2	78	94.7
May	26.8	85	211.4	28.6	83	152.5	27.8	82	122.8	28.1	82	173.3
June	26.2	88	266.6	26.9	85	96.9	27.2	84	274.5	26.4	88	347.2
July	25.3	87	180.9	25.6	88	198.5	25.6	90	275.0	25.7	88	187.2
August	25.4	88	83.5	25.2	87	40.8	25.4	88	226.8	25.1	90	192.6
September	26.3	86	138.5	26.0	86	245.6	25.4	89	226.8	26.12	90	395.7
October	26.9	85	205.8	26.7	86	247.2	25.9	88	318.3	26.7	87	164.0
November	27.2	87	77.5	28.4	82	10.4	27.3	86	76	28.4	84	16.1

Tab. 2. Yield (t/ha) of 12 rice genotypes (G) grown in 4 environments (E), means and first PCA from AMMI analysis

	Environment					
Genotypes	Season I (E_1)	Season II (E_2)	Season III (E_3)	Season IV (E_4)	Mean	First PCA Score
'IRAT 169' (G_1)	3.86	3.31	4.47	2.50	3.53	0.74
'WITA 1' (G_2)	6.35	3.18	4.97	5.32	4.96	-0.04
'TOX 3107' (G_3)	4.96	2.96	4.34	4.76	4.26	0.14
'ITA 230' (G_4)	5.08	3.11	6.47	5.88	5.14	-0.46
'ITA 150' (G_5)	4.47	2.55	3.48	2.84	3.34	0.53
'IR 8' (G_6)	4.07	1.96	4.71	4.07	3.70	-0.21
'OS 6' (G_7)	3.75	1.87	3.22	3.51	3.09	0.18
'ITA 128' (G_8)	5.11	2.37	3.36	3.74	3.65	0.29
'M 55' (G_9)	5.17	1.40	4.19	4.14	3.73	-0.38
'TOX 3226-53-2-2-2'(G_{10})	7.84	2.20	6.30	5.78	5.53	-0.38
'TOX 3180-32-2-1-3-5' (G_{11})	6.13	2.07	6.73	5.15	5.02	-0.85
'SIPI 692033' (G_{12})	6.10	3.80	3.66	3.18	4.19	0.93
Mean	5.24	2.56	4.66	4.24	4.18	
First PCA Score	-0.09	1.60	-0.78	-0.73		

The stability-variance for each genotype was determined by calculating the unbiased estimator, $\hat{\sigma}^2_i$ following the procedure of Shukla (1972). Genotypes with significant $\hat{\sigma}^2_i$ were adjudged unstable. The stability variance was integrated with yield to obtain the YSi statistic as outlined by Kang and Magari (1995). The procedure permits simultaneous selection of high yielding and stable genotypes.

Results

The mean yields of the twelve genotypes grown in four environments (seasons), the environment means and the first PCA scores are presented in Tab. 2. Mean yields ranged from 3.09 tha^{-1} for 'OS 6' to 5.53 tha^{-1} for 'TOX 3226-53-2-2-2'. Six of the genotypes (50%) had above average yields. Among the environments, only the season II had below average yield of 2.56 tha^{-1}. The highest yields were recorded in season I followed by season III with mean yields of 5.24 and 4.66 tha^{-1}, respectively. Only 'WITA I' yielded consistently above the environment average. 'TOX 3226-53-2-2-2', 'TOX 3180-32-2-1-3-5' recorded below environment average yields in season II while 'ITA 230' recorded below average yield in season I. 'TOX 3107' and 'SIPI 692033' had below average yields in seasons II and III respectively.

The AMMI analysis is presented in Tab. 3. The model revealed that differences between the environments accounted for about half (47.6%) of the treatment sum of squares. The genotypes and the GxE interaction also accounted significantly for 28.4% and 24% respectively of the treatment SS. The first interaction PCA was highly significant, capturing 57.4% of the total variation in the GxE interaction SS and 39.4% of the interaction degrees of freedom. The second interaction PCA was also significant ($P < 0.05$). The first two IPCA axes jointly accounted for 87.3% of the GxE interaction SS, leaving 12.7% of the variation in the GxE interaction (within 27.3% of the interaction df) in the residual. The residual in fact accounts for only 2.3% of total SS. The MS for the first PCA is more than three times that of the residual whose MS was indeed not significant.

The biplot of the AMMI-1 result is presented in Fig. 1. The abscissa shows the main effects while the ordinate shows the first PCA axis. The biplot accounts for 97.1% of the treatment SS leaving an insignificant 2.9% in the residual. 'TOX 3107' (G_3) and 'OS 6' (G_7) appeared to have similar interaction with the environment but differ in yield. 'SIPI 692033' (G_{12}) had the largest positive interaction with the environments while 'TOX 3180-32-2-1-3-5' (G_{11}) had the largest negative interaction (-0.85) but a high yield of 5.53tha^{-1}. 'TOX 3107' is considered an average and stable genotype being the only one closest to zero. 'IR 8' (G_6), 'ITA 128' (G_8) and 'M 55' (G_9) are similar in main effects but vary appreciably in interaction. 'WITA 1' (G_2) however, had the least interaction with the environments and is also high yielding. The environments were also variable in both main effects and interaction. Seasons III (E_3) and IV (E_4), however, showed similarity in their interaction with the genotypes. Fig. 2 presents the AMMI-2 biplot, with the IPCA 1 and IPCA 2 for grain

Tab. 3. AMMI Analysis of variance for rice yields

Source	df	Sum of squares	Mean squares
Treatment	47	299.827	6.379 **
Genotype (G)	11	85.131	7.739**
Environment (E)	3	142.751	47.584 **
GxE	33	71.945	2.180 **
IPCA 1	13	41.291	3.176 **
IPCA 2	11	21.899	1.991 *
Residual	9	8.754	0.973 NS
Error	96	79.216	0.825
Total	143	379.043	

*, ** = Significant at P<0.05 and 0.01 respectively; NS = Not Significant

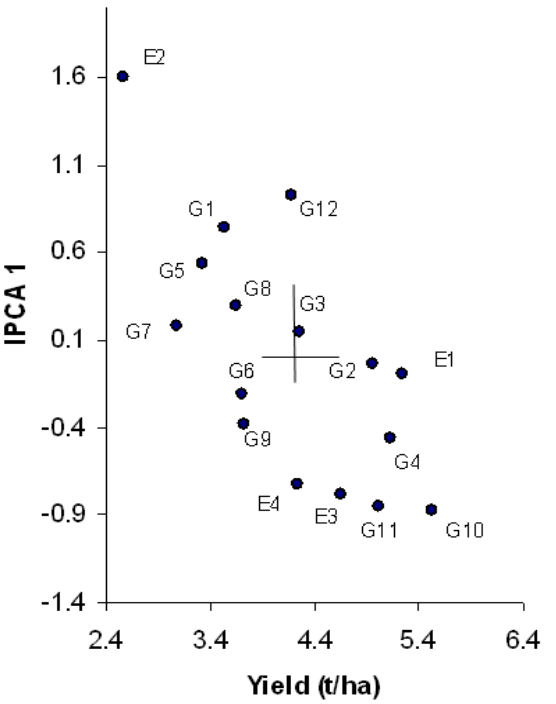

Fig. 1. AMMI-1 model for grain yield (t/ha) showing the means of genotypes (G) and environments (E) against their respective IPCA-1 scores

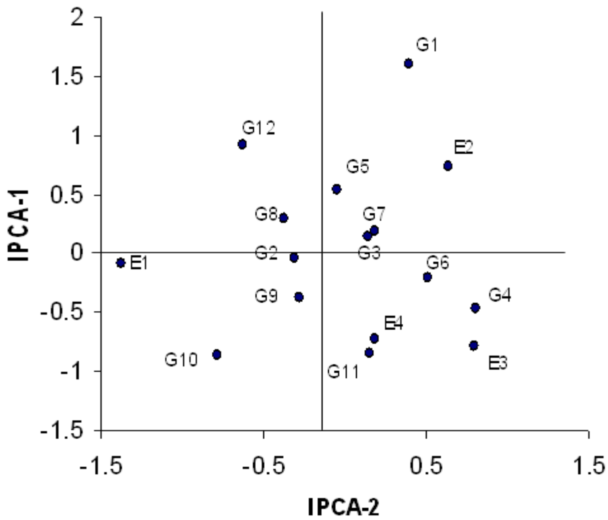

Fig. 2. AMMI-2 model for grain yield (t/ha) showing the IPCA scores of rice genotypes (G) planted across environments (E)

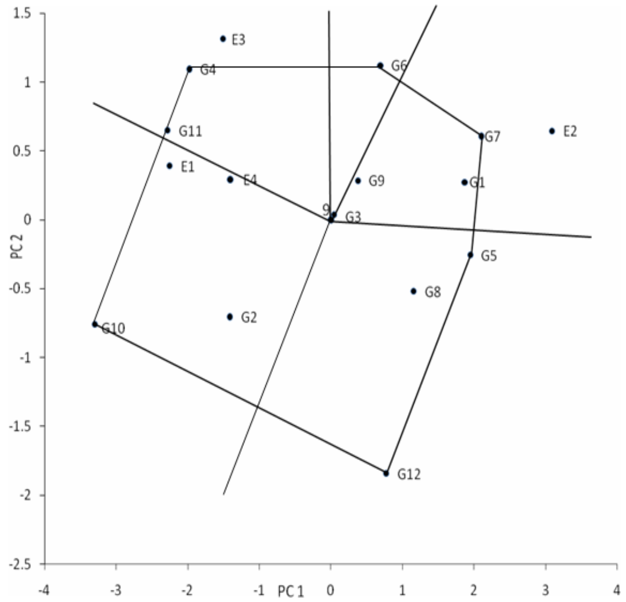

Fig. 3. GGE biplot of the primary (PC1, 69.1%) and secondary axes (PC2, 16.7%) for environment centered analysis of rice yield in an inland swamp over four seasons (Yan *et al*, 2001; 2007)

yield. AMMI-2 accounted for 87.3% of the GXE interaction for grain yield. 'TOX 3107' (G_3) and 'OS 6' (G_7) had little interaction and would fit closely the additive part of the AMMI-2 model. 'TOX 3226-53-2-2-2' (G_{10}), 'SIPI 692033' (G_{12}), 'IRAT 169' (G_1) and 'ITA 230' (G_2) were the most divergent. The GGE biplot (Fig. 3) revealed the characteristic high performer under different environment. Overall the method identified 'WITA 1' (G_2), 'ITA 2330' (G_4), 'TOX 3226-53-2-2-2' (G_{10}) and 'TOX 3180-32-2-1-3-5' (G_{11}) as being good performers when under fairly good seasons represented by E_1, E_3 and E_4. The second season was a poor environment and appeared not to give any useful discrimination among the genotypes. The other genotypes seem not to be high performer in all the seasons. 'TOX 3107' (G_3) was also identified as being stable but very poor in yield and may thus not be appealing either as a selection or for breeding new varieties.

The correlation between IPCA axes and some environmental variables over the four environments (table not presented) revealed that Axis 1 had a positive significant correlation (0.974*) with total rainfall up to flowering and grain filling stages (around the third month of the growing season for most varieties), and with relative humidity (0.955*) at maturity. Environmental variation appeared to be influenced more by total rainfall up to the reproductive stage in the cultivation years.

The correlation coefficients between genotype PC1 and PC2 scores and some agronomic and yield characters also showed significant correlations of both PC1 and PC2 (0.87*, 0.97** respectively) (table not presented).In addition, PC2 expressed significant correlation with tillering ability (0.72**) while it was negatively correlated with final plant height (-0.67*).

The mean yield, stability variance and simultaneous selection for stable and high yielding genotypes are shown in Tab. 4. The yield-stability statistic selects 'TOX 3226-53-2-2-2' and 'ITA 230', which though had significant $\hat{\sigma}^2_i$, also recorded the highest mean grain yields among the genotypes. 'TOX 3107', 'IR8' and 'M55', which had below average yields and 'WITA 1' with above average yields, were also selected. 'TOX 3180-32-2-1-3-5' and 'SIPI 692033' which would have been selected based on yield rank alone were not selected by the YSi statistic.

Tab 4. Mean Yield (t/ha), stability variance ($\hat{\sigma}_i^2$) and simultaneous selection of genotypes based on yield and stability (Kang and Magari, 1995)

Genotype	Mean yield	Rank (Y)	Selected genotype (S)	Adjustment to rank	Adjusted rank	$\hat{\sigma}_i^2$	Stability rating	Ysi	Selected genotype (S) (50%)
'IRAT 169'	3.534	3	-	-1	2	1.473**	-8	-6	-
'WITA 1'	4.956	9	S	1	10	0.104	0	10	S
'TOX3107'	4.255	8	S	-1	7	0.156	0	7	S
'ITA 230'	5.135	11	S	1	12	0.958*	-4	6	S
'ITA150'	3.335	2	-	-1	1	0.364	0	1	-
'IR8'	3.701	5	-	-1	4	0.273	0	4	S
'OS 6'	3.089	1	-	-1	0	0.305	0	0	-
'ITA128'	3.646	4	--	-1	3	0.267	0	3	-
'M 55'	3.726	6	-	-1	5	0.231	0	5	S
'TOX 3226-53-2-2-2'	5.531	12	S	2	14	1.754**	-8	6	S
TOX3180-32-2-1-3-5	5.020	10	S	1	11	1.243**	-8	3	-
'SIPI 692033'	4.185	7	S	1	8	1.660**	-8	0	

Discussion

The AMMI analysis left a non-significant 2.3% of the total variation in the residual and identified 'TOX 3107' as having a combination of low GxE interaction and average yield, making it the most suitable for cultivation across seasons in the rainfed inland swamps in terms of stability. AS identified by both AMMI and GGE, however, its low grain yield even under fairly good season makes it less attractive. The variety typically has low effective tillering even under very moist field condition. This may account for its consistent low average performance across season. 'WITA 1' had an overall negative but low interaction with the environments. The variety, however, recorded above average yields in all the seasons and would therefore be suitable for cultivation in the cultivation ecology and similar ones. 'WITA 1' also recorded the highest yield- stability rating and would therefore qualify for selection for a combination of yield and stability. Though 'OS 6' also recorded little interaction, it had a very low yield. 'TOX 3180-32-2-1-3-5' recorded the highest yields and show high positive interaction with all the environments except the second environment. This explains its identification with good environment by GGE. The non selection of this variety by Ysi was thus due to its very poor performance in the second season. Consequently, the genotype would be suitable for cultivation in years with adequate soil water either from rainfall or supplemental irrigation. 'SIPI 692033' and 'ITA 230', which are among the most recently recommended cultivars for the study ecology (Imolehin and Wada, 2000), were adjudged unstable for cultivation across seasons. Where soil moisture is low particularly in a season with low and erratic precipitation as in the second environment 'TOX 3107' would be most appropriate. Short duration genotypes like 'IRAT 169', 'ITA 150', 'ITA 128' and 'SIPI 692033', which showed positive interaction with the second environment, could be cultivated as a second or third crop (Tran *et al*., 1999) when soil moisture is likely to have declined.

The use of simultaneous selection for high yield and stability resulted in the selection of some genotypes with significant stability variance. These ordinarily, would have been dropped based on stability variance alone. By considering yield along with stability variance, the quality of selections is enhanced. 'ITA 230' and 'TOX 3236-53-2-2-2', which would not have been selected based on $\hat{\sigma}_i^2$, had below average yield in only the first and second environments respectively. Conversely, most of the stable genotypes had below average yield in all the seasons. From practical point of view, therefore, the Ysi statistic should usefully complement the AMMI method for selecting stable and high yielding rice genotypes.

Correlation between PC scores and environmental factors identified total rainfall up to the reproductive stage as the most important variable contributing to different genotypic performance. This period represent the vegetative and panicle initiation stages (De Datta, 1981). Availability of water in the inland swamps could however be very erratic, as in this study. Ouk *et al.* (2007) has further discussed the important contribution of water availability in the lowland as an important component of GxE interaction especially when varieties exhibit differential response to this factor. By implication, therefore, appropriate timing of transplanting to ensure adequate moisture during this developmental stage is necessary for superior genotypic performance i.e. high yield. The significant correlation between genotype PC 1 and PC 2 and average yield of genotypes across seasons indicate that the scores can adequately represent the genotype main effects. PC 2 however represents disproportionate or variable genotype response or crossover GxE interaction (Yan and Hunt, 2001). Consequently, the significant positive correlation between PC 2 scores and tillering ability imply that variation in tiller number is an important contributor to yield differences among the genotypes. Environment with high PC 2 scores and having the same sign would also facilitate selection of high tillering genotypes. The negative interaction shown by most lowland (high tillering) genotypes with the second season, when field moisture condition was poor, indicated that the tillers produced are not effective (failed to form panicles) resulting in drastic decline in yield. Conversely, the positive interaction observed for genotypes adapted to upland ecology, explained their frequent cultivation in the rainfed swamps by farmers in the study area. 'IRAT 169' indeed had above average yield for the second season. 'ITA 150' and 'ITA 128' also had higher yields compared to 'IR8', 'TOX 3226-53-2-2-2' and 'TOX 3180-32-2-1-3-5' which had greater tillering ability. However since 'SIPI 692033' which had moderate tiller number also performed better than the average for the season, the development of cultivars with moderate tillering along with other considerations would be appropriate for the rainfed inland swamps. Such cultivars would probably tolerate the moisture variation characteristic of the ecology to give consistent average to good yield. 'ITA 230' and 'IR 8' which had the more tillers and high positive PC 2 values interacted with the environment with the highest positive PC 2 (season IV) to record their highest yields. Low tillering genotypes like 'ITA 150', 'M 55', 'OS 6' and 'ITA 128' had the least yield in the season. Similarly 'WITA 1' and 'TOX 3226-53-2-2-2', which also had large tiller numbers and negative PC 2 scores, performed better in the environment with high negative PC 2 value (season I). The negative significant correlation between final plant height imply that short stature genotypes are favoured by the environment with high positive PC 2 to give high yield. Short stature genotypes would tolerate the strong winds that often accompany tropical rains and thus avoid yield losses due to lodging. 'ITA 230' and 'TOX 3180-32-2-1-3-5' with a final height of 103 cm and 104 cm respectively had their highest yields in season I.

The procedures used in this study obviously are not particularly contradictory in selection of genotypes for the study environments and could consequently be jointly used to explore characteristic features of varieties for location based GxE/stability analyses for genotype selection.

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