Performance of Established and Improved Interspecific Rice Genotypes under Variable Soil Moisture

Adesola L. Nassir[1]*and Kayode M. Adewusi[1]

[1]Department of Crop Production, College of Agricultural Sciences, Olabisi Onabanjo University, Nigeria.

*Correspondence: Adesola Nassir, Department of Crop Production, College of Agricultural Sciences, Olabisi Onabanjo University, PMB 2002, Ago Iwoye, Ogun State, Nigeria. Tel: +234 80 33 895 773. E-mail: solanassir@hotmail.com.

Abstract

Newly developed interspecific rice (NERICA)were evaluated along with other genotypes under conditions of imposed water deficit to study the variability of genotypes through drought adaptive characters especially root characters and other vegetative and yield characters. Data were subjected to analysis of variance as well as principal component, discriminant and cluster analyses to expound special features of genotype performance that promote tolerance to drought. Root thickness and branching recorded the high broad sense heritability (Hb) of 74.8 and 63.1 percent respectively. Root volume, weight and thickness had significant interaction with moisture level and were also identified by principal component and discriminant analyses as the foremost characters that described the response to moisture levels. One hundred-grain weight and days to flowering also had the highest Hb of 97.2 and 95.4 percent respectively and concomitantly little interaction mean square. Cluster analysis separated the genotypes into three groups with root volume, thickness and weight being strong discriminating characters. WAB 880 had a combination of these characters but recoded lower effective tillering and spikelets fertility relative to ITA 150, which had a higher grain weight per plant.

Keywords: Rice, multivariate analysis, root characters, drought tolerance, grain yield

1. Introduction

The potentials of upland ecology for rice production is often limited by occasional cessation in rainfall spanning days and weeks. Kamoshita et. al. (2008) had observed that upland paddies are exposed to water stress on continuous basis with more severe stress developing between major rainfall events. Indeed, the effect of the concomitant drought on the performance of rice at the different phenological stages has been an active area of interest for researchers. Fukai and Cooper (1995) noted that a drought-resistant genotype will be one with higher grain yield than other genotypes when all are exposed to the same level of water stress. Additionally, it was concluded that a deep root system, with high root density is useful in extracting water thoroughly in upland conditions. Boonjung and Fukai (1996) found out that occurrence of water stress at vegetative stage had relatively lower effect on grain yield than when it occurred at the reproductive stage where grain yield is reduced by up to 30%. Nonetheless, reduction in leaf area index, growth rate, dry matter, was generally the case with the occurrence of drought. In addition, shortage of water instigated a reduction in assimilate availability between panicle initiation and anthesis and between anthesis and maturity, culminating into negative effects on grain yield. (Boonjung and Fukai, 1996; Pantuwan *et al.*, 2002; Asch *et al*., 2005; Kumar *et al*., 2008). Over the years, research reports have shown that rice reacts to drought stress with reductions in height, leaf area and biomass production, tiller abortion, changes in root dry matter and rooting depth, particularly deep rooting and a delay in reproductive development, especially flowering (Pantuwan *et al*., 2002; Price *et al*., 2002; Asch, *et al*., 2005, Folkard *et al*., 2005; Acuña, *et al*., 2008). The development of drought tolerant varieties for good level grain yield under conditions of water stress has received some amount of research attention. The works of Fukai and Cooper (1995) indicated that direct selection for yield under drought conditions may not be particularly rewarding and preferred laying emphasis on traits related to drought tolerance. Recent works reported by Venuprasad *et al*. (2008) however indicated that with carefully managed drought stress, direct selection for yield in the dry season can lead into increased grain production under natural stress in the rainy period. Nonetheless, various traits including continued leaf area development, continued photosynthesis, early flowering, early maturation, a deeper and thicker root system, more extensive root system, osmotic adjustment, increase in harvest index and reduction in plant height have been associated with drought tolerance (Ekanayake *et al*., 1985; Asch *et al*., 2005; Lafitte *et al*., 2007). Recently, the New Rice for Africa (NERICA) varieties were developed from crosses involving the *Oryza sativa* and the indigenous drought tolerant *Oryza glaberrima* varieties. The selections from the crosses are supposed express better adaptation to the moisture drought typical of upland ecologies, to give good grain yield. Nassir and Adewusi (2011) had observed the need for further upgrading of these varieties for drought tolerance within the overall goal of improvement of grain yield. This would necessarily involve continuous varietal hybridization and selection to obtain genotypes with adequate combination of characters that would impact positively on drought tolerance. The assessment of genotype sources of traits contributing to drought tolerance would be an initial step and a credible result would be achieved when such assessment is carried out in the environment that is representative of the ecology for eventual cultivation and the typical water stress encountered in the field is incorporated. The objective of this study is therefore to evaluate some newly developed NERICA varieties and some established cultivars under imposed water stress and to measure the eventual effect on plant attributes especially root characters and grain production. The overall goal is to identify genotypes sources of beneficial traits to drought tolerance for subsequent recombination of genes that would produce better drought tolerance and grain production.

2. Methods

2.1 Genotypes Used for Experiments

Sixteen rice genotypes were assessed in this study. The genotypes were obtained from the WARDA unit of the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. The genotypes are composed of five recent interspecific releases: NERICA 1 (WAB 450-1-B-38-HB), NERICA 2 (WAB 450-11-1-P31-1-HB), NERICA 3 (WAB 450-1-B-P-28-HB), NERICA 4 (WAB 450-1-B-P-91-HB), and NERICA 5 (WAB 450-11-1-P31-HB); six breeding lines: WAB 880-9-32-1-1-12-HB (simply expressed as WAB 880), WAB 56-50, WAB 224-8-HB, WAB 189-B-B-B-HB (WAB 189), WAB 337-B-B-20-1-12 (WAB337), WAB 181-18 and five established genotypes: ITA 150, ITA 321, ITA 257, 0S6, IRAT 170. The NERICA varieties and breeding lines are selections from crosses involving *Oryza glaberrima* which are the red skinned rice adapted to the West African sub-region with the characteristic erratic rainfall.

2.2 Plant Establishment

Nursery polythene bags measuring 28cm in diameter and 28cm in depth were filled with 5kg loamy sand soil. At three weeks after sowing (WAS), each of the sixteen upland rice were transplanted into nine polythene bags. For each variety water application (moisture regime, MR) was made at 100 percent, 75 percent and 50 percent average moisture requirement. Preliminary study at the study location had shown that each plant would require 1.6 litres per week at the tillering stage, 2.4 litres per week at panicle initiation stage and 3.2 litres per week at grain filling stage of growth for adequate development. Each treatment was replicated three times. The experimental pots were arranged following the randomized complete block design with the MR as the blocking factor. The entire plants were recovered at maturity (harvesting stage) and used to investigate the effect of the "simulated drought" on eventual plant performance.

2.3 Data Collection

Data collection on collection on vegetative, root and their yield components were as described by International Rice Research Institute (1988), Table 1. Effective tillers were determined as the percentage number of tillers that ended in panicles relative to the total number of tillers produced. Whole plants were recovered at maturity and used to determine root characters as described by Ekanyake *et al.,* (1985): The roots of three plants for each genotype and moisture regime were recovered by carefully washing away the soil in water and drying briefly under shade. Root volume was measured as volume of displaced water when soil free root was inserted in distilled water. Root thickness was scored visually as 1 = all thicker than 2mm and 9 = all the roots thinner than 1mm. Root branching was also scored as 1 = little branching and 4 = extensive branching (Ekanayake *et al*., 1985). The roots of each plant and the fresh weights were measured in grams. The plant parts were later air dried for many days and weighed for many periods of time till weights remained constant.

Table 1 Characters used in the analysis and their methods of measurement/scoring

S/No	Character	Method of measurement
1	Tillering ability (no)	Tillers counted
2	Leaf number	Counted
3	Panicle number	Counted
4	Grain weight per panicle (g)	Weighed
5	Grain weight per plant (g)	Weighed
6	100-grain weight (g)	Weighed
7	Spikelets fertility (%)	Percentage of filled grains from primary panicle.
8	Days to flowering	Number of days from seeding to 50% flowering.

Source: Standard evaluation system for rice (International Rice Research Institute, 1988)

2.4 Statistical Analysis

Results were analyzed using the means measured on characters of each variety. Computer analyses of variance (ANOVA) were done using the GENSTAT (Edition 12) to obtain mean squares (variances) for the characters. Phenotypic and genotypic variances were estimated as described by Breese (1969). Broad sense heritability estimate Hb for each character was obtained by determining the ratio of variance due to the genotypes to the total variance. The mean values of root characters separately and all characters jointly were subjected to multivariate analysis to obtain the eigen values and the covariate scores for both the principal components and discriminant analyses. A cluster analysis was done to group genotypes for ease of decision on hybridization.

3. Results

3.1 Coefficient of Variability and Heritability Estimates

The results of the phenotypic and genotypic coefficient of variability (PCV and GCV) and broad sense heritability estimates (Hb) are presented in Table 2. The phenotypic and genotypic coefficient of variability was high for root thickness and branching but low for all other characters. Grain weight per plant had a moderate PCV and GCV of 45.7% and 42.6% respectively but a low heritability estimate. One hundred-grain weight and days to flowering recorded the highest Hb of 97.2 and 95.4 respectively. Root thickness and root branching also had high Hb of 74.8 and 63.1 respectively. The other traits recorded low heritability estimate of 4.4% for plant height to 37.9% root volume.

Table 2 Means, phenotypic and genotypic coefficient of variability (PCV, GCV) and broad sense heritability (Hb) for characters measured on rice

Character	Mean	PCV(%)	GCV(%)	Hb
Root thickness (RT)	5.79	94.20	86.50	74.78
Root Branching (RB)	2.42	80.50	64.93	63.08
Root volume (RV)	6.54	37.20	35.61	37.85
Dry root weight (DRW)	8.473	31.27	29.40	28.89
Fresh root weight FRW)	21.92	31.39	29.56	28.29
Effective tillering (ET)	71.10	34.29	17.96	26.12
Leaf number (LN)	31.85	27.19	24.88	25.05
Plant height (PH)	107.20	6.62	5.62	4.35
Days to flowering (DF)	84.30	13.87	13.82	95.42
Grain weight per panicle (GWPN)	1.783	20.80	19.67	23.08
Grain weight per plant (GWPP)	12.52	45.66	42.64	21.37
100-Grain weight (HGW)	3.158	20.48	20.32	97.23
Spikelets fertility (SF)	86.18	6.60	2.85	15.21

3.2 Mean Squares and Percent Mean Squares

The mean squares (MS) and percent mean squares (PMS) for the root and vegetative traits are presented in Tables 3 and 4. The MS for variety was significant for all the traits. Moisture regime had significant mean squares for all the traits except root thickness and root branching. With respect to the interaction of variety and moisture regime, only root thickness and effective branching had a non significant interaction. As reported for GCV, variety recorded the largest PMS for root thickness and root branching. The interaction component accounted for the largest PMS for the other traits. The residual component was generally low except effective tillering which was as high as 14.3 percent.

The mean squares (MS) and percent mean squares (PMS) for the reproductive traits are presented in Table 5. The mean squares for all the traits were significant for both variety and moisture regime. The interaction MS were also significant for all the traits with the exception of spikelets fertility. Variety had the largest partition of PMS for days to flowering and 100-grain weight while moisture regime had the largest PMS for the other traits. Only spikelets fertility had the largest residual of 11.9%. All the other traits had very low residual PMS.

3.3 Principal Component and Discriminant Analyses

The results of the principal component and discriminant analysis for the root characters are presented in Table 6. The first principal component axis captured 60.5percent of the total variation and is mainly loaded by dry root weight, fresh root weight and root volume in that order. The second axis accounted for 23.2 percent of the variation harboured with root branching and root thickness and root branching having the largest but counteracting loadings.

The dicscriminant analysis captured lower proportion of the variation among the genotypes within similar number of axes. The first axis held 49.8 percent of the variation and had large negative scores for root branching and root volume but a high positive relationship with dry root weight. Axis 2 accounted for 25.3 percent and is described dry root weight which had the highest negative score and fresh root weight which recorded a negative relationship.

For the analysis involving all the characters (Table 7), the first three axes of the PCA captured 70.1percent of the total variability. Axis 1 alone accounted for 41.9 percent and is mainly loaded by fresh root weight, dry root weight, plant height, grain weight per plant, grain weight per panicle and root volume in that order. The second axis contained 15.1percent of the total variance and is mainly related to 100-grain weight, root thickness and spikelets fertility.

The discriminant analysis for all characters the first two axes held 89.3 of the total variance with the first and second axes accounting for63.8 and 57.5 percent of the variance respectively. The two axes jointly emphasized the 100-grain weight, grain weight per panicle and dry root weight as having the largest contribution to the variance.

Table 3 Mean squares (MS) and percentage mean squares (%MS) for root traits of upland rice

Source of variation	**Root volume(ml)**		**Root thickness (mm)**		**Root branching (s)**		**Fresh root wt. (g)**		**Dry root wt. (g)**	
	MS	%MS	MS	%MS	MS	%MS	MS	%MS	MS	%MS
Variety (V)	17.837**	11.846	92.976**	74.653	9.267**	69.776	144.412**	8.330	21.494**	8.655
Moisture regime (MR)	130.691**	86.799	9.250	7.427	0.812	6.114	1565.347**	90.294	223.166**	89.859
V X MR	1.550**	1.029	17.665**	14.184	1.879	14.148	18.477**	1.066	2.880**	1.160
Residual	0.490	0.325	4.654	3.737	1.323	9.962	5.367	0.310	0.812	0.327

** Mean square significant at 1% probability level.

Table 4 Mean squares (MS) and percentage mean squares (%MS) for vegetative traits of upland rice

Source of variation	**Effective tillering (%)**		**Leaf number**		**Plant height (cm)**	
	MS	%MS	MS	%MS	MS	%MS
Variety (V)	778.5*	25.8	216.75**	7.2	165.50**	1.3
Moisture regime (MR)	1519.0*	50.3	2753.26**	91.5	12390.27**	98.1
V X MR	289.4	9.6	28.34**	0.9	56.43**	0.4
Residual	431.4	14.3	12.24	0.4	14.04	0.1

Table 5 Mean squares (MS) and percentage mean squares (%MS) for reproductive/yield traits of upland rice

Source of variation	Days to flowering		Grain weight per panicle (g)		Grain weight per plant (g)		100-grain weight (g)		Spikelets fertility (%)	
	MS	%MS	MS	%MS	MS	%MS	MS	%MS	MS	%MS
Variety (V)	410.263**	82.7	0.420**	6.3	99.053**	5.9	1.254**	95.4	52.74*	23.8
Moisture regime (MR)	82.090**	16.5	6.182**	92.7	1574.419**	93.1	0.035**	2.7	107.62*	48.6
V X MR	3.090**	0.6	0.051**	0.8	13.564**	0.8	0.019**	1.4	34.63	15.6
Residual	0.823	0.2	0.014	0.2	4.189	0.2	0.007	0.5	26.33	11.9

Table 6 Eigen values, variation and vector loadings of principal component analysis(PCA) and the discriminant analysis (DA) of root characters of rice

Method	Axis	Eigen value	Total variation		Scores				
			Percent	Cumulative	Root volume	Root thickness	Root branching	Fresh root weight	Dry root weight
	1	3.023	60.5	60.5	0.566	-0.176	-0.024	0.569	0.570
PCA	2	1.161	23.2	83.7	0.065	0.637	-0.765	0.041	0.060
	3	0.773	15.5	99.2	-0.062	-0.750	-0.643	-0.113	-0.085
	1	4.385	49.8	49.8	-0.656	0.345	-0.994	-0.068	0.734
DA	2	2.229	25.3	75.1	-0.257	0.190	0.417	1.489	-3.737
	3	1.126	12.8	87.9	1.291	-0.019	-0.353	0.683	-2.499

Table 7 Eigen values, variation and vector loadings of principal component analysis (PCA) and the discriminant analysis (DA) of root, vegetative and yield characters of rice

Method	Axis	Eigen value	Total variance %	Cumulative	Vector loadings					
PCA	1	5.452	41.94	41.94	Fresh root weight (0.381)	Dry root weight (0.381)	Plant height (0.373)	Grain weight per plant (0.368)	Grain weight per panicle (0.365)	Root volume (0.364)
	2	1.969	15.14	57.08	100-grain weight (-0.522)	Root thickness (-0.477)	Spikelets fertility (-0.402)	Grain weight per panicle (-0.280)	Root volume (0.276)	
	3	1.687	12.98	70.06	Effective tillering (0.532)	Days to flowering (-0.490)	Root Branching (0.416)	Root thickness (-0.308)		
DA	1	143.86	63.8	63.8	100-grain weight (15.961)	Grain weight per panicle (-5.154)	Dry root weight (2.846)	Days to flowering (1.062)		
	2	57.46	25.5	89.3	100-grain weight (10.506)	Grain weight per panicle (-4.034)	Dry root weight (3.197)	Fresh root weight (-1.707)		

3.4 Cluster Analysis

The dendrogram of the sixteen rice genotypes from the single linkage cluster analysis is presented in Figure 1. At 90 percent maximum similarity, the genotypes clustered into three groups: Group I (genotype 1), Group II (genotype 13) and Group III comprising all the other genotypes. At 86 percent, however, all the genotypes clustered into one group. As shown in Table 8, Genotype 1(WAB 880) had large root volume and thick roots and eventually had the largest fresh and dry root weights. Genotype 13(ITA 257) also had thick roots and high root branching relative to most other genotypes though inferior to WAB 880 and NERICA 4 in that regard. The genotype however recorded the least root volume, fresh root weight and dry root weight, and one of the poorest leaf number and grain weight per plant. Genotype 3 (ITA 150) which is a member of Group III had a distinctly higher grain weight per plant and spikelets fertility.

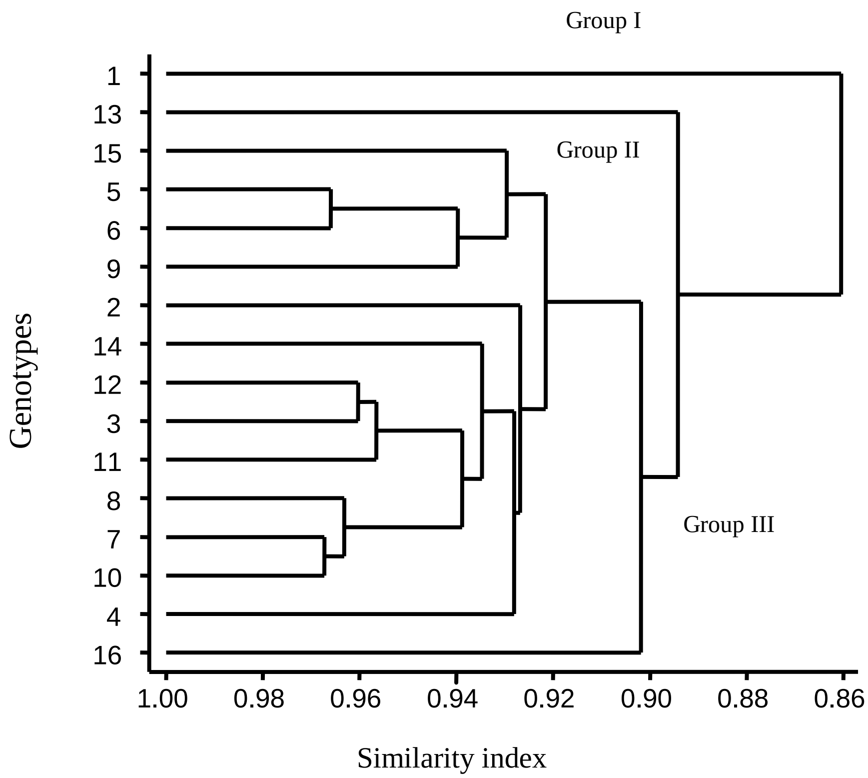

Figure 1 Dendrogram of the sixteen rice genotypes from the single linkage cluster analysis

4. Discussion

High coefficient of variability, especially at genotypic level is an indication of availability of opportunity for further selection for the concerned characters in the direction of improvement. This is true for root thickness and branching in this study. The high heritability for the characters should facilitate rapid improvement through direct selection for higher expression of the characters. Expectedly, this should also impact advantageously on root volume which draws from improvement in branching and thickness. The importance of these characters and other related ones to fairly stable grain yield of upland rice has been affirmed by Fukai and cooper (1995); Price *et al*. (2002); Asch, *et al*. (2005). In doing this, however, a balance must be struck between the root volume (and mass) and the kind of prevailing drought. Pantuwan et al., 2002 and Acuna et al., 2008 had noted nonetheless that under prolonged drought with limited soil water, large root volume leads to rapid depletion of water with the attendant negative consequences on plant growth and grain yield. In the study location, soil water condition is usually erratic and early planting may offer opportunity for less severe drought. Even at this, a balance must be maintained between having adequate root volume and avoidance of excessive water uptake during prolonged drought.

Table 8 Mean values of the main characters that described the variability and clustering of rice genotypes.

Genotypes	Root volume (ml)	Root thickness (s)	Root branching (s)	Fresh root weight (g)	Dry root weight (g)	Effective tillering (%)	Leaf number	Grain weight per pant (g)	Spikelet fertility (%)
WAB 880-9-32	10.5	1.0	1.7	31.8	12.7	69.8	37.0	16.1	84.9
NERICA 1	7.1	8.1	4.0	24.3	9.1	64.5	35.0	14.0	86.5
ITA 150	6.0	9.0	2.7	20.3	7.6	76.4	35.7	20.1	90.2
WAB 56-50	5.8	9.0	1.0	19.6	7.7	58.8	32.3	10.3	86.0
NERICA 2	5.8	3.7	1.0	19.6	7.5	73.0	25.7	8.5	86.1
NERICA 3	8.2	2.8	2.7	27.4	10.1	75.9	29.6	11.1	80.4
WAB 224-8-HB	6.8	8.1	2.0	22.6	8.7	85.1	25.3	9.7	86.0
NERICA 4	5.7	1.0	4.0	19.8	7.5	72.6	27.3	8.8	81.7
ITA 321	8.4	9.0	2.0	28.0	10.8	48.0	40.0	9.5	86.9
NERICA 5	6.1	3.7	3.0	20.7	7.8	82.3	32.0	13.1	87.7
WAB 189-B-B-6	5.2	6.3	1.3	19.1	7.6	72.3	27.6	10.1	87.2
OS6	6.2	6.3	1.7	20.7	8.1	63.3	40.3	12.3	84.9
ITA 257	5.2	1.9	3.7	17.5	7.0	71.6	26.7	11.0	87.4
WAB 337	6.4	3.7	3.7	21.6	8.5	70.8	29.7	12.7	87.5
IRAT 170	5.4	9.0	2.0	17.9	7.0	71.0	35.3	17.1	86.7
WAB 181-18	5.9	9.0	2.3	19.9	7.9	82.5	30.1	15.8	88.9

Although some recent efforts to improve performance of rice under water stress (Babu *et al*., 2003; Yue *et al*., 2005; Kumar *et al*., 2007; Kato *et al*., 2008; Cairn *et al*., 2009) has focussed on identification and incorporation of QTL's for stable grain yield, this still translates directly or indirectly to phenotypic expression. The correlation between laboratory, greenhouse study on genotype rooting and field performance further underscores the importance of this kind of phenotyping for character identification for genotype improvement to drought tolerance.

The large percent mean squares for root thickness and branching is consistent with the reported high heritability for the characters. The differential effect of different levels of moisture to varietal performance further attests to the complexity of rice genotypes and their response to rice environments and drought conditions. This observation and those of Price *et al*. (2002), Lafitte *et al*. (2007), Nassir and Adewusi, (2011) points to the fact that specific drought tolerant varieties can, at best, only be bred for a restricted region.

The principal component and discriminant analysis appeared to have placed emphasis on the root volume and its derivative, root weight as the major focus in identifying genotype performance under varying moisture condition. The importance of the traits to drought tolerance is attested to by the relatively better grain production recorded by WAB 880 compared to ITA 257 which had low root volume and weight .This characters may be selected for directly and indirectly through other root traits like root thickness. However, root volume and weight would also be promoted by traits like packed cell volume, cell density and other weight indices. The joint analysis involving vegetative and grain characters also emphasized root weight along with grain weight per plant and 100-grain weight and characters that must be concurrently focussed on in selection for good genotype performance under moisture stress.

The cluster analysis identified WAB 880 as a genotype source of genes for improvement for root thickness, volume and weight. ITA 150, which is an established variety, can be further improved for root characters and better tolerance to drought stress through carefully managed hybridization and selection with WAB 880 and ITA 257. This perhaps would translate to better grain production under moisture stress and non-moisture stress soil conditions.

In conclusion, root volume, thickness and weight were the characters that explained differential performance of rice genotypes in the study. These characters would be beneficial traits for tolerance to erratic soil moisture frequently encountered in the tropical derived savannah ecology. The development of cultivars with improved expression of these characters must however be necessarily coupled with high effective tillering to ensure that no tillers are produced than the typical soil water fluctuations can support to produce panicles with well filled grains. This would translate to higher spikelets fertility and grain production which appeared to be the strength of ITA 150 in this study.

References

[1] Acuña, B. T. L., Lafitte, H. R., & Wade, L. J. (2008). Genotype x environment interactions for grain yield of upland rice backcross lines in diverse hydrological environments. *Field Crops Res.*, 108, 117-125.

[2] Asch, F., Dingkuhn, M., Sow, A., & Audebert, A. (2005). Drought-induced changes in rooting patterns and assimilate partitioning between root and shoot in upland rice. *Field Crops Res.*, 93, 223-236.

[3] Babu, R. C., Nguyen, B. D., Chamarerk, V., Shanmugasundaram, P., Chezhian, P., Jeyaprakash, P., Ganesh, S. K., Palchamy, A., Sadasivam, S., Sarkarung, S., Wade, L. J., & Nguyen, H. T. (2003). Genetic analysis of drought resistance in rice by molecular markers: association between secondary traits and field performance. *Crop Sc.*, 43, 1457–1469.

[4] Breese, E. L. (1969). The measurement and significant of genotype- environment interactions in rice. *Heredity*, 24, 27 – 44.

[5] Boonjung, H., & Fukai, S. (1996). Effects of soil water deficit at different growth stages on rice growth and yield under upland conditions. 2. Phenology, biomass production and yield. *Field Crops Res.*, 48, 47 - 55.

[6] Cairns, J. E., Acuña, B. T. L., Simborio, F. A., Dimayuga, G., Lakshmi Praba, M., Leung, H., Torres, R., & Lafitte, H. R. (2009). Identification of deletion mutants with improved performance under water-limited environments in rice (Oryza sativa L.). *Field Crops Res.*, 114, 159 -168.

[7] Ekanayake, I. J., Garvity, D. P., Masajo, T. M., & O'Toole, J. C. (1985). A root pulling resistance of rice. Inheritance and association with drought tolerance. *Euphytica*, 34 (3), 905 - 913.

[8] Folkard, A. F., Dingkuhnb, M., Sowc, A., & Audebert, A. (2005). Drought-induced changes in rooting patterns and assimilate partitioning between root and shoot in upland rice. *Field Crops Res.*, 93, 223–236.

[9] Fukai, S., & Cooper, M. (1995). Development of drought - resistance cultivars using physiomorphological traits in rice. *Field Crops Res.*, 40, 67- 86.

[10] International Rice Research Institute (1988). *Standard evaluation system for rice* (3rd ed.). Philippine. International Rice Research Institute.

[11] Kamoshita, A., Babu, R. C., Boopathi, N. M., & Fukai, S. (2008). Phenotypic and genotypic analysis of drought-resistance traits for development of rice cultivars adapted to rainfed Environments. *Field Crops Res.*, 109,1–23.

[12] Kato, Y., Hirotsu, S., Nemoto, K., & Yamagishi, J. (2008). Identification of QTLs controlling rice drought tolerance atseedling stage in hydroponic culture. *Euphytica*, 160, 423 - 430. http://dx.doi.org/ 10.1007/s10681-007-9605-1

[13] Kumar, A., Bernier, J., Verulkar, S., Lafitte, H. R., & Atlin, G. N. (2008). Breeding for drought tolerance: Direct selection for yield, response to selection and use of drought-tolerant donors in upland and lowland-adapted populations. *Field Crops Res.*, 107, 221–231.

[14] Kumar, R., Venuprasad, R., & Atlin, G.N. (2007). Genetic analysis of rainfed lowland rice drought tolerance under naturally-occurring stress in eastern India: heritability and QTL effects. *Field Crops Res.*, 103, 42–52.

[15] Lafitte, H. R., Yongsheng, G., Yan, S., & Li, Z-K. (2007). Whole plant responses, key processes, and adaptation to drought stress: the case of rice. *J. of Exp. Bot.*, 58 (2), 169-175.

[16] Nassir, A. L., & Adewusi, K. M. (2011). Drought response of some tropical rice genotypes: Rooting, vegetative traits and grain production. *African J. of Plant Sci.*, 5(12), 710-717.

[17] Pantuwan, G., Fukai, S., Cooper, M., Rajatasereekul, S., & O'Toole, J. C. (2002). Yield response of rice (Oryza sativa) genotypes to drought under rainfed lowlands: Selection of drought resistant genotypes. *Field Crops Res.*, 73, 169 – 180.

[18] Price, A.H., Steele, K.A., Moore, B.J., & Jones, R.G.W. (2002). Upland rice grown in soil-filled chambers and exposed to contrasting water deficit regimes II. Mapping quantitative trait loci for root morphology and distribution. *Field Crops Res.*, 76, 25-43.

[19] enuprasad, R., Sta Cruz, M. T., Amante, M., Magbanua, R., Kumar, A., & Atlin, G. N. (2008). Response to two cycles of divergent selection for grain yield under drought stress in four rice breeding populations. *Field Crops Res.*, 107, 232–244.

[20] Yue, B., Xiong, L., Xue, W., Xing, Y., Luo, L., & Xu, C. (2005). Genetic analysis for drought resistance of rice at reproductive stage in field with different types of soil. *Theor. App. Genet.*, 111, 1127–1136.