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ROOT RESPONSE OF SOME SELECTED RICE VARIETIES TO SOIL MOISTURE STRESS AT DIFFERENT PHENOLOGICAL STAGES

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ABSTRACT

Physiological adjustment in plant root system is a determinant for survival and crop productivity in situation of moisture stress. A screen house experiment was conducted to access response of rice roots to moisture stress. Thirteen varieties of rice comprising six NERICAs, WAB 56-104, CG 14, ART26-3-1-B, AC 103549, MOROBEREKAN, ART19-25-1-B and a local check (OFADA) were subjected to twenty-day moisture stress once at each phenological stage. Results indicated that root growth generally showed preference over shoot growth. Moisture stress did not affect root volume (RV), deep root numbers (DRN), root dry weight (RDW) and root depth (RD) of all the rice varieties at reproductive stage. CG14 however recorded 67.6% increase in RD at this stage while NERICA 3, CG14 and OFADA recorded an increase in root depth: shoot length. At vegetative and grain filling stages, RV, DRN, RDW, RD, and RMC were significantly ($p< 0.05$) increased by moisture stress in most rice varieties. NERICA2, NERICA7, ART26-3-1-B, MOROBEREKAN and WAB56-104 however recorded 54%, 76.5%, 72.7%, 57.1%, and 56.3% significant reduction in DRN respectively at vegetative stage. Correlation analysis showed that plant height, leaf area, and number of tillers depend highly on, RD, RV, RDW and deep root weight. Therefore, attention should be focused on these parameters in selection for moisture stress tolerance in rice.

Keywords: Moisture stress, Phenological stages, Root system, Rice

INTRODUCTION

The performance of a crop in a given environment depends mostly on how well the plant can tap the available resources using its root system. The environmental conditions under which the plant grows in turn determine its ability to explore these resources. Moisture stress is one of the most important abiotic factors that limits crop productivity and which often results into considerable yield reduction (Boyer, 1985). It affects almost all physiological processes of plant including transpiration, respiration and photosynthesis. Plants undergoing moisture stress display various mechanisms such as tolerance, escape, recovery, and avoidance to cope with the stress. The use of the root systems in tapping the limited moisture within its environment is categorized under an avoidance mechanism as plants make use of them to search for water deep down the soil profile to survive period of low water status (Price *et al*., 2002)

The nature and extent of root characteristics are considered to be major factors affecting plant response to water stress (Abd Allah, 2010). Rice is often described as a shallow-rooted crop and the susceptibility of rice to drought is attributed to its shallow rooting habit. Deep root-to-shoot ratio is one way to characterize depth growth of a rice root system. The deep root-to-shoot ratio is based on the concept that the ability of a variety to absorb water from the deep soil layers is one important characteristic determining a variety's avoidance of drought since soil drying starts with the surface soil during drought.

The soil moisture has a profound impact on root growth, viability and functionality and thus plant growth (Huang *et al*., 1999). Root growth is controlled genetically and also influenced by environmental factors. Root growth, in terms of weight, number, and gross morphology appears to reach its maximum around flowering (Yoshida and Hasegawa, 1982). Branching, however, continues to produce new active portions of the root system until maturity. Those active portions may have important functions during the grain filling period (Kawata and Soezima, 1974). Research at the International Rice Research Institute (IRRI) demonstrated that a highly developed root system was the most important mechanism needed to maintain an adequate flow of water to the canopy during extended dry periods (Steponkus *et al*., 1980). Greater root depth and density of rice plants resulted in more available water and nutrients during periods of drought, and these plants maintain a more uniform transpiration rate (O'Toole, 1982). Varieties with a high deep-root weight to shoot weight ratio exhibit enhanced drought resistance in upland rice (Fukai and Cooper, 1995; Yamauchi and Aragones, 1997). Results of the studies indicated that most drought resistant varieties remained tall during water stress while susceptible varieties were reduced in height. Plant height is positively significantly correlated with root length; root thickness and dried shoot weight (Mao, 1984).

Upland rice root system has few thick and long roots with large xylem vessels capable of water extraction in the deep soil layers (Fukai and Cooper 1995; Nguyen *et al*., 1997). This type of root system is usually associated with plants having a moderate tillering capacity which is linked to extensive production of adventitious roots, which in turn reduces the amount of assimilates available for existing roots to grow deeper (Nguyen *et al*., 1997). This characteristic is crucially considered important in determining drought tolerance in upland rice and substantial genetic variation exists for this (Ekanayake, *et al*., 1985; Fukai and Cooper, 1995; O'Toole, 1982); Yoshida, and Hasegawa, 1982). The shoot environment can also indirectly influence root growth either via carbon supply or signaling processes (e.g. light interception, nutrient status, and water status). It has been earlier reported that plants respond to shifts in resource supply by allocating carbon to the organ involved in capturing the limited resource (Thornley, 1972; Dewar, 1993). Therefore dry matter accumulation to roots as an organ responsible for capturing water during period of moisture stress is important for the survival and adaptability of moisture stressed rice. Information with respect to change in dry matter accumulation between culm and leaf of rice and its dependence on the age of the plant and stress condition is scarce. Similarly, the relationship between the dry matter accumulated to roots and varieties of rice has not been previously reported. It is therefore necessary to evaluate the response of root parameters in the support of the above ground part as condition for selection for tolerance to soil moisture stress.

MATERIALS AND METHODS

Experimental design and procedure

An experiment was conducted inside the Screen house of the College of Plant Science and Crop Production, Federal University of Agriculture, Abeokuta in October, 2011 (late season) using PVC pipes of 90cm long and 13cm in diameter for below ground screening of 13 different varieties of rice. The PVC pipes were arranged in a Completely Randomised Design. The soil used was a sandy loam soil that has been on bush fallow for several years (> five years), which permitted easy drainage of water and allows easy penetration and respiration of the roots. Full dose of phosphorus and potassium at 30kg/ha and 30kg/ha of nitrogen at 80kg/ha to be applied to the soil was applied as basal using N:P:K 15:15:15: fertilizer while the remaining dose of nitrogen (50kgN) at 80kg/ha was top dressed three weeks after planting using urea before imposition of stress.

Before planting, the soil was maintained at 100% field capacity using the gravimetric method of field capacity determination:

$$\text{Field capacity at } 100\% = \frac{\text{Saturated soil weight} - \text{dry soil weight (air dried)}}{\text{Dry soil weight}}$$

The PVC pipes were filled with 23kg of the soil and planted with thirteen varieties of rice. Two-three seeds of each variety were planted per hole to a depth of about 2-3cm and later thinned to one plant per stand ten days after sowing (DAS)

The PVC pipes were maintained to field capacity for 21 days (vegetative stage), 50 days (reproductive stage) and 70 days (grain filling stage) after which 20 day-moisture stress was imposed on all the thirteen rice varieties. At the seedling stage the amounts of water given to the PVC pipes daily were determined through weighing to determine water loss to evapotranspiration while at full canopy formation, watering was done based on drying of the soil surface. At the end of the stress period, the roots were carefully separated from the soil.

Data collection

The following parameters were taken at the end of imposition of soil moisture stress at each stage of rice phenology; number of tillers and leaf area, root depth, deep root (root longer than 30cm) and shallow root (root shorter than 30cm) length and numbers, root volume determined through Archimedes principles, root moisture content, root depth to shoot length ratio, and root weight to shoot dry weight.

Statistical analysis

Data collected were subjected to Analysis of Variance (ANOVA) at 5% probability level and Fisher's Protected Least Significant Difference (LSD) was used to separate means

(Steel and Torrie, 1980). The root-shoot ratio, the shallow and deep root numbers were all transformed using square root transformation and the LSD of the transformed data was used to separate the means (Gomez and Gomez, 1984). The statistical package used for the analysis was GENSTAT, 2012, 12th Edition.

RESULTS

Below ground part response of rice to moisture stress

Table 1 shows the interaction of stress status x varieties on root volume of the rice varieties. Generally, moisture stress induced non-significant increase in root volume in all the rice varieties at all phenological stages except NERICA 7 and NERICA 8 at vegetative stage and CG 14 at grain filling stage. However, 177.7% and 66.6% significant increase in root volume was observed in NERICA 3 and AC 103549 at vegetative stage respectively while NERICA 3, ART 19-25-1-B, MOROBEREKAN, and WAB 56-104 recorded 146%, 257%, 85.6% and 122.2% significant increase in root volume respectively at grain filling stage. At the reproductive stage, NERICAs, CG14 and MOROBEREKAN varieties recorded a non-significant reduction in root volume when stressed while NERICA 3 and other varieties showed a non significant increase in root volume

Table 2 shows the interaction of stress status x varieties on deep root number of the rice varieties. At vegetative stage, moisture stress induced significant reduction in NERICA 2 and 7, ART 26-3-1-B, MOROBEREKAN and WAB 56-104 while at grain filling stage, an increase in deep root number was observed in NERICA 4 and ART 19-25-1-B with ART 19-25-1-B recording higher percentage increase of 131.9% when subjected to moisture stress.

Table 3 presented data on the interaction of stress status x varieties on root dry weight of the rice varieties. Moisture stress induced an increase in root dry weight of most of the varieties at vegetative and grain filling stages. Significant increase in root dry weight was observed in ART 19-25-1-B at vegetative and grain filling stages. At grain filling stage NERICA 3, MOROBEREKAN and OFADA also recorded a significant increase in root dry weight. Across the phenological stages, NERICA 7 recorded a reduction in root dry weight which was only significant at the vegetative stage.

Table 4 shows the interaction of stress status x varieties on root depth of rice varieties subjected to 20 days moisture stress. At vegetative stage 78.1% significant increase in root depth was observed in NERICA 1 and NERICA 4 while at reproductive and grain filling stages, CG 14 and NERICA 1 recorded 67.6% and 44.6% increase in root depth respectively

Table 5 shows the interaction of stress status x varieties on root moisture content of the rice varieties. Most of the rice varieties recorded increase in root moisture content at vegetative and reproductive stages. At vegetative stage, NERICA 7 recorded a 53.6% significant increase in root moisture content when stressed. At reproductive stage, MOROBEREKAN recorded 32.8% significant increase while NERICA 4 recorded 29.1% significant decrease in root moisture content at this stage. At grain filling stage, moisture stress did not cause a significant change in root moisture content in all the rice varieties.

Table 1: Interaction Of Stress Status X Varieties On Root Volume (Ml) Of Rice Varieties Subjected To 20 Days Moisture Stress At Different Phenological Stages Of Growth

	Vegetative			Reproductive			Grain Filling		
	Us	St	Change in volume (%)	Us	St	Change in volume (%)	Us	St	Change in volume (%)
NERICA 1	3.00f	5.33c-f	+77.7	32.10ab	20.00b	-37.7	6.50h	24.67c-h	+279.5
NERICA 2	5.67b-f	7.33b-f	+29.3	26.30ab	19.33b	-26.5	21.0d-h	49.00b-e	+133.3
NERICA 3	3.00f	8.33b-e	+177.7	36.67ab	37.67ab	+2.7	21.00d-h	51.67bc	+146.0
NERICA 4	3.00f	5.33c-f	+77.7	33.80ab	20.01b	-40.8	18.02f-h	30.00b-h	+66.5
NERICA 7	6.50b-f	4.00ef	-38.5	38.80ab	34.93ab	-10.0	9.00h	15.04f-h	+67.1
NERICA 8	10.00a-c	6.00b-f	-40.0	37.50ab	25.33ab	-32.5	13.50gh	20.00e-h	+48.2
ART 19-25-1-B	6.33b-f	10.33ab	+63.2	25.40ab	26.67ab	+5.0	14.00gh	50.00b-d	+257.1
ART 26-3-1-B	7.67b-f	8.33b-e	+8.6	31.30ab	34.00ab	+8.6	18.00f-h	28.33b-h	+57.4
MOROBEREKAN	5.67b-f	8.50b-e	+49.9	45.00a	28.00ab	-37.8	44.00b-f	81.67a	+85.6
WAB 56-104	6.33b-f	9.33a-d	+47.4	28.33ab	36.67ab	+29.4	25.50e-h	56.67ab	+122.2
AC 103549	8.00b-e	13.33a	+66.6	23.33ab	26.67ab	+14.3	14.70gh	27.33c-h	85.9
CG 14	4.67d-f	8.00b-e	+71.3	27.08ab	24.00ab	-11.4	17.25f-h	12.50h	-27.5
OFADA	8.33b-e	8.67a-e	+4.1	33.33ab	35.00ab	+5.0	20.00e-h	42.33b-g	+111.7
LSD	4.73			19.76			29.04		

Means with same alphabets are not significantly different from one another along column and across stress status using Fisher's protected LSD at 5%
probability level
Us = Unstressed Stressed

Table 2: **Interaction Of Stress Status X Varieties On Deep Root Number Of Rice Varieties Subjected To 20 Days Moisture Stress At Different Phenological Stages Of Growth**

	VEGETATIVE			REPRODUCTIVE			GRAIN FILLING		
	Us	St	Change in number (%)	Us	St	Change in number (%)	Us	St	Change in number (%)
NERICA 1	11.00f-k	6.33jk	-42.5	42.50a-c	24.33a-c	-42.8	16.00gh	39.00a-g	+143.8
NERICA 2	21.33a-f	9.67g-k	-54.7	21.87bc	19.33c	-11.6	45.00a-e	58.00a	+28.9
NERICA 3	11.67f-j	10.00g-k	-14.3	35.42a-c	34.00a-c	-4.0	46.00a-e	54.33a-c	+18.1
NERICA 4	11.50f-j	6.67i-k	-42.0	56.88ab	39.95a-c	-29.8	55.37a	61.50h	+11.1
NERICA 7	17.00c-i	4.00k	-76.5	36.0a-c	33.98a-c	-5.6	21.75e-h	11.10h	-49.0
NERICA 8	15.00e-j	7.00h-k	-53.3	43.68a-c	26.67a-c	-38.9	21.50e-h	21.67e-h	+0.8
ART 19-25-1-B	27.33a-c	18.67b-g	-31.7	32.08a-c	43.00a-c	+34.0	23.50f-h	54.50ab	+131.9
ART 26-3-1-B	33.00a	9.00g-k	-72.7	30.42a-c	36.67a-c	+20.5	29.50c-h	37.33a-g	+26.5
MOROBEREKAN	21.00a-f	9.00g-k	-57.1	32.50a-c	23.67a-c	-27.2	55.50a	52.33a-d	-5.7
WAB 56-104	29.00ab	12.67f-j	-56.3	36.25a-c	27.00a-c	-25.5	53.00a-c	64.33a	+21.4
AC 103549	22.00a-f	11.33f-k	-48.5	39.58a-c	51.00a	+28.9	25.50d-h	45.67a-e	+79.1
CG 14	25.33a-d	13.67d-j	-46.0	36.67a-c	40.33a-c	+10.0	43.50a-g	39.00a-f	-10.3
OFADA	24.33a-e	16.00c-h	-34.2	25.42a-c	43.00a-c	+69.2	28.00b-h	40.00a-f	+42.9
LSD	1.35*			1.99*			2.16*		

Means with same alphabets are not significantly different from one another along column and across stress status using Fisher's protected LSD at 5% probability level
*LSD value was from transformed data
Us = Unstressed St= Stressed

Table 3: Interaction Of Stress Status X Varieties On Root Dry Weight (G) Of Rice Varieties Subjected To 20 Days Moisture Stress At Different Phenological Stages Of Growth

	Vegetative			Reproductive			Grain Filling		
	Us	St	Change in weight (%)	Us	St	Change in weight (%)	Us	St	Change in weight (%)
NERICA 1	0.59e-h	0.62e-h	+5.1	4.26a-b	2.33b	-45.3	1.96g	3.57e-g	+82.1
NERICA 2	1.89a-d	0.97c-h	-48.7	3.43ab	2.86b	-16.6	4.04d-g	5.91b-g	+46.3
NERICA 3	0.22h	1.05c-h	+377.3	4.05ab	3.69ab	-8.9	4.03d-g	8.04b-c	+100
NERICA 4	0.41f-h	1.18b-h	+195	`4.04ab	2.35b	-41.8	3.64e-g	5.52c-g	+52.1
NERICA 7	1.60a-f	0.33gh	-80.0	4.57ab	3.14b	-31.3	2.02g	1.57g	-22.8
NERICA 8	1.27b-h	1.27b-h	-	4.13b-e	2.77b	-32.9	2.51g	2.98fg	+19.2
ART 19-25-1-B	1.04c-h	2.35ab	+126.0	5.10ab	4.14ab	-18.8	4.14d-g	10.21a-c	+146.4
ART 26-3-1-B	1.54a-g	2.63a	+70.8	5.87ab	3.76ab	-35.9	6.27b-g	8.35b-c	+5.0
MOROBEREKAN	1.08c-h	1.19b-h	+9.3	7.42a	2.77b	-62.7	5.52c-g	10.43ab	+89.0
WAB 56-104	1.94a-c	1.10b-h	-43.3	4.83ab	4.10ab	-15.1	7.72b-f	8.52a-d	+10.4
AC 103549	0.87c-h	1.66a-e	+90.8	2.17b	2.44b	+12.4	2.90g	5.59c-g	+93.4
CG 14	0.68d-h	0.96c-h	+41.2	3.96ab	2.53b	-36.1	5.88b-g	3.06fg	-48.1
OFADA	1.04c-h	1.67a-e	+60.6	5.65ab	4.12ab	-27.1	4.89d-g	13.20a	+169.9
LSD	1.25			3.33			5.03		

Means with same alphabets are not significantly different from one another along column and across stress status using Fisher's protected LSD at 5% probability level

Us = Unstressed

St= Stressed

Table 4: Interaction of Stress Status X Varieties on Root Depth (Cm) of Rice Varieties Subjected to 20 Days Moisture Stress at Different Phenological Stages of Growth

	Vegetative			Reproductive			Grain Filling		
	Us	St	Change in depth (%)	Us	St	Change in depth (%)	Us	St	Change in depth (%)
NERICA 1	32.50ij	57.87a-d	+78.1	75.33a-f	82.00a-d	+8.9	52.33j	75.67b-h	+44.6
NERICA 2	53.00a-f	65.63ab	+23.8	81.00a-d	79.67a-d	-1.6	75.33b-h	83.67a-e	+11.1
NERICA 3	40.67e-j	52.67a-f	+29.5	78.17a-e	91.67a	+17.3	77.33b-g	98.33ab	+27.2
NERICA 4	31.00j	55.20a-e	+78.1	78.00a-e	80.96a-d	+3.8	81.96a-f	83.00a-e	+1.3
NERICA 7	52.25a-f	49.80c-g	-2.45	73.39b-g	81.96a-d	+11.6	66.50f-j	72.98c-i	+9.7
NERICA 8	54.83a-e	47.20d-i	-13.9	86.94ab	84.33a-c	-3.0	57.33ij	67.67e-j	+18.0
ART 19-25-1-B	33.33h-j	30.33j	-9.0	53.67gh	58.00f-h	+8.1	54.67j	53.00j	-3.1
ART 26-3-1-B	34.60g-j	38.47f-j	+11.1	58.00f-h	65.00d-h	+12.1	59.67h-j	54.67j	-8.3
MOROBEREKAN	67.73a	63.25a-c	-6.6	89.33ab	86.50ab	-3.2	88.67a-c	96.33a	+8.6
WAB 56-104	67.27a	67.33a	+0.1	78.67a-e	93.00a	+18.2	86.00a-d	88.33a-c	+2.7
AC 103549	53.00a-f	63.53a-c	+19.9	66.33c-h	75.67a-f	+14.1	62.00g-j	72.00d-i	+16.1
CG 14	45.83d-j	48.37c-h	+5.5	48.33h	81.00a-d	+67.6	52.67j	62.50g-j	+18.7
OFADA	45.83d-j	50.93b-f	+11.1	61.33e-h	75.33a-f	+22.8	66.33f-j	74.67b-h	+12.6
LSD	15.51			18.21			16.11		

Means with same alphabets are not significantly different from one another along column and across stress status using Fisher's protected LSD at 1% probability level
Us = Unstressed
St= Stressed

Table 5: Interaction of Stress Status X Varieties on Root Moisture Content (%) of Rice Varieties Subjected to 20 Days Moisture Stress at Different Phenological Stages of Growth

	Vegetative			Reproductive			Grain Filling		
	Us	St	Change in moisture (%)	Us	St	Change in moisture (%)	Us	St	Change in moisture (%)
NERICA 1	56b-d	78a-c	+39.3	68a-d	80a	+17.7	52cd	71a-c	+36.5
NERICA 2	69a-c	72a-c	+4.4.	66a-d	77ab	+16.7	66a-d	55b-d	-16.7
NERICA 3	55cd	73a-c	+32.7	69a-d	76a-c	+10.2	48d	67a-d	+39.6
NERICA 4	45d	62a-d	+37.8	79a	56d	-29.1	78a	65a-d	-16.7
NERICA 7	56b-d	86a	+53.6	68a-d	81a	+19.1	63a-d	75ab	+19.1
NERICA 8	69a-c	62a-d	-10.1	81a	72a-d	-11.1	67a-d	57a-d	-14.9
ART 19-25-1-B	76a-c	69a-c	-9.2	58cd	72a-d	+24.1	65a-d	58a-d	-10.8
ART 26-3-1-B	79ab	69a-c	-12.7	59b-d	77a	+30.5	55b-d	62a-d	+12.7
MOROBEREKAN	64a-d	67a-d	+4.7	58d	77ab	+32.8	74ab	67a-d	-9.5
WAB 56-104	66a-d	75a-c	+13.6	75a-c	65a-d	-13.3	69a-c	69a-c	-
AC 103549	74a-c	79a-c	+6.8	68a-d	81a	+19.1	52cd	69a-c	+32.7
CG 14	81ab	76a-c	-6.2	69a-d	77ab	+11.6	55b-d	66a-d	+20
OFADA	73a-c	73a-c	-	69a-d	76ab	+10.1	76a	65a-d	-14.5
LSD	11*			9*			10*		

Means with same alphabets are not significantly different from one another along column and across stress status using Fisher's protected LSD at 5% probability level
*LSD value was from transformed data
Us = Unstressed St = Stressed

Table 6: Interaction of Stress Status X Varieties on Root Depth: Shoot Length of Rice Varieties Subjected to 20 Days Moisture Stress at Different Phenological Stages of Growth

	Vegetative			Reproductive			Grain Filling		
			Change in weight			Change in weight			Change in weight ra-
	Us	St	ratio (%)	Us	St	ratio (%)	Us	St	tio (%)
NERICA 1	0.49g	0.78b-d	+59.2	0.74b-e	0.86ab	+16.2	0.50e	0.61b-e	+22.0
NERICA 2	0.80b-d	0.90ab	+12.5	0.76b-e	0.84a-c	+15.0	0.68a-d	0.61b-e	-10.3
NERICA 3	0.48g	0.68c-g	+41.7	0.72b-e	0.96a	+33.3	0.68a-d	0.61b-e	-10.3
NERICA 4	0.52fg	1.10a	+111.5	0.69b-f	0.77a-c	+11.6	0.70a-c	0.61b-e	-12.9
NERICA 7	0.80bc	0.72b-f	-10.0	0.66c-f	0.64d-f	-3.0	0.65b-e	0.53d-g	-18.5
NERICA 8	0.68b-g	0.58d-g	-14.7	0.73b-e	0.81a-d	+11.0	0.68a-d	0.61b-e	-10.3
ART 19-25-1-B	0.53e-g	0.53e-g	-	0.61ef	0.67c-f	+10.0	0.66b-e	0.61b-e	-7.6
ART 26-3-1-B	0.53e-g	0.69b-f	+30.2	0.69b-f	0.73b-e	+5.8	0.71a-c	0.61b-e	-14.1
MOROBEREKAN	0.78b-d	0.83bc	+6.4	0.77b-e	0.79a-d	+2.6	0.78ab	0.61b-e	-21.8
WAB 56-104	0.74b-e	0.89a-c	+20.3	0.76b-e	0.84a-c	+10.5	0.86a	0.61b-e	-29.1
AC 103549	0.59d-g	0.82bc	+39.0	0.55fg	0.65d-f	+18.2	0.50de	0.61b-e	+22.0
CG 14	0.55e-g	0.69b-f	+25.5	0.43g	0.77a-e	+79.1	0.55c-e	0.61b-e	+22.0
OFADA	0.55e-g	0.68c-g	+23.6	0.54fg	0.76b-c	+40.7	0.60b-e	0.61b-e	+1.7
LSD	0.10*			0.08*			0.05*		

Means with same alphabets are not significantly different from one another along column and across stress status using Fisher's protected LSD at 5% probability level

*LSD value was from transformed data

Us = Unstressed St= Stressed

The interaction of stress status x varieties on root depth: shoot length of rice varieties are presented in Table 6. There was increase in root depth: shoot length of all the rice varieties at vegetative and reproductive stages with the exception of NERICA 7 at both stages and NERICA 8 at vegetative stage. Significant increase in root depth: shoot length was however recorded by NERICA 1, 4, and AC 103549 at vegetative stage and by NERICA 3, CG 14, and OFADA at reproductive stage. The root depth: shoot length of all the rice varieties were not significantly affected by moisture stress at grain filling stage.

Above ground part response of rice to moisture stress

Tables 7 and 8 show the interaction of stress status and varieties on above ground parameters (leaf area and number of tillers) of rice varieties subjected to 20 day moisture stress. Moisture stress significantly reduced the above ground parts of all the rice varieties at grain filling stage except NERICA 7 with 21.2% non-significant decrease in leaf area and 104% non-significant increase in number of tillers. NERICA 1 and 3 recorded a non-significant reduction in number of tillers at grain filling stage. At reproductive stage ART 19-25-1-B and AC 103549 recorded 39.7% and 41.0% significant reduction in leaf area while NERICA 7 and 8 recorded 58.7% and 52.9% significant reduction in number of tillers respectively at the same stage.

The correlation values between the above ground and below ground parameters presented in Table 9 showed that the above ground parameters of rice are significantly influenced by root parameters. Root depth recorded the highest significant correlation with plant height (0.6413, $p < 1.00$) and leaf area (0.6164, $p < 1.00$) while the root dry weight recorded the highest significant correlation with number of tillers (0.5145, $p < 1.00$) and shoot dry weight (0.844, $p < 1.00$). The root volume and deep root number of the rice varieties appeared to be more prevalent among the first five root parameters that recorded the highest significant correlation with the above ground parts.

Table 7: Interaction of Stress Status X Varieties on Leaf Area (Cm^2) 0f Rice Varieties Subjected to 20 Days Moisture Stress At Different Phenological Stages Of Growth

	VEGETATIVE			REPRODUCTIVE			GRAIN FILLING		
	Us	St	Change in area (%)	Us	St	Change in area (%)	Us	St	Change in area (%)
NERICA 1	29.4e-i	35.3c-h	+20.0	63.0b-g	60.70c-h	-3.7	61.5b	0.00g	-100
NERICA 2	49.1a-c	30.6e-i	-37.7	71.60a-f	50.10f-h	-30.0	65.4b	0.00g	-100
NERICA 3	29.8e-i	37.8c-h	+26.9	76.20a-d	67.20a-g	-11.8	61.8b	0.00g	-100
NERICA 4	28.9f-i	16.5i	-42.9	63.70b-g	60.90b-h	-4.4	60.6bc	0.00g	-100
NERICA 7	59.8a	35.0c-h	-41.5	73.40a-e	83.70ab	+14.0	70.3b	55.4b-d	-21.2
NERICA 8	47.62a-d	23.0hi	-51.7	87.60a	69.20a-g	-21.0	52.70b-d	0.00g	-100
ART 19-25-1-B	33.3d-h	26.7g-i	-19.8	65.8a-g	39.70h	-39.7	50.00b-e	9.00fg	-82
ART 26-3-1-B	32.9d-h	27.8f-i	-15.5	56.2c-h	47.10gh	-16.2	37.6c-e	0.00g	-100
MOROBEREKAN	59.7a	42.4b-f	-29.0	86.7a	87.6a	+1.0	101.6a	0.00g	-100
WAB 56-104	46.8a-d	37.2c-h	-20.5	76.1a-d	69.6a-g	-8.5	56.4b-d	0.00g	-100
AC 103549	53.4ab	55.2ab	+3.4	87.9a	51.9e-h	-41.0	28.9ef	0.00g	-100
CG 14	54.8ab	37.5c-h	-31.6	67.8a-g	55.4d-h	-18.3	34.7de	0.00g	-100
OFADA	44.6a-e	42.0b-h	-5.8	78.6a-c	56.2c-h	-28.5	65.3b	0.00g	-100
LSD	15.36			22.83			23.10		

Means with same alphabets are not significantly different from one another along column and across stress status using Fishe2r's protected LSD at 1% probability level

Us = Unstressed

St= Stressed

Table 8: Interaction Of Stress Status X Varieties On Number Of Tillers Of Rice Varieties Subjected To 20 Days Moisture Stress At Different Phenological Stages Of Growth

	VEGETATIVE			REPRODUCTIVE			GRAIN FILLING		
	Us	St	Change in number (%)	Us	St	Change in number (%)	Us	St	Change in number (%)
NERICA 1	1.33h-k	2.67f-i	+100.1	5.00i-k	6.33f-k	+26.6	2.00d-f	0.00f	-100.0
NERICA 2	4.00e-h	5.67c-f	+41.8	6.33e-k	4.67i-k	-26.2	4.33c-e	0.00f	-100.0
NERICA 3	0.33jk	3.00e-i	+809.1	6.00g-k	4.67k	-22.2	2.67d-f	0.00f	-100.0
NERICA 4	2.01g-j	0.01k	-99.5	7.00f-k	4.01jk	-42.7	4.97b-e	0.00f	-100.0
NERICA 7	2.50f-j	1.00i-k	-60.0	9.72c-i	4.01jk	-58.7	1.00ef	2.04d-f	+104.0
NERICA 8	4.67d-g	3.33f-i	-28.7	16.98a	8.00c-k	-52.9	4.33c-e	0.00f	-100.0
ART 19-25-1-B	7.67a-d	9.67a-c	+260.1	16.00ab	17.33a	+8.3	10.00a-c	5.33d-f	-46.7
ART 26-3-1-B	10.67ab	12.33a	+15.6	15.00a-d	15.33a-c	+2.2	16.67a	0.00f	-100.0
MOROBEREKAN	2.00g-j	2.67g-j	+33.5	4.33jk	4.67i-k	+7.9	5.67b-e	0.00f	-100.0
WAB 56-104	5.67c-f	3.67e-h	-35.3	8.67e-j	5.67h-k	-34.6	6.67b-d	0.00f	-100.0
AC 103549	4.33d-g	8.00a-d	+84.8	10.33b-h	11.33a-f	+9.7	10.50a-c	0.00f	-100.0
CG 14	5.00d-g	6.67b-e	+33.4	11.67a-f	11.67a-e	-	17.33ab	0.00f	-100.0
OFADA	5.00d-g	8.00a-d	+60.0	9.33d-i	11.00a-g	+17.9	4.33c-e	0.00f	-100.0
LSD	0.81*			0.89*			1.36*		

Means with same alphabets are not significantly different from one another along column and across stress status using Fisher's protected LSD at 1% probability level

*LSD value was from transformed data

Us = Unstressed St= Stressed

Table 9: Correlation between some roots related parameters and some above ground parameters of thirteen selected rice

	Plant Height (cm)	Number of tillers	Leaf area (cm²)	Root volume (ml)	Root dry weight (g)	Shoot dry weight (g)	Root moisture content (%)	Shoot moisture content (%)	Shallow root length (cm)	Rooting depth (cm)	Shallow root number	Deep root number	Root depth/ shoot height	DRW/ DSW ratio
1	-													
2	0.0558	-												
3	0.6896**	0.6863	-											
4	0.6168**	0.3756**	0.6130**	-										
5	0.4269**	0.5145**	0.4371**	0.7453**	-									
6	0.5947**	0.4812**	0.5159**	0.7370**	0.8444**	-								
7	-0.0779	-0.0601	0.0219	0.1001	-0.2251**	-0.0656	-							
8	-0.3647**	-0.1211	-0.1085	-0.2013*	-0.1904*	-0.3552**	0.2716**	-						
9	0.6219**	0.1049	0.5054**	0.5324**	0.5749**	0.7162**	-0.1158	-0.3508**	-					
10	0.6413**	-0.0070	0.6164**	0.6380**	0.3885**	0.4977**	-0.0910	-0.1837*	0.5083**	-				
11	0.1838**	0.3077**	0.2079**	0.3302**	0.5498**	0.5596**	-0.0895	-0.0777	0.5550**	0.0346	-			
12	0.5107**	0.4553**	0.4501**	0.6642**	0.6398**	0.6886**	0.0287	-0.1987**	0.4451**	0.4471**	0.1917**	-		
13	-0.0952	-0.0831	0.1372	0.2129**	0.0861	0.0760	0.1749*	0.1163	0.0552	0.6795**	-0.1266	0.0680	-	
14	-0.3849**	0.1130	-0.1958*	-0.0790	0.1516*	-0.2514**	-0.3158**	0.2473**	-0.2747**	-0.2562**	0.0601	-0.1589*	-0.0047	-
	1	2	3	4	5	6	7	8	9	10	11	12	13	14

*, ** Correlation values are significant at 5% and at 1% probability levels respectively.

DISCUSSION

The role of root system of rice in determining the survival and adaptability of a moisture stressed rice cannot be unconnected with its ability to explore larger parts of the root environment during stress. The ability of rice plants subjected to moisture stress to show significant increase in root parameters in response to moisture stress is highly dependent on the genetic constitution of the rice plant (Yu *et al*., 1995; Nguyen *et al*., 1997).

In this study, reduction in leaf area was observed in the varieties at grain filling stage. Results however showed non-significant increase in number of tillers in most of the stressed rice varieties at the vegetative and reproductive stage. This morphological response may be responsible for better performance in yield of some stressed rice varieties due to reduced canopy formation by the plant at vegetative stage and the chemical response of which may be due to accumulation of free proline in plant tissue which in excess could induce increased water holding capacity and preserving water in the tissue as reported by Palfi *et al.* (1974). This development ensures continuous growth of more tillers during stress. The significant reduction observed in leaf areas of most stressed rice varieties at grain filling stage may be due to the susceptibility of some of these varieties to moisture stress and also to the death of the leaves experienced by these varieties as the plant grow older. This could presumably lead to reduction in yield of these varieties. According to Evans *et al.* (1975) leaf area duration correlates with grain yield during grain filling.

Contrary to what was observed in most of the above ground parts of rice plant subjected to moisture stress, the root systems of rice appears to be favored by the twenty days moisture stress especially at vegetative and grain filling stage. Results showed that imposed stress does not cause a significant reduction in most root parameters in some of the varieties examined but rather enhanced its function with a significantly higher function of the root systems recorded for some stressed rice varieties at the grain filling stage. The preference of root growth over shoot growth of root system of rice due to the stress it was subjected to may be due to the need to maintain an adequate flow of water to the canopy during extended dry periods (Steponkus *et al*., 1980) which makes it to produce an extensive root system to explore larger volume of soil. It has been affirmed that plants respond to shifts in resource supply by allocating carbon to the organ involved in capturing the limited resource (Thornley, 1972; Dewar, 1993) in this case the roots which could have made it possible for it develop better than the above ground parts.

In most of the root parameters examined in this study, no observable difference was seen between the stressed and unstressed rice in all the varieties at reproductive stage. Significant differences were however observed between few of the stressed and unstressed rice varieties at vegetative and grain filling stages. This observation cannot be unconnected to the new active portion of the root that are produced by the root system of the plant in response to the stress which according to Kawata and Soezima (1974) has an important function during grain filling period. The similarities in root function of both stressed and unstressed rice varieties observed at reproductive stage can be attributed to competition for dry matter accumulation by the reproductive parts and root system of the rice plant. The inhibition of photosynthesis caused by moisture stress as a result of reduction in leaf area of the plant at grain filling stage could have led to reliant on the stem reserve utilization by the rice plant (Blum, 2005) leading to competition between the root and the reproductive parts.

Increase in root volume was recorded by two(2) varieties- NERICA 3 and AC 103549 at vegetative stage which increased to four(4) – NERICA 3, ART 19-25-1-B, MOROBEREKAN, and WAB 56-104 at grain filling stage. Root growth, in terms of weight, number, and gross morphology appears to reach its maximum around flowering. Branching, however, continues to produce new active portions of the root system until maturity (Yoshida and Hasegawa, 1982). This could have been responsible for the increased number of moisture stressed rice varieties with increased root volume. The ability of MOROBEREKAN to produce the highest root volume at grain filling stage might not be unconnected to the variety's ability to naturally produce an extensive root system. It has been reported that MOROBEREKAN has a natural extensive root system which makes it possible to tolerate some level of drought. In the study on root traits for drought tolerance in rice (Oryza sativa L.) conducted by Ganapathy *et al*., (2010), MOROBEREKAN was reported to posses the highest root volume of all rice varieties selected in their study. The ability of other varieties such as NERICA 3, ART 19-25-1-B, and WAB 56-104 to record a significant increase in root volume and root dry weight to explore larger volume of soil could confer tolerance to moisture stress in these varieties.

The differences in root volume increase observed among the varieties could be attributed to genetic variation that exists among them. Genotypic variation in root penetration and other root traits have been reported in rice (Yu *et al*., 1995; Nguyen *et al*., 1997). A measurable variation in root system characteristics of rice genotypes has also long been recognized (Yoshida and Hasegawa, 1982; O'Toole and Bland, 1988). According to Ekanayake, *et al.,* (1985); Fukai, and Cooper, (1995); O'Toole, (1982), the possession of a deep and thick root system which allows access to water deep in the soil profile is crucially considered important in determining drought tolerance in upland rice and substantial genetic variation exists for this. In this study root dry weight, deep root number, and root depth were highly significantly correlated with root volume and could have all played a significant role in determining the rice root volume.

The significant correlation between plant height and shoot dry weight observed in this study supported the earlier claim of Mao (1984) that plant height is positively significantly correlated with root length, root thickness and dried shoot weight. In addition, root depth and root volume significantly correlated with plant height and also the leaf area of the rice varieties signifying that these root parameters are important in selecting moisture stress tolerance in rice varieties.

In conclusion root system of rice plays a significant role in supporting the above ground parts of rice but root depth, root volume, deep root numbers and root dry weight appeared to be distinct in performing this role.

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