USE OF DROUGHT TOLERANCE INDICES AS A PRELIMINARY EVALUATION TECHNIQUE IN THE SCREEN HOUSE FOR SOME SELECTED UPLAND RICE VARIETIES TO SOIL MOISTURE STRESS AT DIFFERENT STRESS INTENSITIES

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Abstract

A trial was conducted in the screen house of the Department of Plant Physiology and Crop Production, College of Plant Science and Crop Production, Federal University of Agriculture, Abeokuta, Nigeria, in October, 2011. The trial aims to evaluate upland rice varieties for moisture stress tolerance at different stress intensity. Thirteen upland rice varieties were selected and subjected to moisture stress for twenty days at different phenological stages. Yield data at different growth stages were used for the analysis of drought tolerance indices. The trial was in a completely randomised design, replicated three times. At reproductive and grain filling stages , NERICA 4 had comparatively superior performance as indicated by its higher stress tolerance attributes; Stress tolerance index and geometric mean productivity (STI and GMP, respectively) and yield attributes (Yield stability index (YSI), yield index (YI) and actual yield). This could have implied that this variety is a better choice under both optimal and sub-optimal water regimes. Conversely, CG 14 across all growth stages had poor performance as indicated by its higher stress susceptibility index (SSI), which is negatively correlated to GMP and STI, especially at grain filling growth stage. This variety is not suited for both optimal and sub-optimal water regimes.

Keywords: Stress intensity, actual yield, potential yield, drought tolerance attributes, soil moisture stress

Introduction

Rice consumption in the developing countries of the world had been on the rise due to changes in demographic profile of the populace (Bamidele *et al*., 2010) and the ease of its preparation (Ojogho and Erhabor, 2011). Rice production is constrained by biotic and abiotic factors, especially among resource challenged famers in Africa, where rainfall pattern was observed to be more erratic than before (Lafitte *et al*., 2002), likely to be caused by changes in global climate.

In recent years there has been the introduction of New Rice for Africa (NERICA) by Africa Rice Center (AfricaRice) to ameliorate the negative impact of abiotic stressors in rice production (Jones *et al*., 1997; Dingkuhn *et al*., 1998; FAO, 2007). Ikedia, (2004) reported that compared to lowland rice (1.4 – 5 t ha^{-1}), upland rice has a lower yield potential (approximately 1 t ha^{-1}), where its rapid adoption was necessitated by serious problem in the management of fresh water (Chapagain and Yamaji, 2010). From an agronomic perspective, yield remains a major criterion in the evaluation of upland rice performance rapidly in the screen house situation. There is the need to have parameters that could evaluate tolerance to stress in field and screen house conditions. Available literature indicated that genotypes could be categorized into four based on their performances under sub-optimal and optimal growth conditions (Fernandez, 1992). Some genotypes are capable of performing under sub-optimal and optimal growth condition (category A). Others could only attain their yield potential under optimal growth condition (category B). Categories C are those that have high actual yield under sub-optimal growth condition, while category D would not reach their genetic potential under both sub-optimal and optimal growing conditions (Fernandez, 1992). Mean productivity (MP) could not distinguish between cultivars in categories A and B, while tolerance (TOL) and stress susceptibility index (SSI) could not distinguish between cultivars in categories A and C. Geometric mean productivity and Stress tolerance indexes were observed to discriminate cultivars in category A from others, thereby allowing the agronomist to evaluate crop performance in both sub-optimal and optimal growth conditions unlike what is obtainable from other listed stress evaluation parameters (Fernandez, 1992).

The objective of this trial was to evaluate some selected upland rice varieties for moisture stress tolerance at different stress intensity under screen house condition.

Materials and Methods

Site characterisation

A pot experiment was conducted in the screen house of the College of Plant Science and Crop Production, Federal University of Agriculture, Abeokuta in October, 2011 (late cropping season). The soil used was a sandy loam soil that has been on bush fallow for some years (> five years), which permitted easy drainage of water and allows root respiration. Full dose of phosphorus and potassium (30 kg ha^{-1}) and half dose of nitrogen was applied to the soil as basal nutrient using N:P:K 15:15:15: fertilizer while the remaining half dose of nitrogen (50 kg ha^{-1}) was applied three weeks after planting using urea before imposition of stress.

Cultural practice

Before planting, the soil was maintained to 100 % field capacity using the gravimetric method.

Semi-coned buckets were filled with 10 kg of soil, watered to field capacity and allowed to drain, later planted with thirteen varieties of upland rice (NERICA 1-4, NERICA 7-8, ART 19-25-1-B, ART 26-3-1-B, Moroberekan, WAB 56-104, AC 103549, CG 14 and Ofada). Two to three seeds of each variety were planted per hole to a depth of about 2-3 cm. The plants were thinned to one plant per stand ten days after sowing (DAS). The pots were maintained to field capacity for 21 days after which moisture stress was imposed. The amount of water supplied to the pots daily was determined through differences in weight at full field capacity and water loss to evapotranspiration (sowing to vegetative growth stage), while between vegetative to reproductive growth stage amount of water supplied was based on the degree of soil surface dryness (visual observation), as reported by Yoshida and Hasegawa, (1982).

Treatments and design

Soil moisture stress was imposed on all the thirteen varieties at 21 days after sowing (DAS) (vegetative), 50 DAS (reproductive), and 70 DAS (grain filling). The pots were arranged in a completely randomised design and replicated three times. Soil moisture stress was imposed once at a particular stage during the crop growth cycle of all stressed plants except the control. The duration of soil water deficit was 20 days at each growth stage and data were collected at 0 (Beginning), 10 (Middle) and 20 (end) days moisture stress duration.

Sampling and measurements

Yield plant^{-1} was determined at the end of the trial for each growth stage, which together with the yield of control varieties was used for the determination stress tolerance indices. The following stress tolerance indices were determined; stress tolerance index (STI), stress susceptibility index (SSI), yield index (YI), yield stability index (YSI), geometric mean productivity (GMP), mean productivity (MP) and tolerance (TOL). STI and GMP were computed according to the formula provided by Fernandez, (1992). Fischer and Maurer, (1978) provided the computation for SSI. YI was determined according to Gavuzzi *et al*., (1997) and Lin *et al*., (1986). YSI was determined according to Bouslama and Schapaugh, (1984). MP and TOL were computed according to Hossain *et al*., (1990).

$$MP = \frac{y_p + y_s}{2}$$

$$TOL = y_p - y_s$$

$$STI = \frac{y_p + y_s}{\bar{y}_p^{2}}$$

$$SSI = \frac{1 - (y_s/y_p)}{1 - (\bar{y}_s / \bar{y}_p)}$$

$$GMP = (y_p \times y_s)^{0.5}$$

$$\text{Yield Index (YI)} = \frac{y_s}{\bar{y}_s}$$

$$\text{Yield Stability Index (YSI)} = \frac{y_s}{y_p}$$

Where y_s and y_p are Yield under suboptimal and optimal growing conditions respectively. $\bar{y}_s$ and $\bar{y}_p$ are means of stressed and unstressed plant

Statistical analysis

Principal component analysis was conducted on drought tolerance indices .The statistical package used for analysis and for plotting PCA biplot was Genstat 12th Edition.

Results

Drought tolerance indices of some selected upland rice varieties

Stress intensity increased with increasing growth of rice as expressed by stress intensity index. The order of stress intensity was vegetative < reproductive < grain filling growth stages. Table 1 indicates stress tolerance attributes of upland NERICA rice at vegetative growth stage. At this growth stage NERICA 2 had higher yield potential (Us), MP, GMP and STI. NERICA 1 was the least susceptible cultivar with lowest SSI, however with a higher TOL than others. It was observed that YI was lowest in NERICA 4, while NERICA 1 had the lowest YSI. ART 26-3-1-B had higher actual yield (St) than the rest. NERICA 8 had the lowest TOL with the highest YI. Variety CG 14 had the least productivity and the most susceptible to moisture stress, conversely with the highest YSI.

Table 2 indicates stress tolerance attributes of upland rice varieties at reproductive growth stage. At this growth stage NERICA 4 had highest actual yield (St) with highest STI, YI and YSI, with the least SSI. Conversely, CG 14 maintained lowest yield potential (Us) and MP, with the lowest TOL and the most susceptible to moisture stress. NERICA 2 had a highest yield potential (Us), MP and TOL. It was observed that NERICA 1 had a highest GMP. At higher stress intensity (grain filling stage) similar pattern was observed for NERICA 4 and CG 14 (Table 3).

At vegetative stage PC1 accounted for 77.71 % variation among the genotypes, while the PC2 was 14.71 % (Table 4). The cutoff limits for vector loading was 0.3 according to Raji, (2002). Vector loading greater than 0.3 was considered to have contributed to the variability on principal component, while lower values than the cutoff limit was not considered. PC1 could be called susceptibility component, while PC2 could be called productivity component (Table 4). At reproductive growth stage, PC 1 and PC 2 accounted for 91.46 % and 8.42 % variation respectively (Table 4).While PC 1 had 83.17 % and PC 2 had 16.83 % variation at grain filling stage (Table 4). With increasing stress intensity MP, TOL and yield potential accounted for PC1, while GMP and YI accounted for PC2 (Table 4).

At vegetative growth stage there is a strong positive correlation among MP, STI and GMP (Fig. 1). However, TOL and yield potential (Us) had a negative correlation with SSI and YSI. Five clusters of upland rice varieties were identified. Cluster 1 (NERICA 1), cluster 2 (Moroberekan, NERICA 7, WAB 56-104, Ofada, NERICA 3, NERICA 4, ART 26-3-1-B and NERICA 8), cluster 3 (ART 19-25-1-B and NERICA 2), cluster 4 (AC 103549) and cluster 5 (CG 14).

There was a negative correlation between SSI with other drought tolerance attributes (YSI, STI, St and YI) at reproductive growth stage, while a weak positive correlation was observed among MP, US and TOL (Fig. 3). Fours clusters were observed at this growth stage. Cluster 1 (NERICA 1), cluster 2 (WAB 56-104 and NERICA 4), cluster 3 (ART 19-25-1-B, NERICA 2) and cluster 4 (ART 26-3-1-B, NERICA 7, NERICA 3, MOROBEREKAN, Ofada, NERICA 8, AC 103549, CG 14).

At grain filling stage similar correlation pattern was established (Fig. 5). However, three clusters were identified. Cluster 1 (NERICA 1, ART 19-25-1-B and NERICA 2) cluster 2 (ART 26-3-1-B, NERICA 7, NERICA 3, WAB 56-104, Moroberekan, Ofada, NERICA 8, AC 103549, CG 14) and cluster 3 (NERICA 4).

Discussion

Increasing stress intensity along the ontogeny of rice could be attributed to the metabolic cost encountered along the growth stages. Though grain filling stage requires lesser maintenance cost compared to other growth stages (Ploschuk and Hall, 1997), due partly to the presence of storage macromolecules, however, presence of soil moisture stress could necessitate more maintenance respiration for phenotypic acclimation (Vierstra, 1993). Comparatively earlier growth stages would require more metabolic cost for growth than maintenance of cellular structures. The low performance of variety CG 14 at vegetative stage despite low stress intensity index could be attributed to its high SSI, which is negatively correlated with TOL and yield potential of rice, making it difficult to separate the performance of this variety under sub-optimal water regime. Similar explanation could be adduced to the performance of variety AC 103549. Conversely, NERICA 2 had better performance, which could be attributed to its higher GMP, MP and STI that had positive correlations. Available literature had indicated that STI is better indicator crop performance under stress and non-stress conditions (Fernandez, 1992).

Increasing intensity of stress indicated that NERICA 4 had a better performance than other varieties. Its superior performance at both reproductive and grain filling stages could be attributed to its higher stress tolerance attributes (STI and GMP) and yield stability (YSI, YI and actual yield). These attributes had positive correlations, but negatively were correlated with SSI. The implication is that NERICA 4 could give good yield under both sub-optimal and optimal water regime. Poor performance of other varieties could be attributed to their susceptibility to soil moisture stress. Such varieties could have incurred more metabolic cost to adapt to soil moisture stress at the expense of high performance, since there is a limited resource available to rice plant for both growth and adaptation. NERICA 1, NERICA 2 and ART 19-25-1-B could only exhibit high performance under optimal condition as reflected in high MP, TOL and yield potential. These preliminary finding could serve as a basis for further field evaluation of promising varieties to soil moisture stress across different locations to validate the result of this screen house trial.

Conclusion

Varietal variability with respect to performance and moisture stress tolerance was observed with increasing moisture stress intensity. NERICA 4 was observed to be the most tolerant to soil moisture stress, with NERICA 1, NERICA 2 and ART 19-25-1-B, occupying intermediate position. The remaining varieties were susceptible to soil moisture stress.

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Table 1: Stress tolerance attributes of upland rice varieties when subjected to stress at vegetative growth stage.

Varieties	Us	St	MP	TOL	SSI	GMP	STI	YI	YSI
NERICA 1	15.79	5.915	10.8525	9.875	-6.7848174	9.664256	1.07293544	0.580471	0.374604
NERICA 2	21.45333	13.87667	17.665	7.57666667	-3.8314803	17.25401	3.41992553	1.361793	0.64683
NERICA 3	8.936667	12.02	10.47833	-3.0833333	3.7430714	10.3643	1.23400449	1.179588	1.345021
NERICA 4	7.365	3.943333	5.654167	3.42166667	-5.0402043	5.389123	0.33363604	0.386981	0.535415
NERICA 7	8.976667	9.16	9.068333	-0.1833333	0.22156927	9.06787	0.94459857	0.898921	1.020423
NERICA 8	6.053333	17.245	11.64917	-11.191667	20.0578034	10.21713	1.19920795	1.692345	2.848844
ART 19-25-1-B	15.78667	13.62667	14.70667	2.16	-1.4843848	14.66696	2.47125058	1.337259	0.863176
ART 26-3-1-B	9.216667	16.47667	12.84667	-7.26	8.54566634	12.32315	1.74453605	1.616945	1.787703
MOROBEREKAN	7.85	7.47	7.66	0.38	-0.5251666	7.657643	0.67363861	0.733072	0.951592
WAB 56-104	8.67	10.14	9.405	-1.47	1.83942223	9.376236	1.00993579	0.995093	1.16955
AC 103549	2.665	8.296667	5.480833	-5.6316667	22.9257167	4.702193	0.25400225	0.814197	3.113196
CG 14	0.81	3.96	2.385	-3.15	42.1899225	1.790977	0.03684825	0.388616	4.888889
OFADA	7.706667	10.33	9.018333	-2.6233333	3.69292166	8.922436	0.9145419	1.013739	1.340398

Us- Unstressed, St- Stressed, MP-Mean productivity, TOL- Stress tolerance, SSI-Stress susceptibility index, GMP-Geometric mean productivity, STI-Stress tolerance index, YI-Yield index, YSI-Yield stability index.

Table 2: Stress tolerance attributes of upland rice varieties when subjected to stress at reproductive growth stage.

Varieties	St	Us	MP	TOL	SSI	GMP	STI	YI	YSI
NERICA 1	0.9333333	15.79	8.361667	14.85667	0.9689307	3.838923	0.05910914	3.45679	0.059109
NERICA 2	0	21.4533	10.72665	21.4533	1.0298013	0	0	0	0
NERICA 3	0	8.93667	4.468335	8.93667	1.0298013	0	0	0	0
NERICA 4	1.3666667	7.365	4.365833	5.998333	0.838709	3.172617	0.18556234	5.061728	0.185562
NERICA 7	0	8.97667	4.488335	8.97667	1.0298013	0	0	0	0
NERICA 8	0	6.05333	3.026665	6.05333	1.0298013	0	0	0	0
ART 19-25-1-B	0	15.7867	7.89335	15.7867	1.0298013	0	0	0	0
ART 26-3-1-B	0	9.21667	4.608335	9.21667	1.0298013	0	0	0	0
MOROBEREKAN	0	7.85	3.925	7.85	1.0298013	0	0	0	0
WAB 56-104	1.1866667	8.67	4.928333	7.483333	0.888852	3.207554	0.13687043	4.395062	0.13687
AC 103549	0	2.665	1.3325	2.665	1.0298013	0	0	0	0
CG 14	0	0.81	0.405	0.81	1.0298013	0	0	0	0
OFADA	0	7.70667	3.853335	7.70667	1.0298013	0	0	0	0

Us- Unstressed, St- Stressed, MP-Mean productivity, TOL- Stress tolerance, SSI-Stress susceptibility index, GMP-Geometric mean productivity, STI-Stress tolerance index, YI-Yield index, YSI-Yield stability index.

Table 3: Stress tolerance attributes of upland rice varieties when subjected to stress at grain filling growth stage.

Varieties	Us	St	MP	TOL	SSI	GMP	STI	YI	YSI
NERICA 1	15.79	0	7.895	15.79	1.0120404	0	0	0	0
NERICA 2	21.45333	0	10.72667	21.45333	1.0120404	0	0	0	0
NERICA 3	8.936667	0	4.468333	8.936667	1.0120404	0	0	0	0
NERICA 4	7.365	1.44333	4.404165	5.92167	0.8137093	3.260387	0.1959715	13.12118	0.195971
NERICA 7	8.976667	0	4.488333	8.976667	1.0120404	0	0	0	0
NERICA 8	6.053333	0	3.026667	6.053333	1.0120404	0	0	0	0
ART 19-25-1-B	15.78667	0	7.893333	15.78667	1.0120404	0	0	0	0
ART 26-3-1-B	9.216667	0	4.608333	9.216667	1.0120404	0	0	0	0
MOROBEREKAN	7.85	0	3.925	7.85	1.0120404	0	0	0	0
WAB 56-104	8.67	0	4.335	8.67	1.0120404	0	0	0	0
AC 103549	2.665	0	1.3325	2.665	1.0120404	0	0	0	0
CG 14	0.81	0	0.405	0.81	1.0120404	0	0	0	0
OFADA	7.706667	0	3.853333	7.706667	1.0120404	0	0	0	0

Us- Unstressed, St- Stressed, MP-Mean productivity, TOL- Stress tolerance, SSI-Stress susceptibility index, GMP-Geometric mean productivity, STI-Stress tolerance index, YI-Yield index, YSI-Yield stability index

Table 4: Eigen vectors, proportion and Eigen value of stress tolerance attributes at vegetative stage, reproductive and grain filling stages of moisture stress.

Stress tolerance attributes	Growth stages					
	Vegetative		Reproductive		Grain filling	
	PC 1	PC 2	PC 1	PC 2	PC 1	PC 2
GMP	0.17809	0.42205	0.02587	0.58255	0.01772	0.23771
MP	0.16808	0.43657	0.33532	0.12800	-0.32718	0.09494
SSI	-0.88120	0.17508	0.00031	-0.02379	-0.00108	-0.01446
STI	0.03442	0.09406	-0.00030	0.02310	0.00107	0.01429
St	0.03948	0.62214	0.00319	0.20466	0.00785	0.10523
TOL	0.25719	-0.37113	0.66426	-0.15333	-0.67005	-0.02059
Us	0.29667	0.25100	0.66745	0.05134	-0.66221	0.08464
YI	0.00387	0.06105	0.01182	0.75801	0.07132	0.95666
YSI	-0.08123	0.01614	-0.00030	0.02310	0.00107	0.01429
Proportion	77.71	14.71	91.46	8.42	83.17	16.83
Eigen value	2922.0	553.0	824.6	75.9	835.4	169.0

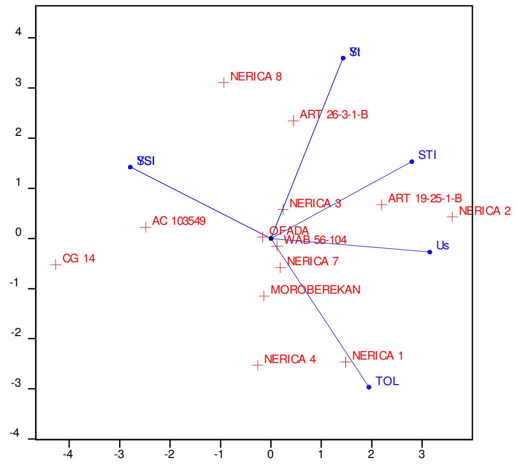

Fig. 1. Biplot of stress tolerance attributes and varieties at vegetative growth stage.

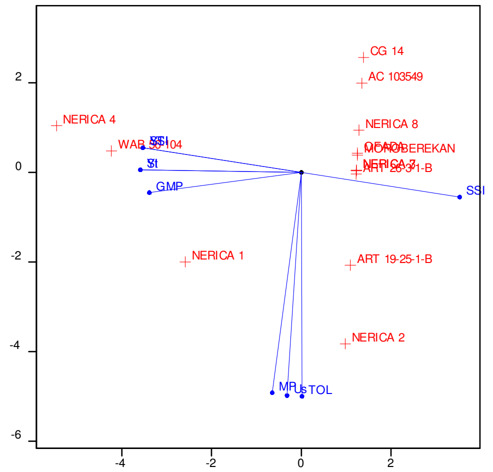

Fig. 3. Biplot of stress tolerance attributes and varieties at reproductive growth stage.

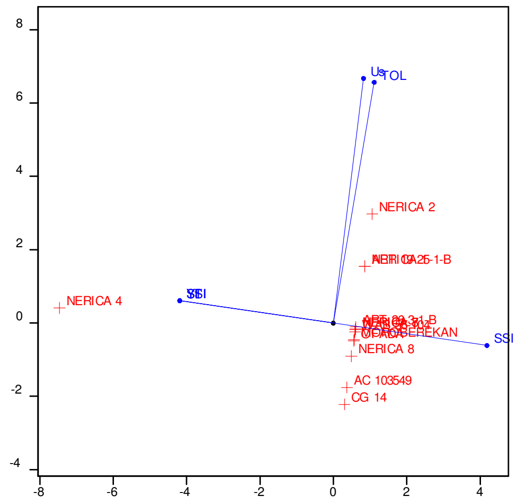

Fig. 5. Biplot of stress tolerance attributes and varieties at grain filling growth stage.