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Full Length Research Paper

Effect of different soil moisture content on physiological and agronomical characteristics of newly developed upland rice varieties

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Abstract

Water deficit is one of the environmental factors that cause a great reduction in the upland rice grain yield. The objective of this study was to access the morpho-physiological responses of some newly developed upland rice varieties (NERICA 1, NERICA 4, NERICA 7, ARICA 4 and ARICA 5) to different levels of soil moisture contents at reproductive stage. Open field and screen house experiments were conducted during 2013 and 2014 both in dry season and wet season. Leaf photosynthesis rate, leaf water potential, flowering date and grain yield were compared at reproductive stage under four levels of soil moisture content estimated through tensiometer readings (0 to -5Kpa; -30 to - 40Kpa; -50 to -60Kpa; -75 to -85Kpa). The results showed that, the leaf photosynthesis rate of all the tested varieties decreased with soil water scarcity. Under well-watered condition (control), NERICA varieties yielded from 439 to 497 g.m^{-2}. The grain yield for ARICA varieties ranged from 306 to 337 g.m^{-2}. Under the most severe water deficit, grain yield for NERICA4 and NERICA 7 were significantly ($P < 0.05$) higher than the other varieties regardless of the years and seasons. Although NERICA 1 had the same trend as the other NERICAs regarding the physiological traits (photosynthesis rate and leaf water potential), it produced lower grain yield under each level of water stress as compared to other varieties. All the entries showed similar trend concerning the delay in days to flowering.

Keywords: ARICA, Agronomical characteristics, NERICA, physiological characteristics, reproductive stage, soil moisture content.

Introduction

Rice is a staple for nearly half of the world population of more than seven billion people and it is cultivated in more than 100 countries, with a total harvested area of 161 million hectares, producing more than 700 million tons of paddy rice in 2013/2014 (Yamano *et al.,*2016).Upland rice covers 12% of global rice production area and it is of a proportionately greater importance in Africa and Latin America, where it accounts for around 40 and 45% of the rice‑growing areas, respectively (Guimarães *et al.,* 2015). With the population of Africans living in urban areas expected to increase from current 38% to 48% by 2030, rice consumption in Africa is expected to increase tremendously (AfricaRice, 2013, Onyango, 2014). To meet rising demand for rice, it is estimated that the global rice production needs to increase by 116 million tons by 2035. Water deficit is one of the environmental factors that cause a great reduction in the upland rice grain yield (Guimarães et al., 2013). According to Serraj *et al* (2011), drought is the major constraint to rice production in rainfed areas across Asia and sub-Saharan Africa. Soil moisture deficit affects physiological processes such as photosynthesis and translocation of assimilate from their main sources (leaves) to their main sinks (plant tissues) (Anjum *et al.,* 2013). Its effects on rice production vary with rice plant growth stages, being most sensitive at flowering, followed by booting and grain filling stage (Pandey *et al.,* 2014). Development of rice cultivars with improved drought tolerance is thus important in order to increase productivity, and then alleviate poverty in communities that depend on rain-fed rice. AfricaRice's scientists have developed sets of new generations of rice namely NERICAs (New Rice for Africa) and ARICAs (Advanced Rice for Africa) suitable for upland ecology with short duration and high yield potential (Ndjiondjop *et al.,* 2010). Diagne *et al.* (2015) demonstrated upland varieties mainly NERICA (New Rice for Africa) as a group occupied about 8% of the rice cultivated area of 6.8million ha across 13 rice-growing countries in sub-Saharan Africa. In the context of current unpredictable water availability exacerbated by the worldwide instability of rainfall pattern due to climate change, water deficit may occur at any stage during the growth of rice plants and cause enormous losses in terms of grain yield especially when this deficit occurs during the reproductive stage (Ndjiondjop *et al.,* 2012). The adaptation to water stress, among other factors, results from the maintenance of good water status in plant tissues, which can be evaluated by leaf‑water potential, stomatal diffusive resistance and leaf photosynthesis (Guimarães *et al.,* 2015). Drought tolerant plants have ability to maintain relatively higher leaf water potential and leaf photosynthesis rate under water stress as compare to drought susceptible varieties (Sanchez and Silva,2013).The relative stability of leaf water potential and photosynthesis rate leads to less delay in flowering date and higher grain yield production under water-limited conditions (Sakay, 2010; Guimarães *et al*., 2013).

This study was conducted to compare the effects of drought intensity at reproductive stage on five newly developed upland rice varieties widely cultivated by farmers in SSA. Such study can help in using physiological and agronomical parameters of water deficit tolerance, as an auxiliary method for the selection of upland rice genotypes.

Materials and methods

Plant material

Three upland NERICAs (New Rice for Africa): NERICA1, NERICA 4, NERICA 7 and two ARICA (Advanced Rice for Africa): ARICA 4 and ARICA 5 were used. Both generations of rice varieties were developed by AfricaRice (AfricaRice, 2013). All the selected rice varieties are well adapted to upland ecology and widely adopted by farmers in Sub-Saharan Africa (SSA) (Diagne *et al.,* 2015). NERICA1, NERICA4, NERICA7 and ARICA4 were developed by interspecific hybridization between two cultivated species of rice - *O. sativa* (Asian rice) and *O. glaberrima* (African rice) (AfricaRice, 2008).

Experiments location and period

The study was carried out during two consecutive years, 2013 and 2014, in wet season (WS) under screen house at the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo state, Nigeria latitude, $7^0$30'8'' N and longitude $3^0$54'37'' E. In wet season (WS) 2013 and 2014, the same experiments were conducted in opened field at Ikenne (Nigeria) at 6°52' N latitude, and 3°43' E longitude. Dry season at Ikenne starts early November and ends late April while the rainy season starts early May and ends late October of each year. The dry season experiments were established on 25th November while wet season experiments were established on May 30th of each year.

Experimental design

The experiments were laid out in split plot design with three replications. In the open field, land was ploughed and harrowed using a machine. In the screen house, soil was dug (20cm depth) and then filled with Ikenne soil. Soil sampled from Ikenne was spread in the screen house such as to maintain in situ soil bulk density (1.4 $g.cm^{-3}$BD) as in Ikenne. The bulk density of the soil in the screen house was carefully monitored when compacting using a Static Cone Penetrometers (model HM-559A, Gilson company, INC. Ohio, USA). In each experiment, seeds were hand-dibbled; four seeds were sown at a depth of about 2cm at a spacing of 20cm × 20cm. Seedling were thinned to two plants per hill. The single plot size measured 3m x 2m = $6m^2$ in open field and 0.8m x 2m = $1.6m^2$ in screen house; single plot were separated by 0.5m while sub-plots were separated by 5m. Water was supplied through sprinkler irrigation from seeding to the beginning of the stress (7 weeks after planting). Two rows of border plants were maintained in all the trials. Fertilizer was applied as follows; NPK fertilizer was applied at the rate of 50-50-50 $kg.ha^{-1}$(as basal treatment) at 10 days after sowing (DAS). Top dressing urea was done at 30 and 40DAS at the rate of 40kg $N.ha^{-1}$. In the open field, the whole experimental field was surrounded by wire net to prevent rice plants against rats and other rodents. From flowering to harvesting, the field was covered by a bird-net to avoid any reduction of grain due to bird damages. Each plot was maintained weed free by periodic hand weeding.

Water management and soil moisture monitoring

Before the beginning of the stress period, each plot was well watered (soil moisture close to the field capacity) using overhead sprinkler irrigation in both sites. During the stress, water was supplied using watering can in the screen house while sprinkler irrigation was used in open field. Soil water status was monitored using tensiometersIrrometer (Model ''R'' 30cm, IRROMETER COMPANY, Riverside California) installed at 30cm soil depth in each plot. In each experiment, four levels of water regimes were used as treatments:

L0: In the first treatment, plots were maintained at the soil moisture content close to field capacity throughout the experiment (Tensiometer readings were maintained within0 to -5Kpa throughout the trial);
L1:Low stress intensity; plots were maintained at tensiometers readings fluctuated between -30 to -40Kpa from 49 days (7 weeks) after planting until harvesting;
L2: Moderate stress in which water supply was withdrawn until harvesting and the soil moisture maintained between -50 and -60Kpa;
L3: Severe water stress in which tensiometers readings were maintained between-70 and -85Kpa from 7 weeks after planting to harvesting.

Data collection

- Before planting, soil samples (0 - 20 cm depth) from Ikenne was collected and analyzed in IITA Soil Science Laboratory to access its properties.
- Environmental data were collected using a weather station Model WS-GP1 of Delta-T devices Ltd, 130 Low Road, Burwell Cambridge, CB25 OEJ, UK) installed near (15 meters) the field at Ikenne.
- Leaf photosynthetic rate (PH) was measured using Infra-Red Gas Analyzer (Model CI-340 Photosynthesis System, CID, Inc., USA).
- Leaf water potential (LWP)was measured using pressure chamber (ARIMAD 3000, MRC) as described by Gindaba *et al.*, (2004). This was conducted on the terminal leaf let of the uppermost fully expanded leaf of each plant.
- Days to flowering was recorded when the panicle was exerted in approximately 50% of the plants in a plot
- To determine grain yields, panicle from each plot were harvested, dried, threshed, cleaned and weighed to obtain grain yield and was adjusted to 14% moisture content.

Data analysis

The data of each experiment were analyzed using SAS (2003, SAS Inst., Cary, NC.). Significant difference between varieties was performed using t-test while means of parameters were separated using the Least Significant Difference at 5% level of probability.

Results

Environmental conditions

Soil properties in opened field were as described in Table 1. Ikenne soil is an utisol type with average pH ranking between 4.5 and 5.4.As seen by the variation pattern of the tensiometer readings (Figure 1), the soil moisture contents were successfully maintained at the selected levels throughout the experiments. Also, it was observed that no other biotic or abiotic stress was developed by tested rice varieties during the experiments. Monthly means Air Temperature, Air humidity, wind speed, solar radiation and rainfall during the experimentation period are shown in Table 2. The average rainfall of0.1 and 0.075 mm during the experimental period in dry seasons 2013 and 2014respectively were not enough to disturb the stress although during the two years it rained 0.1 mm during the water stress periods.

Table 1: Soil properties of the experimental site

Physical analysis	
pH(H20)	5.6
%OC	1.6
%N	0.161
Mehlich P(ppm)	12.4
%Sand	77
%Silt	6
%Clay	17
Exchangeable cations	
Ca(cmol/kg)	3.9
Mg(cmol/kg)	0.72
K(cmol/kg)	0.23
Na(cmol/kg)	0.11
Exch. Acidity	0
ECEC	4.98
Zn(ppm)	24.75
Cu(ppm)	0.55
Mn(ppm)	120.49
Fe(ppm)	66.74

Table 2: Means Air Temperature, Air humidity, wind speed, solar radiation and rainfall during the experiments periods

	Dry season		Wet season	
Parameters	2013	2014	2013	2014
Air Temperature (deg C)	27.3	27.9	25.0	25.4
Humidity (%)	87.9	86.15	91.3	93.1
Wind speed (m.s-1)	1.1	1.3	0.5	0.6
Radiation (w.m-2)	152	174	118	121
Rainfall (mm)	0.1	0.075	97	59

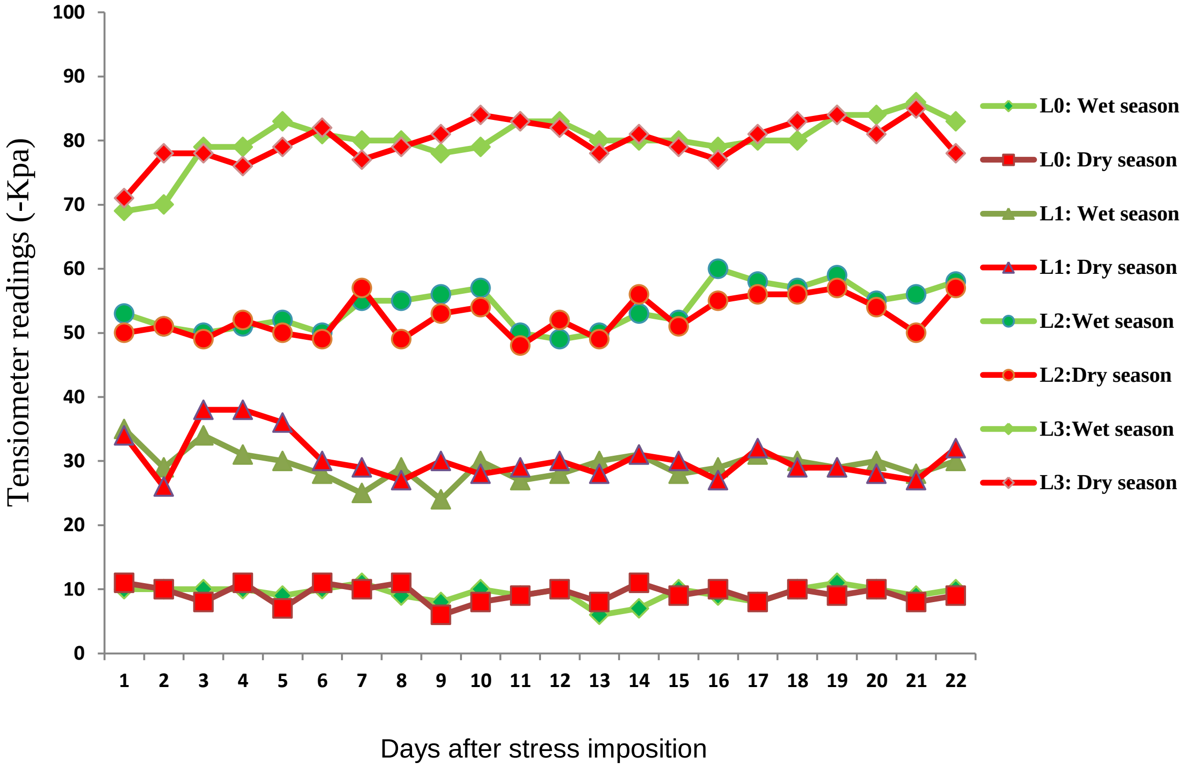


Figure 1: Fluctuations of tensiometer readings during the stress periods

Physiological parameters

Photosynthesis rates under no stress conditions across years and seasons showed no clear differences among genotypes (Table 3). However, the photosynthesis rates decreased significantly ($P< 0.05$) as compared to the non-stress condition under each water deficit condition. Under moderate and severe water deficit conditions (L2 and L3). NERICAs varieties maintained higher photosynthesis activity with assimilation rate ranging from 7 to 10 µmol m^{-2} s^{-1} while ARICAs showed lower values of assimilation between 4 to 5 µmol m^{-2} s^{-1} (Table 3) indicating their inability to maintain higher photosynthesis activity under severe water deficit conditions. Concerning Leaf water potential, in all the experiments across years, all the genotypes showed almost same leaf water potential value (-4 MPa) under non-stress conditions (Table 3). However, significant decreases in leaf water potential were observed under all the stressed conditions as compared to non-stress condition (Table 3). A clear difference was observed between the two generations of rice under moderate and severe water deficit condition. NERICAs showed higher water potential status under L1, L2 and L3 than ARICAs (Table 3). Among NERICAs, under severe water deficit condition, NERICA1 showed higher leaf water potential (from -11 to -12 bars) than NERICA 4 and NERICA 7 which Leaf water potential ranged from -14 to -21 MPa and from -17 to -21 MPa respectively (Table 3).

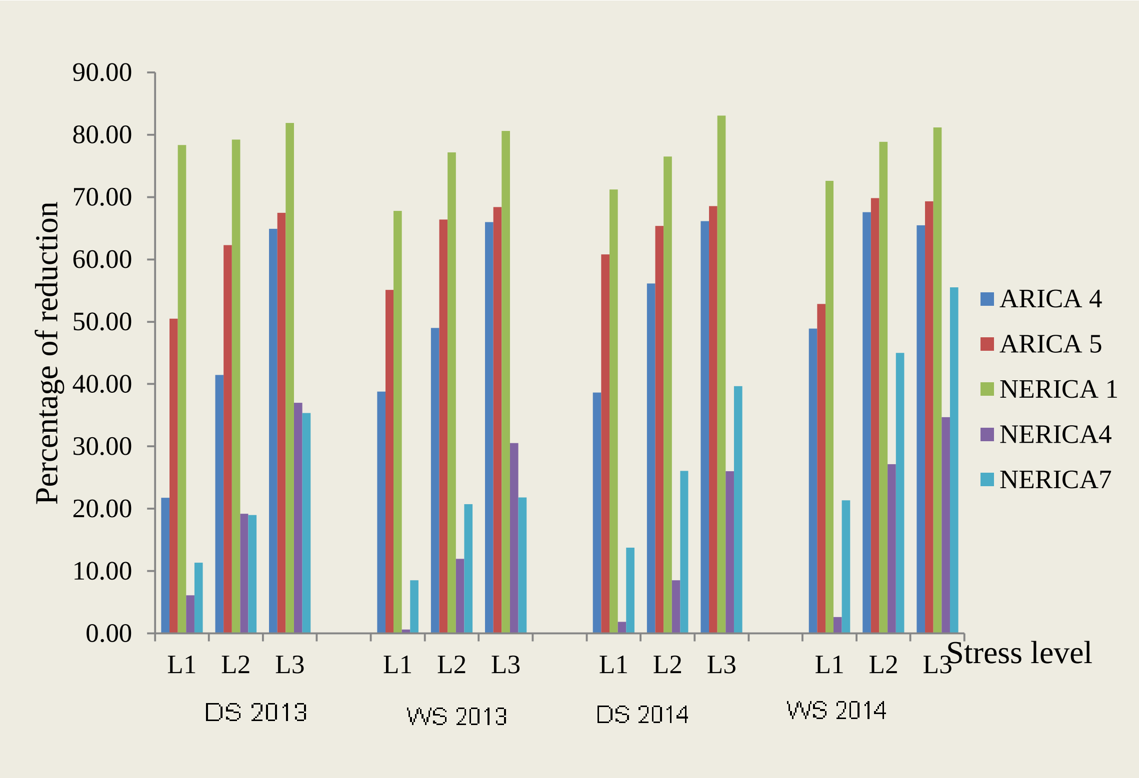
Table 3: Variation of Leaf photosynthesis rate and Leaf water potential of the tested varieties related to soil moisture levels

		Screen house (Wet season)				Opened field (Dry season)			
		2013		2014		2013		2014	
Genotypes	SL	PH	LWP	PH	LWP	PH	LWP	PH	LWP
ARICA4	L0	20	-4	20	-4	21	-4	20	-4
	L1	9	-15	8	-18	9	-15	11	-17
	L2	4	-22	6	-21	5	-22	8	-21
	L3	4	-24	4	-24	4	-24	5	-23
ARICA5	L0	20	-4	20	-4	21	-4	20	-4
	L1	10	-20	9	-20	9	-20	10	-20
	L2	6	-21	6	-21	4	-21	6	-20
	L3	4	-24	4	-21	3	-25	4	-23
NERICA1	L0	20	-4	20	-4	20	-4	20	-4
	L1	11	-7	10	-12	11	-13	11	-12
	L2	8	-8	9	-16	10	-9	8	-7
	L3	6	-11	7	-12	8	-11	7	-12
NERICA4	L0	21	-4	19	-4	21	-4	20	-4
	L1	11	-9	9	-11	11	-9	11	-11
	L2	10	-16	9	-16	9	-16	10	-16
	L3	9	-14	8	-17	8	-21	7	-16
NERICA7	L0	19	-4	21	-4	20	-4	20	-4
	L1	9	-12	11	-11	10	-12	8	-11
	L2	8	-19	10	-20	11	-21	10	-19
	L3	7	-21	10	-16	8	-17	9	-20
Mean		10	15	10	-15	10	-15	10	-17
SE		1.18	1.52	1.08	1.20	0.98	1.36	1.28	1.20

Note: PH = Leaf photosynthesis rate (μmol m^{-2} s^{-1}); LWP: Leaf water potential (MPa); SE = Standard error, L0: Well-watered; L1:-30 to -40Kpa; L2: -50 to -60Kpa; L3: -70 to -85Kpa

Agronomic parameters

Unlike the physiological traits (Photosynthesis and Leaf-water potential), a varietal difference in grain yield production was observed under well-watered conditions. NERICAs produced significant higher grain yields (366 to 497 gm^{-2}) while the maximum grain yield recorded under the same conditions for ARICAs was 337 gm^{-2} (Table 4). Grain yield production significantly decreased with the scarcity of water for all the genotypes (Table 4). NERICA 4 and NERICA 7 had significant higher grain yield under moderate and severe stress condition as compared to other genotypes. Surprisingly, NERICA 1 which showed better water status under severe water deficit conditions had the lowest grain yield production under the same condition (Table 4). The grain yield reduction of NERICA 1 ranged from 81 to 83% under severe water deficit (L3) condition (figure 2). Among the genotypes used, NERCA 4 showed better performance in terms of grain yield production with at least an average of 300 gm^{-2}under severe water deficit condition each year (Table 4) corresponding to about 32 % decreased of its grain yield production as compared to non-stress condition (figure 2).Under the same soil moisture content level, grain yield reductions from 21 to 55 %; 64 to 66 % and 62 to 66 % were observed for NERICA 7, ARICA 4 and ARICA5 respectively (figure 2). Delay in flowering induced by water deficit in all trials ranged from 5 to 11 days (Table 4). The highest delay was observed with ARICA 5 (11 days) under screen house in 2013 while the lowest (5 days) was recorded by NERICA 4 in the same year under screen house (Table 4).



DS: Dry season; WS: wet season
L0: Well-watered; L1:-30 to -40Kpa; L2: -50 to -60Kpa; L3: -70 to -85Kpa

Figure 2: Percentage of reduction of grain yield related to soil moisture levels

Table 4: Effect of soil moisture levels on grain yield and days to flowering of the tested varieties

		Screen house (Wet season)				Opened field (Dry season)			
		2013		2014		2013		2014	
Genotypes	SL	GY	FLOW	GY	FLOW	GY	FLOW	GY	FLOW
ARICA4	L0	337.90	64.33	327.10	61.67	324.58	61.67	319.21	66.00
	L1	206.52	63.67	167.06	66.33	253.87	66.33	195.78	66.67
	L2	172.35	69.33	106.08	72.67	189.96	67.33	140.02	72.00
	L3	114.93	72.67	112.98	71.67	113.91	70.33	108.05	70.33
ARICA5	L0	318.32	61.67	309.28	61.33	306.10	61.67	307.02	60.67
	L1	142.91	66.67	145.79	71.33	151.53	64.67	120.39	70.00
	L2	106.96	75.67	93.23	76.67	115.42	74.33	106.28	75.67
	L3	100.56	72.67	94.86	71.00	99.50	71.33	96.60	70.00
NERICA1	L0	444.04	61.00	443.43	60.00	472.09	60.33	438.78	61.67
	L1	143.11	67.00	121.34	67.33	102.23	70.00	126.27	67.00
	L2	101.26	69.33	93.68	67.33	98.16	67.67	103.05	69.00
	L3	86.15	68.33	83.58	69.00	85.4	69.00	74.22	68.67
NERICA4	L0	466.79	62.67	449.90	60.00	496.57	62.67	437.49	61.33
	L1	454.51	67.33	447.28	67.33	466.23	66.33	429.31	65.67
	L2	340.10	66.00	396.21	68.33	401.20	68.00	400.23	68.00
	L3	305.24	68.33	312.62	68.33	312.94	68.00	323.58	69.33
NERICA7	L0	408.94	62.67	387.44	63.00	451.54	63.67	366.17	60.67
	L1	374.04	67.00	304.84	64.33	400.39	67.33	315.76	67.67
	L2	324.08	71.67	213.16	70.33	365.74	68.33	270.78	69.67
	L3	319.69	71.33	172.24	72.25	291.98	70.67	220.86	71.00
Mean		263.92	67.46	238.50	67.98	278.89	66.83	246.93	67.49
SE		12.62	1.12	6.10	0.98	10.58	0.88	5.90	1.08

L0: Well-watered; L1:-30 to -40Kpa; L2: -50 to -60Kpa; L3: -70 to -85Kpa
Note: GY: grain yield (gm-^{2}); FLOW: days to flowering (Day); SL: Stress levels

Discussion

The increased occurrence and severity of drought stress have led to a high yield decline in rice in recent years in drought-affected areas (Kumar, 2014). Plants have a variety of physiological and biochemical responses at cellular and whole organism levels making it a more complex phenomenon (Farooq *et al.,* 2012). Understanding response of rice plants to drought stress is critical for developing drought tolerant genotypes with stable performance under water limiting conditions (Saikumar *et al*, 2016). In this study, the results showed that the responses to soil water availability varied with genotypes~~.~~ Differential response of upland rice varieties under drought stress was reported by Raman *et al,* (2012), Guimarães *et al* (2013). Significant decreases in photosynthesis rate and leaf water potential were observed under all the stressed conditions as compared to well-watered/non-stress condition for all the genotypes. Variation of the photosynthetic rate of rice due to drought has been well documented by Ji *et al*. (2012); Lauteri *et al.* (2014); Yang et al. (2014).Reduction of rate of leaf photosynthesis is mainly due to the stomata closure, membrane damage and disturbed activity of various enzymes, especially those involve in ATP synthesis (Farooq, 2012). The reductions of leaf water potential are likely due to the loss of water through leaves stomata (transpiration) and the reduction of water absorption through the roots systems due to low water availability in the soil as discussed by Parent *et al,* (2010). According to He and Serraj (2012), leaf‑water potential is strongly correlated with spikelet sterility under water stress. These last authors also found that grain yield was highly associated with spikelet fertility and leaf‑water potential. NERICA varieties showed higher leaf water potential values as compared with ARICA varieties under moderate and severe water stress. Similar trend was found with leaf photosynthesis rate. These results imply the ability of NERICA 4 and NERICA 7 to maintain physiological activities under water deficit conditions which allows them to be more drought tolerant than many genotypes including ARICA varieties. These findings are in line with those discussed by Fofana al., 2016 (in press). Maintenance of relatively higher level of physiological activities observed with NERICA varieties could partially be due to their deeper and uniform roots system across soil layers that allows maximum water and nutrients uptake (Sikuku *et al.,* 2012, Fofana *et al* 2015 unpublished data). Further investigation is ongoing to access the contribution of their above ground part in the maintenance of suitable leaf water potential under drought stress. Several authors over time have reported the flowering delay and reduction in grain yield production due to drought (O'toole, 1982; Fukai and Boonjung, 1996; Pantuan *et al.* 2002; Guimarães et al, 2015; Saikumar et al.2016). The molecular mechanisms underlying photoperiod or temperature control of flowering time have been recently elucidated, but how plants regulate flowering time in response to other external factors, such as water availability, remains poorly understood. Grain yield reduction observed is definitively related to the significant reduction in photosynthesis activities and leaf water potential which induced the reduction in fertile panicle number and filled grain percentage (Mostajean and Eichi, 2009). Findings showed significant interaction between water deficit and type of rice varieties, these results are in line with Bouman and Toung (2001) findings that showed that different cultivars might have different response to the same drought stress timing and intensity. NERICA 1 showed better water status and maintained good level of physiological activities under each stress level but its grain yield production was significantly lower than other varieties.

Conclusion

Under non-stress condition, the two generations of rice (NERICAs and ARICAs) showed significant differences in grain yield production; the first generation (NERICAs) had higher grain yield under drought as compared to the second (ARICA). Results from this study also clearly showed that water deficit negatively affected grain yield production of all the rice genotypes tested. NERICA 4 and NERICA 7 were identified as more drought tolerant than all the other cultivars under all level of drought stress. ARICA generation which is the newness upland varieties developed by AfricaRice showed lower grain yield under stress conditions as compared to NERICA 4 and 7 but higher grain yield as compared to NERICA 1. From the above findings it becomes obvious that criteria (or process) of cultivar release in SSA should be more stringent and the passport data associated to each cultivar should be more elaborated.

References

Africa rice center (AfricaRice) (2013). Annual Report, Africa-wide Rice. Agronomy Taskforce.Cotonou, Benin.

Africa Rice Center (WARDA)/FAO/SAA (2008). NERICA®: the New Rice for Africa – a Compendium. EA Somado, RG Guei and SO Keya (eds.). Cotonou, Benin: Africa Rice Center (WARDA); Rome, Italy: FAO; Tokyo, Japan: Sasakawa Africa Association. P. 210.

Anjum F, Yaseen M, Rasul E, Wahid A, Anjum S (2013). Water stress in barley (Hordeumvulgare), Effects on morphological characters. *Pak. J. Agric. Sci*., 40:43-47.

Bouman BAM, Toung TP (2001). Field water management to save water and to increase its productivity in irrigated lowland rice. Agric. Water Manage, 49(1): 11-30.

Chaves MM, Maroco JP, Pereira JS (2003). Understanding plant responses to drought from genes to the whole plant.*Functional Plant Biol*., 30: 239-244.

Chen THH, Murata N (2002). Enhancement of tolerance of abiotic stress by metabolic engineering of betaines and other compatible solute.Curr.Opin.Plant Biol., 5(3): 250-257.

Diagne A., Kinkingninhoun-Medagbe FM,Amobing-Assagba E, Tebila N, Sanni K, Toure A(2015). Evaluating the key aspects of the performance of genetic improvement in priority food crops and countries in Sub-Saharan Africa: the case of rice. In: Walker, T., Alwang, J. (Eds.), Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa. CABI, United States, p. 480

Fukai S,Boonjung H (1996). Effects of soil water deficit at different growth stages on rice growth and yield under upland conditions. Phenology, biomass production and yield. F.Crop. Res., 48 (1):47-55.

Gindaba J, Rozanov A, Negash L, (2004). Response of seedlings of two Eucalyptus and three deciduous tree species from Ethiopia to severe water stress. For. Ecol. Manag., 2001(1):119-129.

Guimarães CM, Stone LF, Castro AP, Morais Junior OP(2015). Physiological parameters to select upland rice genotypes for tolerance to water deficit.Pesq.agropec. bras., Brasília, 50(7): 534-540.

Guimarães CM, Stone LF, Rangel PHN, Silva, AC (2013). Tolerance of upland rice genotypes to water deficit. Revista Brasileira de Engenharia Agrícola Ambiental, (17):805‑810. DOI: 10.1590/S1415‑43662013000800001.

He H, Serraj R (2012). Involvement of peduncle elongation, anther dehiscence and spikelet sterility in upland rice response to reproductive‑stage drought stress. Environmental and Experimental Botany, 75: 120-127 DOI: 10.1016/j. envexpbot.2011.09.004.

Herdt RW (1991). Research Priorities for Rice Biotechnology.In Rice biotechnology, Khush, G.H., Tenniessen G.H. (Eds.). CAB International. Wallingford, UK., p. 19-54.

Ji KX, Wang YY, Sun WN, Lou QJ, Mei HW, Shen SH, Chen H (2012).Drought-responsive mechanisms in rice genotypes with contrasting drought tolerance during reproductive stage.*J Plant Physiol*, 169(4): 336–344.

Kumar A, Dixit S, Ram T, Yadaw RB, Mishra KK, Mandal NP (2014). Breeding high-yielding drought-tolerant rice: genetic variations and conventional and molecular approaches. J Exp Bot.65(21): 6265-78.

Lauteri M, Haworth M, Serraj R, Monteverdi M C, Centritto M (2014). Photosynthetic diffusional constraints affect yield in drought stressed rice cultivars during flowering. *PLoS One*, 9(10): e109054. Lee S C, Lan W, Buchanan B B, Luan S. 2009. A protein kinase phosphatase pair interacts with anion channel to regulate ABA signaling in plant guard cells. *ProcNatlAcadSci USA*, 106(50):21419-21424.

Mostajean A, Eichi VR (2009). Effects of drought stress on growth and yield of rice (*OryzasativaL.*) Cultivars and accumulation of proline and soluble sugars in sheath and blades of their different ages leave. *J. Agric. Environ. Sci*., 5(2): 264-272.

NdjiondjopM, Seck PA, Lorieux M, Futakuchi K, Yao KN, Djedatin G, Sow ME, Bocco R, Cisse F, Fatondji B (2012). Effect of drought on *OryzaGlaberrima*, Rice Accessions and *OryzaGlaberrima* Derives-Lines.Asian J. Agr. Res. 6(4):144-157.

Ndjiondjop M, Manneh B, Cissoko M, Dramé NK, Glele-Kakai R, Bocco R, Baimey H, Wopereis M (2010). Drought resistance in an interspecific backcross population of rice (*Oryza*spp.) derived from the cross WAB56-104 (*O. Sativa*), CG14 (*O. Glaberrima*). Plant Sci.179:364–373.

O'Toole JC (1982). Drought Resistance in Crops with Emphasis on Rice. J.Agr.crop Sci., 4:129-136

Parent B, Suard B, Serraj R, Tardieu F (2010). Rice leaf growth and water potential are resilient to evaporative demand and soil water deficit once the effects of root system are Plant, Cell & Environment., 33(8):1256-1267

PandeyR, Agarwal RM, Jeevaratnam K, Sharma GL (2004). Osmotic stress-induced alterations in rice *(Oryzasativa* L.) and recovery on stress release. Plant Growth Regul., 42:79-84.

Pantuwan G, Fukai S, Cooper M, Rajatasereekul S, O'Toole JC (2002). Yield response of rice (*Oryza sativa* L) genotypes to different types of drought under rainfed lowlands. 2. Selection of drought resistant genotype. Field Crop Res. 73(2-3):169-180.

Raman A, Verulkar SB, Mandal NP, Variar M, Shukla VD, Dwivedi JL, Singh BN, Singh O N, Swain P, Mall AK, Robin S, Chandrababu R, Jain A, Ram T, Hittalmani S, Haefele S, Piepho HP, Kumar A (2012). Drought yield index to select high yielding rice lines under different drought stress severities. Rice 201225:31. DOI: 10.1186/1939-8433-5-31

Saikumar S,Varma CMK, Saiharini A., Kalmeshwer GP, Nagendra K, Lavanya K, Ayyappa D (2016). Grain yield responses to varied level of moisture stress atreproductive stage in an interspecific population derived from Swarna/*O. glaberrima* introgression line. NJAS - Wageningen J. Life Sci. (2016).http://dx.doi.org/10.1016/j.njas.2016.05.005

Sakai T, Cristina MD, Cabrera FAV, Martínez CP, Ishitani M (2010).Establishment of drought screening protocols for rice under field conditions. Actaagronomica. 59 (3): 338-346

SAS Institute (2003). The SAS system for Windows.Version 9.1.SAS Inst., Cary, NC.

Sanches RFE, Silva EA (2013). Changes in leaf water potential and photosynthesis of *Bauhinia forficate.* Hoehnea 40(1): 181-190.

Serraj R, McNally KL,Slamet-Loedin I, Kohli A, Haefele SM, Atlin G, Kumar A(2011). Drought Resistance Improvement in Rice: An Integrated Genetic and Resource Management Strategy. Plant Production Science, 14(1): 1-14, DOI: 10.1626/pps.14.1

Sikuku PA, Onyango JC, Netondo GW (2012). Physiological and biochemical responses of five NERICA rice varieties to water deficit at vegetative and reproductive stage. Agric. Boil. J*.,* 3(3):93-104.

Takashi T, Arouna A, Labarta RA, Huelgas ZM, Mohanty S (2016). Adoption and impacts of international rice research technologies. Global FoodSecurity (8):1-8

Stanton KM, Mickelbart MV (2014). Maintenance of water uptake and reduce of water loss contributed to water stress tolerance of Spiraea alba Du Roi and SpiraeaTomentosa L. Horticulture Research 1, number 14033. Doi: 10.1038/hortre.2014.33.

Yang PM, Huang QC, Qin GY, Zhao SP, Zhou JG(2014).Different drought-stress responses in photosynthesis and reactive oxygen metabolism between autotetraploid and diploid rice. Photosynthetica, 52(2): 193-202.