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Soil Moisture Simulation for Genotype-by-Environment Interaction Analysis of Grain Production in Upland Rice

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ABSTRACT

Sixteen upland rice genotypes comprising established cultivars and some interspecific Oryza sativa x O. glaberrima selections were established in the screenhouse under conditions that simulate ten different moisture-centred environments to study genotype and genotype-by-environment response of grain production. Data were collected on grain weight per plant (GWPP) and other traits and used to determine genotype stability under moisture stress. Linear response to environment (moisture stress) constituted 80.4% of the total sum of squares while G and GE jointly accounted for a low but significant 19.6%. The GGE analysis classified the two environments into two groups with the rainfed environment as the most discriminating. A few of the environments overlapped indicating similarity in their ability to represent moisture stress condition and discriminate among rice genotypes. Correlation coefficient of GWPP across environments was significant with root dry weight (0.972), shoot dry weight (0.986), spikelets number per panicle (0.961), grain weight per panicle (0.967), 100-grain weight (0.695) and spikelet fertility (0.759). Two genotypes, ITA 150 and NERICA 1 (WAB 450-1-B-38-HB), in order of preference, were identified as having a combination of high and stable grain weight under controlled moisture. Genotypes 15 (IRAT 170) had high yield under adequate moisture condition but was also unstable.

Key words: Oryza, upland rice GGE, stability, drought, grain yield

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INTRODUCTION

Genotypic response to different cultivation ecology, with the underlying environmental influence, has been an active area of research for quite some time now. The necessity of characterizing environments and genotypes and the biplot method (Kempton, 1984) has become refined through the Additive Main Effect and Multiplicative Interaction (AMMI) procedure to the Genotype and Genotype-by-Environment Interaction (GGE) biplot which gives a clear view of superior genotype in a particular environment or set of similar environments (Zobel *et al*., 1988, Yan *et al*., 2000, Yan and Hunt, 2001; Gauch, 2006, Yan *et al*., 2007). In many genotype-by-environment analysis involving different crops, environment often accounts for the largest proportion of GE interaction (Yan *et al*., 2000; Samonte *et al.,* 2005, Egesi *et al*., 2007, Acuna *et al*., 2008, Nassir and Ariyo, 2011). This is without doubt expected especially where a number of contrasting environments are used in the analysis. Consequently there is the frequent recourse to identify environment with similar cultivation conditions cum genotype reaction in what is now tagged mega environment analysis (Yan *et al*., 2000; Yan and Tinker, 2005, Gauch, 2006). In such analyses the pooled total of G and GE component is appreciable and important in genotype and test environment evaluation and hence suitability for cultivation (Gauch, 2006; Yan *et al*., 2007). These two components according to Yan *et al.* (2007) stressed the importance of GGE biplot as a better tool for identifying specific genotype adaptation and high performance in specific environments. One strong feature of AMMI and GGE is the power to relate discriminating ability with certain underlying environmental variables. Concomitantly, efforts have been aimed at selecting genotypes compatible to one or a few locations or selecting environments with similar ecological indices for the cultivation of certain genotypes. For both, the selection of genotypes with superior performance and adaptation or at least compatibility to certain environment-dictated conditions remains the focus. This would necessarily entail understanding the environment, for the possibility of grouping them (Yan *et al*., 2010). Although, Gauch (2006) noted that little GE remains within mega-environments, yet the importance of incorporating environmental concerns for a more all-encompassing analysis was alluded to. Thus, location based genotype by environment studies would be further enriched by relating both trait and environmental covariates to further elucidate on the causes of differential G and GE results. Yan and Tinker (2006) identified yield-trait covariates like kernel weight, early heading and lodging resistance as important to mega environment-genotype selection. Yan and Hunt (2001) have identified different weather indices as the underlying cause of G x E. Haji and Hunt (1999) identified variation in the temperature of cultivation environment as the main cause of G x E in wheat. Signor *et al.* (2001) also identified temperature differences at certain growth stages as the cause of the GE interaction in maize; Samonte *et al.* (2005) delineated cultivation locations on the basis of heat index and identified genotypes adapted to such locations; Nassir and Ariyo (2011) and Nassir and Adewusi (2015) further discussed moisture differential in rice and its implication on genotype tolerance to drought.

Moisture availability, and by extension drought occur at different stages in the cultivation of rice (Pantuwan *et al.*, 2002; Ouk *et al.*, 2007; Acuna *et al.*, 2008). Upland rice is frequently cultivated with natural precipitation, which is often unpredictable and creates multiple conditions in the life of a single crop. This genotypic-environmental interaction for yield consequent upon water deficit at different stages requires some studies in order to identify genotypes with better adjustment to moisture shortage and still produce fairly stable amount of grains. In addition, the plant trait conditioning genotype-environment response would offer some information for the development of ecology specific genotypes.

This study was thus designed to investigate Genotype-by-Environment (GE) interaction consequent upon imposed differential moisture application on upland rice. It is an attempt to stimulate variable levels of drought and identify genotype that interact to produce better grains under the different conditions

MATERIALS AND METHODS

Sixteen rice genotypes developed for upland cultivation were obtained from the Africa Rice Center the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. The genotypes and their designation are in Table 1.

This study was conducted in the screen house of the College of Agricultural Sciences, Olabisi Onabanjo University, Ayetoro which is located in a derived savannah ecological zone of South Western Nigeria (6.5^0N, 10^0E). Three-week old seedlings of each of genotype were transplanted into three black polythene bags measuring 28cm in diameter and 28cm in depth previously filled with 5kg of loam top soil obtained from the upland paddy. All plants received adequate moisture up to two weeks after transplanting. Varying levels of moisture were thereafter applied following a factorial of three watering regimes and three times of application between maximum tillering and maturity to create nine treatments. Hence plants received 100%, 75% and 50% of moisture needs at two times as twice weekly and weekly and once bi-weekly applications. Additionally, all genotypes were also raised in pots under natural rainfall. In total, there were ten soil moisture-mediated environments (Table 2). Using the moisture levels as the homogenizing factor, the pots were arranged following the completely randomized block design with three replications.

Table 1: Genotypes used in the study with their designation and status

Genotype	Designation	Status
WAB 880-9-32-1-1-12-HB	G1	Breeding line
NERICA 1 (WAB 450-1-B-38-HB)	G2	Recent release
ITA 150	G3	Established line
WAB 56-50	G4	Breeding line
NERICA 2 (WAB 450-11-1-P31-1-HB)	G5	Recent release
NERICA 3 (WAB 450-1-B-P-28-HB)	G6	Recent release
WAB 224-8-HB	G7	Breeding line
NERICA 4 (WAB 450-1-B-P-91-HB)	G8	Recent release
ITA 321	G9	Established line
NERICA 5 (WAB 450-11-1-P31-HB)	G10	Recent release
WAB 189-B-B-B-HB	G11	Breeding line
OS6	G12	Established line
ITA 257	G13	Established line
WAB 337-B-B-20-1-129	G14	Breeding line
IRAT 170	G15	Established line
WAB 181-18	G16	Breeding line

Data collection and analysis

Data collection on the vegetative and yield characters was as described by Anon (1988). After harvesting, the remaining plant parts were recovered. Roots were cleansed by carefully washing off the soil from the roots. The shoot and the roots were separated and air dried to constant weight in the laboratory.

Mean values for each data for each genotype in each replicate were computed subjected to analysis of variance with the SAS software (Version 9.2). The Additive Main Effect and Multiplicative Interaction (AMMI) was done using GENSTAT (Version 12) following the procedure of

Zobel *et al*., (1988). Genotype by environment analysis was done with Genotype and Genotype by Environment (GGE) model (Yan *et al.,* 2000). The analysis model was adapted to assist in identifying good screening conditions and also to enable the removal of redundant ones. Some plant performance traits were correlated with grain yield across environments to further investigate their structural relationship as dictated by increasing moisture levels.

Table 2: Description of moisture-based environmental simulation for drought

Environment number	Description
1	100% moisture requirement applied twice per week
2	100% moisture requirement applied once per week
3	100% moisture requirement applied once in 2 weeks
4	75% moisture requirement applied twice per week
5	75% moisture requirement applied once per week
6	75% moisture requirement applied once in 2 weeks
7	50% moisture requirement applied twice per week
8	50% moisture requirement applied once per week
9	50% moisture requirement applied once in 2 weeks
10	Rainfed

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) results for the grain weight of rice is shown on Table 3. Genotype (G), environment (E) and their interaction (GE) were highly significant and contributed 7.1, 80.4 and 12.4 percent of the total sum of squares respectively. Of the interaction components, the first and second interaction principal components (IPC) accounted for 55.1 and 26.9 percent respectively. It would appear that linear response to differential level of moisture or imposed drought was the main thrust of the performance of the genotypes. This is amply expressed in Table 4 where reduction in mean grain yield followed the availability of moisture by volume and spread, with each environment uniform enough to allow high heritability estimates. Obviously, the interaction component is rather small compared to the E component; nonetheless, it still had significant influence on the overall genotypic performance. The GE influence however appeared to be shared largely between proportionate and disproportionate response even though the former accounted for more. Indeed, the PCs were not correlated to the main effects giving initial possibility of one or very few environment groups (Yan *et al*., 2000). The environment based means and other estimates (Table 4) showed declining means with reduction in moisture and frequency of application. The heritability estimates were consistently high, the least being 68%, indicating that gain in selection for grain weight per plant, under drought condition, which underlined the experimental conditions, would be appreciable.

The genotype plus genotype by environment (GGE) biplot for grain weight per plant (GWPP) is presented in Figure 1. The PC1 and PC2 incorporated 84% of the GGE. The GGE polygon view classified the environment into three sectors. With the exception of environments 3 and 10, all the other environments are in one sector where genotype 3 appeared at the vertex and is thus the most compatible. Genotypes 2 and 10 shared the same polygon and are both selections from the *O. sativa* x *O. glaberrima* interspecific hybrid. Genotype 15 which had the best GWPP in environment 10 with excessive moisture from rainfall shared the polygon with genotype 16. The genotypes would be expected to perform well mainly when moisture is not limiting, and this is atypical of tropical upland paddy. Genotype 8 was the best genotype for environment 3, defined by reduced moisture in terms of both amount and frequency.

Figure 2 displays the mean-by-stability aspect of GGE analysis. Given the low proportion of GE for the data the environments were considered as a whole. Genotype 3 recorded largest grain production and was followed by genotype 1, genotype 2 and genotype 15 respectively. Overall, genotypes 2 and 3 combined ample production of grains with stability. Genotypes 1, 10, 14, 15 and 16 had above average yields but were quite unstable. As earlier observed, Genotype 15 obviously appeared to be suitable under adequate moisture unlike genotypes 3 which apart from recording the most grains also had above average performance in all the moisture limited conditions (Table 5). G3 (ITA 150) is a tall genotype with relatively lower vegetativeness, and with well branched roots Adewusi and Nassir, 2011). It would appeared the genotype had relatively lower vegetation to support under moisture limitations such that most assimilates are channelled to the grains as it also recorded the largest panicle number and grain weight per panicle. Conversely, G5 (NERICA 2) had relatively lower expression for root, vegetative, and panicle traits. G15 had thick roots but recorded the least root volume. Such genotype would only perform well where moisture is not a limitation and possibly explain why it was the best under adequate rainfed condition but was the most unstable with imposed moisture stress.

Table 3: Genotype-by-environment (GxE) analysis of variance with Interaction Principal Components (IPC) for grain weight per plant (GWPP) of rice

Source	DF	SS	MS	%of SS	% of GE
Total	479	42812.54			
Genotype (G)	15	2936.75	195.78**	7.17	
Environment (E)	9	32940.08	3660.01**	80.42	
GxE	135	5081.021	37.64**	12.41	
IPC1	23	2799	121.70**		55.09
IPC2	21	1369	65.19**		26.94
IPC3	19	406	21.37**		7.99
Residual	72	508	7.06^{ns}		10
Block	20	191.69	9.58*		
Error	300	1662.99	5.54		

Table 4: Environmental values for moisture induced response of grain weight per plant of rice

Environment	Mean	SE	LSD 5%	Heritability (%)	CV%
1	18.069	2.511	4.276	0.892	13.9
2	16.85	4.959	8.445	0.677	29.43
3	3.287	0.82	1.396	0.983	24.93
4	12.852	2.251	3.834	0.909	17.52
5	11.069	1.652	2.813	0.965	14.92
6	2.071	0.495	0.842	0.988	23.89
7	6.629	1.26	2.145	0.871	19
8	4.718	0.96	1.635	0.923	20.35
9	1.025	0.458	0.779	0.953	44.64
10	28.431	3.62	6.165	0.926	12.73

Table 6: Means of some plant traits and their across environment correlation with grain weight per plant

	Root Traits			Vegetative traits			Grain yield traits			
Environment	Root volume (cm^3)	Root thickness (s)	Root dry weight (g)	Tillering (No)	Plant height (cm)	Shoot dry weight (g)	Grain weight per panicle (g)	Spikelet number per panicle (No)	100-grain weight (g)	Spikelet fertility (%)
1	8.14	5.33	10.55	11.92	122.25	45.74	2.11	72.38	3.17	87.38
2	8.69	5.83	11.36	11.5	120.44	42.03	2.05	69.67	3.18	88.67
3	3.48	5.33	6.54	7.73	98.06	9.99	0.77	26.83	1.57	42.76
4	6.91	6.18	8.98	9.92	109.96	38.69	1.93	66	3.2	87
5	6.89	4.5	8.95	9.23	110.23	36.38	1.67	58.63	3.15	86.26
6	3	5	3.86	6.75	89.25	9.12	0.58	21.02	1.35	36.26
7	4.85	6	6.24	7.83	90.27	22.89	1.4	49.04	3.13	84.5
8	4.19	5.33	5.46	7.29	89.46	19.93	1.17	41.79	3.13	84.27
9	1.89	5.83	2.37	5.44	77.81	4.69	0.46	16.46	2.04	36.9
10	12.19	7.22	16.03	12.36	133.16	59.79	2.67	88.71	3.23	92.01
Mean	6.02	5.66	8.03	9	104.09	28.93	1.48	51.05	2.72	72.6
Correlation with GWPP	0.990**	0.488	0.972**	0.943**	0.958**	0.986**	0.967**	0.961**	0.695*	0.759*

Table 5: Genotype means for some plant traits over the environments

	Root Traits			Vegetative traits			Grain yield traits				
Genotypes	Root volume (cm^3)	Root thickness (s)	Root dry weight (g)	Tillering (No)	Plant height (cm)	Shoot dry weight (g)	Grain weight per plant (g)	Grain weight per panicle (g)	Spikelet number per panicle (No)	100-grain weight (g)	Spikelet fertility (%)
WAB 880-9-32-1-1-12-HB (G1)	8.71	1.8	10.84	10.1	108.43	36.38	13.53	1.53	49.3	2.35	60.97
NERICA 1 (WAB 450-1-B-38-HB) (G2)	7.02	7.93	9.02	9.93	93.1	24.6	12.21	1.79	60.9	4.32	85.64
ITA 150 (G3)	5.12	7.4	6.46	10.23	107.33	23.7	23.19	2.11	63.33	3.66	87.4
WAB 56-50 (G4)	4.91	6.6	6.42	8.8	103.07	25.5	8.02	1.22	37.6	2.49	60.28
NERICA 2 (WAB 450-11-1-P31-1-HB)(G5)	4.95	5.8	6.39	6.53	103	25.05	7.8	1.23	46.97	1.97	60.88
NERICA 3 (WAB 450-1-B-P-28-HB) (G6)	7.47	2.87	12.71	8.2	109.7	28.3	9.01	1.51	58.9	2.77	81.72
WAB 224-8-HB (G6)	5.64	8.47	7.22	7.43	103.2	26.21	7.37	1.11	48.23	1.74	60.11
NERICA 4 (WAB 450-1-B-P-91-HB) (G7)	5.55	2.07	7.25	7.33	102.67	25.57	8.93	1.44	57.37	2.78	83.74
ITA 321 (G8)	7.54	6.33	9.94	11	102.73	38.44	8.5	1.17	39.53	2.27	61.01
NERICA 5 (WAB 450-11-1-P31-HB) (G9)	5.33	2.07	6.88	9.3	109	26.81	10.46	1.49	62.13	2.64	87.84
WAB 189-B-B-B-HB (G10)	5.38	6.07	7.29	7.43	110.23	31.55	8.32	1.44	47.23	2.65	69.56
OS6 (G11)	6.06	8.47	7.98	10.5	105.17	26.38	9.94	1.21	43.2	2.09	60.44
ITA 257 (G12)	4.89	3.4	6.43	8.1	104.43	23.94	9.66	1.67	55.5	3.24	87.99
WAB 337-B-B-20-1-129 (G13)	5.52	3.93	7.45	8.83	95.53	30.72	11.95	1.71	52.1	3.56	88.49
IRAT 170 (G14)	5.58	8.47	7.34	11	105.17	32.24	14.09	1.57	47.47	2.51	62.43
WAB 181-18 (G15)	6.18	8.73	8.22	8.97	100.33	35.29	12.2	1.42	44.8	2.39	62.64
Standard Error ($P<0.05$)	0.13	0.45	0.46	0.36	0.7	1.1	1.88	0.03	0.84	0.28	0.7

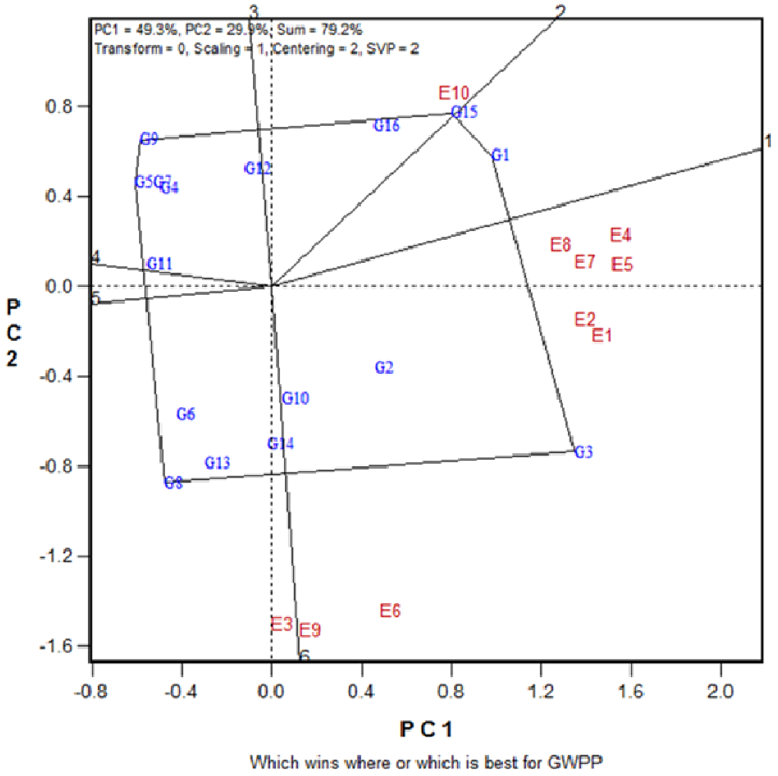

Figure 1: GGE Biplot for grain weight per plant (GWPP) of rice genotypes (G) evaluated under different moisture-centered environments (E).

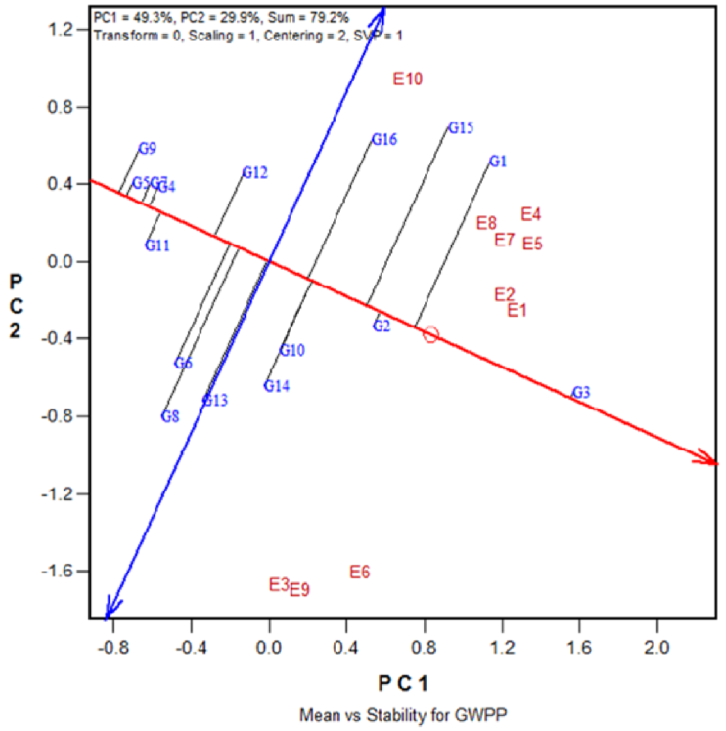

Figure 2: Mean versus stability representation for grain weight per plant (GWPP) of rice genotypes (G) evaluated under different moisture-centered environments (E).

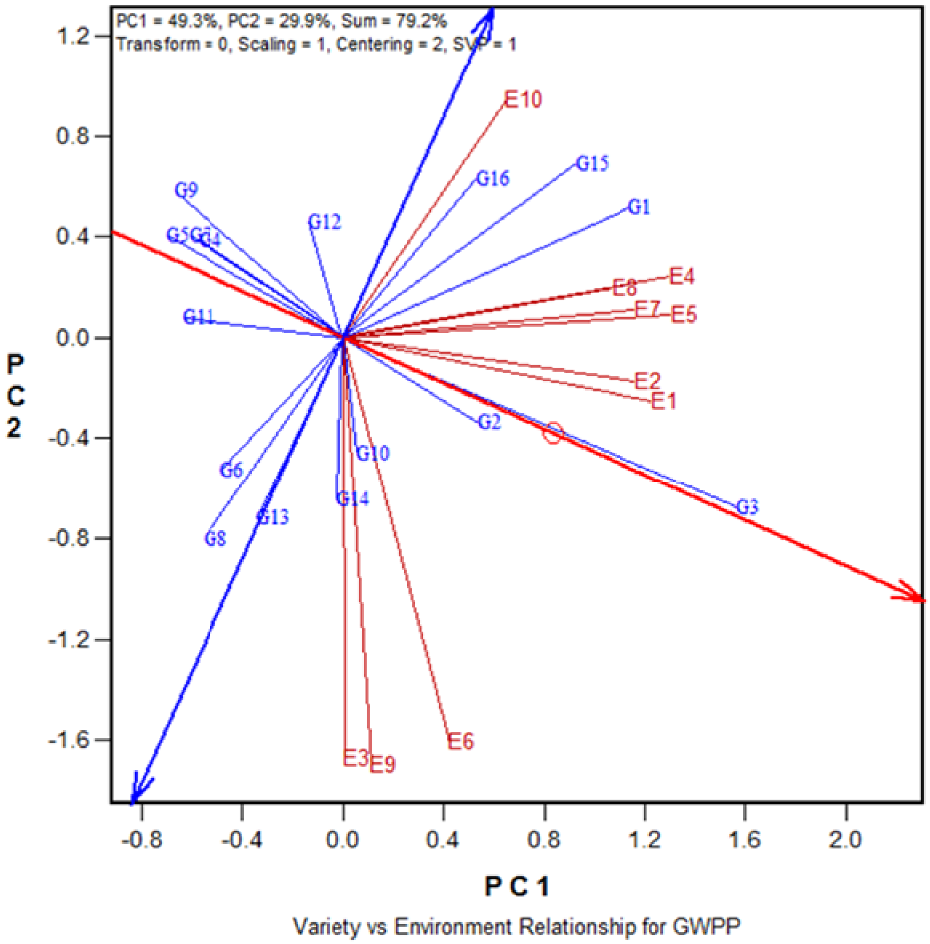

Figure 3: Variety by environmental relationship for grain weight per plant (GWPP) of rice genotypes (G) evaluated under different moisture-centered environments (E)

The discriminating ability and representativeness of the levels of moisture stress and the influence on grain production is as presented in Figure 3. It would appear that some of the imposed discriminating moisture levels can be removed in genotype evaluation for moisture stress (Yan *et al*., 2007). Environments 4, 5, 7 and 8 appeared to be similar in their discriminating ability with respect to moisture stress as all genotypes performed poorly, owing, naturally to poor moisture. The environments can be duly represented by E4 without losing any significant information. E1 and E2 appeared to be most representative in imposing drought condition and following the suggestions of Yan *et al*. (2007), either of the two should be useful enough. Similar conclusion can be drawn for E3, E6 and E9 also have similar capacity for discriminating the genotypes. Environment 10 was a rainfed condition with excessive moisture over the cultivation period and was also quite discriminating. Such environment with adequate moisture as it seems would be good for determining best performer in terms of grain production but would obviously not serve the purpose for identifying drought tolerant ones. In terms of moisture based screening for drought tolerance, some overlap in the amount of moisture and spread is obvious and can be of value in reducing screening cost. For instance, moisture spread would be capable of drought representation than actual amount of water available, once it did not reach acute shortage as in environment 9. Consequently, either of 100% or 75% moisture, spread over fairly evenly spaced applications would be appropriate. From the foregoing, E1, E3, E4, E6 and E10 would be appropriate for discriminating among genotypes for grain production under variable soil moisture.

Nonetheless, across the environments, grain weight had significant positive correlation ($p<0.01$) with root volume (0.990), root dry weight (0.972), tiller number (0.943), plant height, (0.948), shoot dry weight (0.986), spikelet number per panicle (0.961), grain weight per panicle (0.967). It was also significantly correlated ($p<0.05$) with 100-grain weight (0.695) and spikelet fertility (0.759) (Table 6). This underscores the largely linear response of the traits to increasing moisture level and would therefore make selection easier irrespective of the moisture condition of the selection environment. For development of genotypes with a good combination of stable, drought tolerance, and high grain yield, it would appear that genotype 3 would be a source of integration of genes for such attributes.

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