ISSN:
Print - 2277 - 0755
Online - 2315 - 7453

Journal of Agricultural Science and Environment

PHYSIOLOGICAL AND YIELD RESPONSE OF SOME UPLAND RICE VARIETIES TO RE-WATERING AFTER IMPOSED SOIL MOISTURE STRESS

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ABSTRACT

.A pot experiment was conducted in the Screen house of Federal University of Agriculture, Abeokuta, October, 2011 (late dry season) to study drought recovery ability of 13 upland rice varieties exposed to soil moisture stress (20 days) at three growth stages (vegetative, reproductive and grain filling stage). The experiment was in completely randomized design, with three replicates. Under moisture stress significantly higher growth recovery, more erect canopy and flatter leaf surface were obtained in all the rice varieties at vegetative growth stage than other growth stages with increasing duration of re-watering. Under stress condition NERICA 4 maintained a significantly higher leaf area (27.50 cm^2 and 40.18 cm^2), plant height (53.45 cm and 67.62 cm) and number of tillers (1.67 and 1.67), but with a depressed number of leaf, slanted leaf posture and curved leaf especially during the later stage of its growth (Reproductive and grain filling stage respectively). It could be concluded that NERICA 4 had higher recovery ability than other rice varieties in drought prone upland ecology.

Keywords: Rice, Growth recovery, foliar character, re-watering, growth stage, NERICA

INTRODUCTION

Drought is a common environmental phenomenon in most parts of the world (Reddy *et al*., 2004). It is a production constraint that is accompanied with high temperature and moisture stress. Soil moisture stress alone could limit crop performance owing to the fact that most physiological and biochemical processes that support crop yield could only take place in the presence of water as a substrate. The severity of this phenomenon is compounded by the changes in global climate (Cheves *et al*., 2003). Tropical regions of the world are characterized by erratic pattern of rainfall, mostly the rainforest transitory zone of Nigeria.

Rice is a staple food for most people in the developing countries. Its production, constrained by moisture stress in upland ecology could grossly compromise food security and its concomitant socio-economic effects. Rice is highly susceptible to soil moisture stress due to the peculiarity of its leaf morphological characteristics; low epicuticular surface (Austin, 1989), with increasing loss of water through evapotranspiration therefore creating water deficit between demand and supply. In order to forestall this effect, various cultural practices such as irrigation and the use of drought tolerant varieties had been put in place. NERICA is one of such low resource input rice varieties, which have proven to survive soil moisture stress (Jones, 1997a; Jones, 1997b). Crops have devised varied strategies to mitigate against the adverse effect of soil moisture stress; such as spatial escape from dehydration through changes in crop growing period to accommodate period of moisture availability. Other strategies include physical avoidance of dehydration through changes in the root architecture to explore deeper depth in search of water, tolerance of soil moisture stress with the active accumulation of compatible osmolyte, constitutive changes in the carbon assimilation and budgeting along the crop ontogeny and phylogeny. Recovery mechanism had been poorly understood after re-watering especially among the NERICA varieties. It is assumed that application of water after a spell of drought period could rejuvenate growth and may eventually influence the performance of rice. Recovery could be as a result of changes in rice's water status, thus facilitating cell expansion, eventually resulting in growth (Spollen and Sharp, 1991). Other mechanisms ascribed to accompany recovery include in hormonal balance (Hu *et al*., 2012), dynamics of cavitation (Volker *et al.,* 2003), and the activities of the scavengers of reactive oxygen radical (Lu *et al*., 2010), thus maintaining the structural integrity of the cell. Recovery is assumed to be dependent on the phenological phase, genotypic specific and *apriori* stress status of rice variety. Information on the recovery mechanism after moisture is restored is therefore required.

Phenotypic screening of NERICA for drought tolerance using recovery parameters could be less expensive. Thus the objective of this study was to examine growth and foliar character response and yield of some selected NERICA varieties to soil moisture stress at different phenological phase.

MATERIALS AND METHODS

Experimental Site

The 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 season). The Screen house was covered with a plane glass for easy penetration of sunlight. Sides were covered with nets and the floor was cemented to prevent underground seepage of water. The soil used was a sandy loam soil from a fallowed soil (> five years), which permitted easy drainage of water and allows root respiration. Recommended full dose of phosphorus and potassium (30 kg ha^{-1}) and half dose of nitrogen was applied to the soil as basal 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 (Oikeh *et al*., 2008).

Cultural practice

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

$$\frac{\text{saturated soil weight} - \text{dry soil weight (air dried)}}{\text{dry soil weight}} \times 100\ \%$$

Semi-coned buckets, filled with 10 kg of soil were watered to field capacity and allowed to drain; thereafter 2-3 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, 10 days after sowing (DAS) to ensure consistency in data collection. The pots were maintained to field capacity for 21 days after which moisture stress was imposed. At the seedling stage the amount of water given to the pots daily were determined through weighing to determine water loss to evapotranspiration while at full canopy formation, watering was done based on rate of loss of soil moisture from the soil surface.

Treatments and design

Soil moisture stress was imposed on all the thirteen varieties at 21 DAS, 50 DAS, and 70 DAS representing the three growth stages of rice (vegetative, reproductive and grain filling growth stages). 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 for each growth stage after which watering was resumed to study the response of the rice plants to re-watering. The total of treatment combination was 234 pots per replicate. The pots were arranged in a completely randomised design.

Sampling and measurements

Data were collected at the end of moisture stress imposition on growth parameters (plant height, leaf area, number of leaves, number of tillers), and foliar physiological parameters (leaf rolling score, and leaf posture) at 0, 7, and 12 days after re-watering (DAR) at each growth stage of rice. Leaf area was determined as described by Gomez (1972), which is as follows:

Leaf area = Leaf area of main culm × number of tillers/hill × 0.67, where

Leaf area of main culm = length × breath.

A three- point scale was used for leaf posture (1-erect, 2-curved and 3-droopy) as described by Chang *et al*., (1965). Similar scale was used on rolling (1-flat, 2-curved and 3-totally rolled). Yield/ plant of each rice variety were taken at harvest maturity.

Statistical analysis

Data collected were subjected to Analysis of Variance (ANOVA) at 5 % probability level using Genstat 12th Edition. The treatment structure was added control (stress status) plus other treatments. Significant means were separated using Duncan Multiple Range Test (DMRT). All variables collected were checked for the violation of ANOVA assumption before analysis. Data on leaf rolling score and posture were transformed using square root transformation.

RESULTS

Growth recovery

Significant interaction ($P < 0.05$) of stress status × growth stage × recovery period was observed on leaf area, plant height and number of leaves after re-watering (Tables 1, 2 and 3). All rice varieties under unstressed condition had significantly ($P < 0.05$) higher leaf area than the stressed rice plants at all growth stages (Table 1). Under stressed condition at vegetative growth stage, rice varieties had increasing leaf area with increasing duration of re-watering. At other growth stages under stressed condition, rice varieties had similar leaf area with increasing duration of re-watering, which was significantly lower than LA at vegetative stage under stress condition. Rice varieties under unstressed condition were taller ($P < 0.05$) than stressed condition for all growth stages. Under stressed condition for all growth stages there were no significant differences in the plant height of rice varieties with increasing duration of re-watering except at vegetative growth stage, where with increasing duration of re-watering taller rice plants were observed. Similar pattern was observed on the number of leaves under stressed condition at all growth stages (Tables 2 and 3).

Table 1: Interaction of stress status × growth stage × recovery period on leaf area of some selected rice varieties after re-watering

Growth stage	Unstressed			Stressed		
	0 DAR	7 DAR	12 DAR	0 DAR	7 DAR	12 DAR
Vegetative	42.22d	52.37c	57.95bc	21.08e	31.57d	38.67d
Reproductive	64.97ab	66.80ab	66.20ab	4.92f	4.62f	5.40f
Grain filling	60.37bc	74.80a	61.86bc	3.17f	2.82f	3.28f

a, b, c, d, e, f Means with same alphabets are not significantly different from one another at 1% probability level.
DAR – Days after re-watering

Table 2: Interaction of stress status × growth stage × recovery period on plant height of some selected rice varieties after re-watering

Growth stage	Unstressed			Stressed		
	0 DAR	7 DAR	12 DAR	0 DAR	7 DAR	12 DAR
Vegetative	78.25c	88.01b	92.67b	52.60f	63.20e	70.93d
Reproductive	104.87a	106.86a	108.50a	8.21gh	8.62gh	10.67g
Grain filling	108.11a	108.55a	108.53a	5.84gh	4.55h	5.21gh

a, b, c, d, e, f Means with same alphabets are not significantly different from one another at 1 % probability level.
DAR – Days after re-watering

Table 3: Interaction of stress status × growth stage × recovery period on number of Leaves of some selected rice varieties after re-watering

Growth stage	Unstressed			Stressed		
	0 DAR	7 DAR	12 DAR	0 DAR	7 DAR	12 DAR
Vegetative	13.85b	14.96b	17.13b	6.86d	9.55c	18.77b
Reproductive	28.50a	29.33a	30.13a	1.31e	1.13e	1.54e
Grain filling	31.18a	31.87a	32.87a	0.46e	0.41e	0.51e

a, b, c, d, e, f Means with same alphabets are not significantly different from one another at 1% probability level.

Table 4: Interaction of stress status × growth stage × variety on leaf area of some selected rice varieties After re-watering

Variety	Vegetative			Reproductive			Grain filling		
	Unstressed	Stressed	% reduction	Unstressed	Stressed	% reduction	Unstressed	Stressed	% reduction
NERICA 1	53.97g-o	34.36l-s	36.34	56.24f-n	18.64q-u	66.86	52.46g-o	0.00u	100.00
NERICA 2	53.01g-o	27.63o-t	47.88	81.31c-f	0.00u	100.00	133.92a	0.00u	100.00
NERICA 3	46.6i-p	32.41m-s	30.45	64.02f-k	0.00u	100.00	68.90e-i	0.00u	100.00
NERICA 4	33.8l-s	17.77q-u	47.43	48.91h-p	27.50o-t	43.77	56.59f-n	40.18j-r	29.00
NERICA 7	53.26g-o	32.36m-s	39.24	74.3d-g	0.26u	99.65	75.57d-g	0.00u	100.00
NERICA 8	49.25g-p	45.05i-p	8.53	73.61d-g	0.00u	100.00	56.13f-n	0.00u	100.00
ART 19-25-1-B	38.64k-r	15.18r-u	60.71	44.05i-q	0.00u	100.00	48.07h-p	0.00u	100.00
ART 26-3-1-B	34.11l-s	24.36p-u	28.58	48.33h-p	6.03tu	87.52	50.62g-p	0.00u	100.00
MOROBEREKA N	59.55f-l	33.56l-s	43.64	106.28b	0.00u	100.00	103.73bc	0.00u	100.00
WAB 56-104	55.16g-n	32.47m-s	41.13	70.15d-i	12.32s-u	82.44	70.36d-i	0.00u	100.00
AC 103549	66.35e-j	39.1k-r	41.07	55.37g-n	0.00u	100.00	30.43n-t	0.00u	100.00
CG 14	59.64f-l	34.18l-s	42.69	40.85j-r	0.00u	100.00	16.84r-u	0.00u	100.00
OFADA	57.68f-m	27.19o-t	52.86	94.47b-d	0.00u	100.00	90.19b-e	0.00u	100.00

Means with same alphabets are not significantly different from one another at 1% probability level.

DAR– Days after re-watering

Significant interaction (P < 0.05) of stress status × growth stage × variety was observed on leaf area, plant height, number of leaves and number of tillers (Tables 4, 5, 6 and 7). At all growth stages, rice varieties under unstressed condition had significantly higher leaf area than rice varieties under stressed condition. There was a depression in leaf area of rice varieties under stressed condition with age, which was most pronounced at grain filling stage, except NERICA 4 that had increase in leaf area. At vegetative growth stage NERICA 8 had the least percentage reduction in leaf area than others, while the highest was observed in ART 19-25-1-B. At reproductive and grain filling growth stages NERICA 4 had the least percentage reduction in leaf area, while most varieties had similar percentage reduction at both growth stages (Table 4).

All the rice varieties under unstressed condition were significantly (P <0.05) taller than rice varieties under stress condition. There was a reduction in plant height among rice varieties under stress condition at all growth stages, except NERICA 4. At vegetative growth stage NERICA 7 had the least percentage reduction in plant height than other rice varieties, while Ofada rice variety had the highest percentage reduction in plant height than others.

Percentage reduction in plant height observed at reproductive and grain filling stage indicated that NERICA 4 had the least, while other rice varieties had comparatively similar percentage reduction at both growth stages (Table 5).

Rice varieties under unstressed condition had significantly higher number of leaves than rice varieties under stress condition. For most rice varieties under stress condition it was observed that there was a significant decrease in the number of leaves with growth stages. At vegetative growth stage, under stressed condition, most rice varieties had a depression in the number of leaves, the least percentage decrease in the number of leaves was observed in NERICA 7, while the highest percentage decrease in the number of leaves was observed in NERICA 3. However, some rice varieties (Ofada, NERICA 8 and Moroberekan) at vegetative growth stage under stressed condition had a percentage gain in the number of leaves. At reproductive growth stage under stressed condition most varieties had 100 % reduction in the number of leaves except NERICA 1 and NERICA 4. Under stress condition, at grain filling stage all the rice varieties had a total loss of leaves (Table 6).

At vegetative growth stage, most rice varieties under stressed condition had a reduction in the number of tillers, except some (NERICA 7, Moroberikan and WAB 56-104) that expressed a gain in the number of tillers. Under stressed condition most varieties at reproductive growth stage had total reduction in the number of tillers except NERICA 4 that had a gain in the number of tillers. Similar pattern in the number of tillers under stressed condition was observed at grain filling stage, except that NERICA 4 had no loss in the number of tillers (Table 7).

Table 5: Interaction of stress status × growth stage × varieties on height of some selected rice varieties after re-watering

Variety	Vegetative			Reproductive			Grain filling		
	Unstressed	Stressed	% reduction	Unstressed	Stressed	% reduction	Unstressed	Stressed	% reduction
NERICA 1	80.59q-u	63.59x-A	21.09	104.8g-l	33.11D	68.41	102.46h-m	0.00G	100.00
NERICA 2	85.91o-s	63.89x-A	25.63	114.52c-h	0.00FG	100.00	116.04c-g	0.00G	100.00
NERICA 3	87.20-s	60.28z-A	30.87	117.57c-g	0.00FG	100.00	118.82c-f	0.00G	100.00
NERICA 4	77.46r-w	48.4BC	37.52	94.541l-p	53.45A-C	43.46	100.63i-n	67.62u-z	32.80
NERICA 7	88.36n-r	70.5t-z	20.21	121.09c-e	0.11G	99.91	134.86ab	0.00FG	100.00
NERICA 8	84.56p-s	64.91w-A	23.24	101.4i-n	0.00FG	100.00	97.74j-o	0.00FG	100.00
ART 19-25-1-B	69.01t-z	43.98CD	36.27	78.76q-v	0.00FG	100.00	76.19r-x	0.00FG	100.00
ART 26-3-1-B	70.94t-z	53.46A-C	24.64	80.98q-t	12.97EF	83.98	80.07q-v	0.00G	100.00
MOROBEREK AN	94.99k-p	67.14v-z	29.32	121.68c-e	0.00FG	100.00	125.44a-c	0.00G	100.00
WAB 56-104	97.87j-o	77.16r-w	21.16	111.02d-i	19.5E	82.44	111.83d-i	0.00G	100.00
AC 103549	97.08j-p	74.33s-y	23.43	109.97e-j	0.00FG	100.00	112.52d-i	0.00FG	100.00
CG 14	90.64m-p	59.71z-B	34.12	107.72f-k	0.00FG	100.00	96.47k-p	0.00G	100.00
OFADA	97.48j-p	61.81y-A	36.59	123.4b-d	0.00FG	100.00	36.111a	0.00G	100.00

Means with same alphabets are not significantly different from one another at 1 % probability level.

Table 6: Interaction of stress status × growth stage × varieties on number of leave of some selected rice varieties after re-watering

Variety	Vegetative			Reproductive			Grain filling		
	Unstressed	Stressed	% reduction	Unstressed	Stressed	% reduction	Un-stressed	Stressed	% reduction
NERICA 1	9.11t-z	7.17x-A	21.30	22.11h-n	5.33A-C	75.89	25.22g-k	0.00DE	100.00
NERICA 2	13p-x	9.83s-z	24.38	28.44f-i	0.00DE	100.00	27.22f-j	0.00E	100.00
NERICA 3	12.72q-x	5.56z-B	56.29	20.44i-p	0.00DE	100.00	19.22j-r	0.00DE	100.00
NERICA 4	6.00zA	3.11A-C	48.17	9.06t-z	5.50z-B	39.29	8.11v-z	0.00z-B	100.00
NERICA 7	7.22y-A	5.84Za	19.11	14.11p-x	0.03E	100.00	13.44r-y	0.00E	100.00
NERICA 8	8.11w-z	33.7g-l	-315.54	20.89h-o	0.00DE	100.00	19.78j-r	0.00DE	100.00
ART 19-25-1-B	33.89e-g	17.39m-t	48.69	74.22a	0.00DE	100.00	78.22a	0.00DE	100.00
ART 26-3-1-B	29.89f-h	19.89j-r	33.46	64.33ab	4.06B-D	93.68	63.56ab	0.00DE	100.00
MOROBERE KAN	7.67w-z	8.00w-z	-4.30	15.33m-u	0.00DE	100.00	23.11h-m	0.00DE	100.00
WAB 56-104	12.33q-x	9.00t-z	27.01	15.33k-r	0.00C-E	100.00	17.78k-r	0.00DE	100.00
AC 103549	22.78h-n	14.78n-v	35.12	43.78de	0.00DE	100.00	59.11bc	0.00DE	100.00
CG 14	16.1m-u	9.33t-z	42.05	16.22l-s	0.00DE	100.00	13.67o-w	0.00DE	100.00
OFADA	20.33i-q	87.83u-z	-332.02	35.44ef	0.00DE	100.00	47.22cd	0.00DE	100.00

Means with same alphabets are not significantly different from one another at 1% probability level.

Table 7: Interaction of stress status × growth stage × varieties on number of tillers of some selected rice varieties after re-watering

Variety	Vegetative			Reproductive			Grain filling		
	Unstressed	Stressed	% reduction	Unstressed	Stressed	% reduction	Unstressed	Stressed	% reduc-tion
NERICA 1	1.67o-x	1.11s-y	33.53	5.33g-k	1.56s-y	70.73	5.67f-j	0.00y	100.00
NERICA 2	2.78k-v	2.06n-w	25.90	6.44e-h	0.00y	100.00	6.11e-i	0.00y	100.00
NERICA 3	3.00k-s	1.44q-x	52.00	3.67i-p	0.00y	100.00	4.67g-m	0.00y	100.00
NERICA 4	0.78w-y	0.33xy	57.69	1.44p-x	1.67p-x	-15.97	1.67o-x	1.67p-x	0.00
NERICA 7	1.11t-y	2.33o-x	-109.91	2.67m-w	0.03y	98.88	2.67m-w	0.00y	100.00
NERICA 8	1.89n-w	1.51p-x	20.11	4.67g-m	0.00y	100.00	5.33g-l	0.00y	100.00
ART 19-25-1-B	8.67d-f	3.33k-s	61.59	19.44bc	0.00y	100.00	22.67b	0.00y	100.00
ART 26-3-1-B	7.33e-g	5.67f-k	22.65	17.33c	1.56u-y	91.00	21.44bc	0.00y	100.00
MOROBEREKAN	0.89w-y	1.11v-y	-24.72	3.11k-s	0.00y	100.00	3.67i-p	0.00y	100.00
WAB 56-104	2.67l-v	4.00j-s	-49.81	4.22h-n	1.33v-y	68.48	4.11h-o	0.00y	100.00
AC 103549	4.72g-m	3.78l-q	19.92	17.89c	0.00y	100.00	31.56a	0.00y	100.00
CG 14	3.44j-r	1.33r-y	61.34	7.11e-h	0.00y	100.00	11.78d	0.00y	100.00
OFADA	3.11k-t	2.89k-u	7.07	9.11de	0.00y	100.00	11.56d	0.00y	100.00

Means with same alphabets are not significantly different from one another at 1% probability level.

Foliar physiological character recovery

Significant interaction ($P < 0.05$) of stress status × growth stage × recovery period was observed on leaf posture after re-watering (Table 8). Under unstressed condition at all growth stages, all rice varieties had a curved leaf posture with increasing duration of re-watering. Under stressed condition at vegetative growth stage with increasing duration of re-watering most rice varieties had curved leaf posture except at 7 DAR, when the leaves were erect. However, at later growth stages under stressed condition with increasing duration of re-watering most rice varieties had erect posture except at the beginning of re-watering when most of them had a curved leaf posture (Table 8).

Table 8: Interaction of stress status × growth stage × recovery period on Leaf posture of some selected rice varieties after re-watering

Growth stage	Unstressed			Stressed		
	0 DAR	7 DAR	12 DAR	0 DAR	7 DAR	12 DAR
Vegetative	2.12b	1.97b	2.00b	2.05b	1.68c	1.97b
Reproductive	2.00b	2.00b	2.00b	2.88a	0.23de	0.30d
Grain filling	2.00b	2.00b	2.00b	2.92a	0.15e	0.15e

a, b, c, d, e, f Means with same alphabets are not significantly different from one another at 1% probability level

There was a significant interaction ($P < 0.05$) of stress status x growth stage × recovery period on leaf rolling score (Table 9). At all growth stages under unstressed condition, all the rice varieties had flat leaves. Under stressed condition at all growth stages, most rice varieties with increasing duration of re-watering had flat leaves, except at vegetative stage , where the leaves were curved with increasing duration of re-watering (Table 9).

Table 9: Interaction of stress status × growth stage × recovery period on leaf rolling score of some selected rice varieties after re-watering

Growth stage	Unstressed			Stressed		
	0 DAR	7 DAR	12 DAR	0 DAR	7 DAR	12 DAR
Vegetative	1.14c-e	1.36c	1.00de	2.04b	1.21cd	1.15c-e
Reproductive	1.00de	1.00de	1.00de	2.86a	0.31f	0.17fg
Grain filling	1.00de	1.00de	1.00de	2.92a	0.13g	0.08g

a, b, c, d, e, f Means with same alphabets are not significantly different from one another at 1% probability level.

Leaf posture was significantly ($P < 0.05$) affected by the interaction of stress status × growth stage × variety (Table 10). At all growth stages under unstressed condition most rice varieties had curved leaf posture. Under stressed condition, at vegetative growth stage most rice cultivars had erect leaf posture except Ofada with curved posture. Similar leaf posture was displayed by CG 14 and AC 103549. Under stressed condition at reproductive and grain filling stage most varieties had erect leaf posture after re-watering, except NERICA 4 that still maintained curved leaf posture under stressed condition at grain filling stage.

Table 10: Interaction of stress status × growth stage × variety on leaf posture of some selected rice varieties after re-watering

Variety	Vegetative		Reproductive		Grain filling	
	Unstressed	Stressed	Unstressed	Stressed	Unstressed	Stressed
NERICA 1	2.00a-e	1.83a-f	2.00a-e	1.22h	2.00a-e	1.00i
NERICA 2	2.00a-e	1.72c-f	2.00a-e	1.00i	2.00a-e	1.00i
NERICA 3	1.89a-f	1.67d-f	2.00a-e	1.00i	2.00a-e	1.00i
NERICA 4	2.00a-e	1.89a-f	2.00a-e	1.67df	2.00a-e	2.00a-e
NERICA 7	2.00a-e	2.00a-e	2.00a-e	1.00i	2.00a-e	1.00i
NERICA 8	2.00a-e	1.83a-f	2.00a-e	1.00i	2.00a-e	1.00i
ART 19-25-1-B	2.00a-e	1.89a-f	2.00a-e	1.00i	2.00a-e	1.00i
ART 26-3-1-B	2.00a-e	2.11ab	2.00a-e	1.56g	2.00a-e	1.00i
MOROBEREKAN	2.11a-e	1.78a-f	2.00a-e	1.00i	2.00a-e	1.00i
WAB 56-104	2.00a-e	1.78b-f	2.00a-e	1.33gh	2.00a-e	1.00i
AC 103549	2.17a	2.11a-c	2.00a-e	1.00i	2.00a-e	1.00i
CG 14	2.11de	2.00a-c	2.00a-e	1.00i	2.00a-e	1.00i

a, b, c, d, e, f Means with same alphabets are not significantly different from one another at 1% probability level.

Significant interaction ($P < 0.05$) of stress status × growth stage × variety was observed on leaf rolling score (Table 11). Under stressed and unstressed condition at vegetative growth stage, the leaf flat, however it was observed that ART 26-3-1-B under stressed condition had a curved leaf, which was also observed in WAB 56-104, AC 103549, CG 14 and Ofada. The leaf was flat under stressed and unstressed condition at both reproductive and grain filling stage for all the rice varieties after re-watering, except NERICA 4 had curved leaf under stress condition at both reproductive and grain filling stage.

Imposition of soil moisture stress significantly affected all varieties investigated; however among the stressed varieties NERICA 8 (5.75 g plant^{-1}) had the highest yield/plant, which was not significantly different from other varieties (Table 12). NERICA 8 equally had the least percentage reduction on grain yield (5 %) with the imposition of moisture stress, while maximum reduction in grain yield/plant with imposition of moisture stress was observed in NERICA 1 (86 %). Variety AC 103549 and CG 14 had a percentage increase in grain yield under stress condition

Table 11: Interaction of stress status × growth stage × variety on leaf Rolling score of some selected rice varieties after re-watering

Variety	Vegetative		Reproductive		Grain filling	
	Un-stressed	Stressed	Unstressed	Stressed	Un-stressed	Stressed
NERICA 1	1.11f-i	1.22d-h	1.00g-i	1.00hi	1.00g-i	1.00i
NERICA 2	1.00g-i	1.33b-g	1.00g-i	1.00i	1.00g-i	1.00i
NERICA 3	1.44a-g	1.17d-h	1.00g-i	1.00i	1.00g-i	1.00i
NERICA 4	1.00g-i	1.28c-g	1.00g-i	1.83a	1.00g-i	2.56a-f
NERICA 7	1.00g-i	1.00g-i	1.00g-i	1.00i	1.00g-i	1.00i
NERICA 8	1.00g-i	1.50a-f	1.00g-i	1.00i	1.00g-i	1.00i
ART 19-25-1-B	2.22a-c	1.67a-e	1.00g-i	1.00i	1.00g-i	1.00i
ART 26-3-1-B	1.00g-i	2.00b	1.00g-i	1.39e-h	1.00g-i	1.00i
MOROBEREKAN	1.00g-i	1.33b-g	1.00g-i	1.00i	1.00g-i	1.00i
WAB 56-104	1.11f-i	1.67a-d	1.00g-i	1.22g-i	1.00g-i	1.00i
AC 103549	1.17d-h	1.67a-c	1.00g-i	1.00i	1.00g-i	1.00i
CG 14	1.11f-i	1.67a-d	1.00g-i	1.00i	1.00g-i	1.00i
OFADA	1.00g-i	1.56a-f	1.00g-i	1.00i	1.00g-i	1.00i

a, b, c, d, e, f Means with same alphabets are not significantly different from one another at 1% probability level.

Table 12: Interaction of stress status × variety on yield/plant (kg) of rice

Variety	Unstressed	Stressed	% Reduction	% Increase
NERICA 1	15.79b	2.28fg	85.56	-
NERICA 2	21.45a	4.63c-g	78.11	-
NERICA 3	8.94c	4.01c-g	55.15	-
NERICA 4	7.36cdef	2.25fg	69.43	-
NERICA 7	8.98c	3.03efg	66.26	-
NERICA 8	6.05c-g	5.75c-g	4.96	-
ART 19-25-1-B	15.79b	4.54c-g	71.25	-
ART 26-3-1-B	9.22c	5.49c-g	40.46	-
MOROBEREKAN	7.85cde	2.49efg	68.28	-
WAB 56-104	8.67cd	3.78c-g	56.40	-
AC 103549	2.67efg	2.77efg	-	3.74
CG 14	0.81g	1.32g	-	62.96
OFADA	7.71cdef	3.44d-g	55.38	-

a, b, c, d, e, f Means with same alphabets are not significantly different from one another at 1%

DISCUSSION

This trial indicates that re-watering after soil moisture stress significantly affected growth and yield of some selected upland rice varieties. In the course of its ontogeny, crop plants have devised various strategies for coping with abiotic stress, recovery mechanism inclusive. This strategy could be used as one of the criteria for screening for moisture stress.

Under stressed condition all the growth parameters (leaf area, plant height and number of leaves) at all growth stages were stable in rice varieties with increasing duration after re-watering except at vegetative growth stage, where there was a significant increase in growth with increasing duration after re-watering. Vegetative growth stage have been characterised as the period with significant increase in growth, this would have indicated the response observed at this growth stage (Taiz and Zeiger, 2003). Effect of re-watering on the growth of rice varieties that were earlier subjected to soil moisture stress could be attributed to improvement in the cellular water status of rice varieties especially at vegetative growth stage. This effect is mostly reflected on the cellular turgor pressure, subsequently implicated on cellular expansion (Spollen and Sharp, 1991). Among the processes involved in growth at the cellular level is cell expansion. This process is dependent on turgor pressure (Spollen and Sharp, 1991) and rheological properties of the cell (Lockhart, 1965). MacAdam *et al.*, (1992) opined that soil moisture stress could to lead to tightening of the cell wall. It could be inferred that re-watering must have delayed cell wall tightening, increasing the window of response to leaf area growth after re-watering in all the investigated upland rice varieties (Lechner *et al.*, 2008). Other factors could have influenced the rheological properties of cell wall after re-watering, such as activity of cell wall peroxidase (MacAdam, 1992; Thompson, 1998) and expansin (Catala *et al*; 2000; Belfield *et al.*, 2005). However, nexus between re-watering and the activities of these molecules could not be established in this study.

Meanwhile, under stressed condition rice varieties foliar characters (leaf posture and leaf rolling score), a proximate indicator of water status in cereals indicated erect leaf posture, stable and flat leaf surface at all growth stages with increasing duration after re-watering. Erect leaf posture and a flat assimilatory surface with increasing duration of re-watering could have positively altered the leaf water status. Available literature had indicated that erectophile leaf posture could alter attenuation of light in the canopy, especially interception of diffuse light into the canopy, thus increasing the photosynthetic capacity of the rice varieties after re-watering (Monneveux *et al.*, 2004; Innes and Black, 1983). Similar argument could be suggested with respect to flat leaf surface. Increased leaf surface after re-watering would aid water and gas exchange in all the rice varieties at all growth stages, consequently affecting rice varieties productivity that were earlier subjected to soil moisture stress but later recovered its growth through re-watering.

Under stress condition, at different growth stages varietal differences was observed on the leaf area, number of leaves, number of tillers and plant height. Better assimilatory surface observed in NERICA 4 under stress condition especially at reproductive and grain filling growth stages could be premised on the reduced percentage reduction in those growth parameters. With comparatively higher assimilatory surface there is the tendency that it would ensure capture of more radiant energy, especially diffused ones with taller NERICA 4 rice cultivar under moisture stress at reproductive and grain filling stages. These stages had earlier been reported to be the growth stage most cereals are susceptible to stressors (Zinolabedin *et al*., 2008). Varietal variability, stress status and growth stage could have informed differences in growth responses.

Leaf posture of most rice varieties was stable when subjected to soil moisture stress at vegetative growth stage. However at other growth stages (reproductive and grain filling stages) most of the rice varieties had a more erect leaf posture under stress than the slanted canopy architecture under unstressed condition at both growth stages. NERICA 4 under soil moisture stress condition was able to sustain a stable canopy architecture (dropped leaf posture) at reproductive and grain filling stages. Leaf rolling response for all the rice varieties at vegetative growth stage was similar under soil moisture, which was predominantly flat for most rice varieties. However, NERICA under soil moisture stress at both reproductive and grain filling growth stages maintained a curved leaf. This response is very typical of the grass family when they are under soil moisture stress. A curved leaf in this context is to reduce assimilatory surface thus reducing the amount of water loss into the atmosphere when the supply of water is disrupted compared to its demand. One could infer that NERICA 4 had devised a mechanism to escape the negative influence of soil moisture stress xylem water potential status. Available literature indicated that soil moisture stress could result in reduced water potential of the xylem, resulting in an increased xylem cavitation (Tyree *et al*., 1986). Increased xylem cavitation could reduce hydraulic conductance of rice, recursively leading to further reduction of xylem water potential, exacerbating negatively hydraulic property of the xylem. This could be one of the constraints in reduced stomata conductance (Galle *et al*., 2009). The foliar response of NERICA 4 could have predisposes it to reduced transpiration and gas exchange, compromising photosynthetic efficiency and ultimately yield. But NERICA 4 compensated for this after re-watering with a higher number of tillers and leaf area that could allow it to intercept more radiant energy for photosynthesis.

Apart from the cavitation dynamics that could have changed the water status of NERICA 4 towards a better growth after re-watering, other factors had been suggested in the literature to aid hydraulic properties of the plant during plant adaptation to stress or at recovery stage (Catala *et al*., 2000; Belfield, 2005; MacAdam *et al*.,, 1992; Pierre *et al*., 2002). Such factors include activities of scavengers of reactive oxygen radicals that have been reported to be activated during re-watering in ensuring structural integrity of the cell against photoinhibition (Lu *et al*., 2010). Activities of aquaporin and increase in root pressure are some of the factors that were earlier reported in the literature to facilitate hydraulic conductance of rice plant positively during moisture stress and recovery (Pierre et al., 2002; Miller, 1985; Tyree et al., 1986; Sperry *et al*., 1987; Picard, 1989; Cochard *et al*., 1994). It could be suggested that NERICA 4 could have used this mechanism during its recovery process apart from the growth and foliar characters response observed in this trial.

The yield response to moisture stress in all varieties indicated that there was no significant difference among them. This could suggest that there could be a trade-off between performance and recovery to moisture stress. NERICA 4 that had a better growth after recovery did not perform better than other varieties with respect to yield. It must have placed a high premium on its resistance to soil moisture stress at the expense of yield per plant. Meanwhile, with respect to percentage reduction in yield NERICA 8 had the least (4.96 %), which had higher growth rate at the beginning of its growth stage, especially at the vegetative phase in contrast to NERICA 4. This could have suggested availability of photosynthates to NERICA 8 to ensure survivability at the most critical stage of its developments (reproductive stage).

This study was limited by the availability of physiological parameters to elucidate underlying mechanism responsible for the recovery mechanism of the selected upland variety when subjected to stress at different growth phases.

In conclusion, at vegetative growth stage all growth parameters recovered, leaf posture was erect and assimilatory surface was flat with increasing duration of re-watering in rice varieties earlier subjected to soil moisture stress. Conversely, growth parameters, leaf posture and assimilatory surface were stable with increasing duration of re-watering at reproductive and grain filling stages in rice varieties earlier subjected to soil moisture stress. NERICA 4 had more growth, adaptive canopy architecture than other varieties at all growth stages under moisture stress condition. Recovery parameters could be used for screening upland rice, apart from other resistance parameters, with respect to soil moisture stress.

ACKNOWLEDGEMENTS

This project was funded by Agricultural Research Council of Nigeria (ARCN) through RFA 4.20.

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(Manuscript received: 23rd July, 2013; accepted: 27th February, 2015)