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Yield Traits and Water Productivity Responses among Rice Varieties (*Oryza sativa* L.) Grown in A *Fadama* Ecosystem in Akure, Southwestern Nigeria

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Authors' contributions

Author SOA conceived the idea for the study, participated in its design, performed the statistical analysis and coordinated the draft the manuscript. Author ATBA carried out the field study, performed the soil and plant, and statistical analysis and helped to draft the manuscript. Author TOO participated in the design of the study and performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Drought is the most important factor limiting rice productivity under rainfed system of the humid tropics. Field experiments were conducted to determine the effects of soil water management strategies (growth on residual soil moisture at the vegetative stage supplemented with irrigation at the reproductive stage and growth under full irrigation throughout) on water use, yield and yield components of four varieties of rice grown in the dry season in an inland valley swamp (fadama). The four selected varieties were two upland (Ekpoma local and upland Nerica 4) and two lowland (lowland Nerica 1 and 2). The first planting (December, 2010) adequacy of soil moisture from planting to date of first flowering was assumed, thereafter irrigation was imposed during reproductive growth. In the second sowing (Janaury, 2011), rice plants were drip-irrigated from

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planting to seed harvest. The results indicated that differences between the December and January sowing dates were found significant for most of the traits measured (root and shoot weight, leaf area, plant height, number of tillers, weights of panicle and 100-seed and harvest index). Total seed yield and harvest indices (3.19 t ha^{-1}:10.1) were higher in January over December (1.24 t.ha^{-1}: 6.3) sowing in addition to higher water use efficiencies (0.053 and 0.031 t.ha^{-1}.mm^{-1}). The seed yield reduction was associated with reductions in plant height (103.4:76.8 cm), leaf area (51.9: 76.1 m^2) and shoot weight (103.7: 76.8 g) across all tested lines. Seasonal soil moisture storage ranged from 186 to 223 mm for the respective first (December) and second (January) sowing dates. The two best lines (Upland cultivars: Ekpoma and Nerica 4), had similar yield performance when grown under irrigation from planting to maturity (harvest) but differed significantly in their trait combinations. Over other varieties, upland Ekpoma and Nerica 4 exhibited superior ability to produce tillers, panicle and seed weights in both first and second sowing dates. Functional relationships between some weather variables and growth and yield characteristics of rice which gave high regression coefficients (R^2) showed that, the differences in shoot biomass and seed yield production between the sowing dates were explained by a combination of weather parameters. The evaluated varietal yield potential and related traits measured under variable soil moisture regimes were discussed in relation to genotypic adaptation (drought tolerance) among the tested rice varieties. It is concluded that, in a cultivar, higher yield potential may be related to ability to tolerate multiple and concurrent abiotic stresses of soil and air moisture deficit and temperature stresses.

Keywords: Fadama; inland flood plain; rice; water management; drought; adaptation.

1. INTRODUCTION

Rice (*Oryza sativa* L.**)** is a major staple cereal grown worldwide especially in rainfed and irrigated cropping systems. Rice is one of the most common of all domesticated cereals, a tropical C_3 species, carries an odd behavior of tolerance and susceptibility to abiotic stresses as compared to other field crops [1]. Rice thrives well in water logged soil and can tolerate submergence at levels that would kill other crops, also is moderately tolerant of salinity and soil acidity, but highly sensitive to drought and cold [2]. In the lowland ecosystem, rice is subjected to intermittent submergence (water depth of 0.5 to 1 m that cover the foliage), to salinity stress in coastal regions and drought in upland conditions. The rainfed areas occupy about 30 % of the total world rice growing areas where high yielding semi-dwarf rice varieties are not widely grown because of their poor adaptability to the more stressful rainfed conditions [3]. Among the abiotic stresses in the rainfed systems, drought is the most important factor limiting rice productivity [4,5,6].

Tuong and Bauman [1] presented a review of water productivity in rice and surveyed the irrigation and associated technologies available given a water limited future. The author concluded that periodic surface irrigation or flush irrigation methods are viable water management strategies for rice production. Water limited condition is related to insufficient soil moisture available to support average crop production, this situation affects 23 million hectares of rice yearly [7]. Rice is particularly sensitive to drought stress and even mild drought stress can result in significant yield reduction [8,9]. Drought stress particularly during the reproductive (flowering) stage can result in severe yield losses. The physiological processes during the sensitive reproduction stage, negatively affecting spikelet fertility under water stress anther dehiscence and pollen germination [10,3] were similar to high-temperature stress [11,12]. Additionally, panicle exertion [8], and peduncle length [13] may be partly responsible for increased sterility under water stress. Genotypic attributes such as stature (plant height and vigor), tillering habits, root size, root morphology and density and other physiological attributes such as stomatal closure and osmotic adjustment had been implicated as possible mechanisms for drought tolerance [14,3].

The rice growing agroecologies are characterized by maximum day-time temperatures either close to or higher than the critical threshold ranging between 33°C [15] and 35°C [11]. High-temperature stress can cause irreversible damage to plant growth and development [16]. Temperatures greater than 35°C at anthesis and lasting for more than 1 h can lead to high sterility in rice [12]. A high-temperature stress-induced increase in spikelet sterility is attributable to abnormal anther dehiscence [17], impaired pollination and pollen germination [12]. Moreover, high temperature of 39°C given a day before flowering resulted in poor anther dehiscence during subsequent anthesis [17]. High temperatures stress given a day prior to anthesis affected the normal functioning of the pollen sac dehiscence and pollen viability [17]. The reproductive stage in rice is affected irreversibly by high temperatures [18] and soil moisture deficit stress than the vegetative stage. The occurrence of water deficit during reproductive stage significantly reduced pollen viability, spikelet fertility [19] and grain yield [20]. The response of plants to water and temperature stresses depends on the duration and severity of the stress [21,22] and the developmental stage [23].

In circumstance of the changing climates of the future, rice could more subjected to simultaneous high temperature and water stress during sensitive developmental stages such as heading and seed filling. As the global climate changes continue, water shortage and drought have become an increasingly serious constraint limiting rice production worldwide [24]. Hence, overcoming the effects of high temperature and water stress on rice production is essential in the attainment of food security now and in the future. Rice varieties are different among regions and locality, and their response to ecological variations is different. The high yielding varieties of rice that had been developed will respond differently at different locations and ecosystem (agroecologies). There is need to investigate varietal suitability of rice especially the newly improved lines to the soil and weather condition in rice growing agroecologies of Nigeria.

In sub-Saharan Africa, inland wetlands constitute about 135 million ha of land [25]. Extensive land areas in Nigeria are characterized by shallow water tables fed by steams and river courses. These ecosystems which are seasonally flooded, are called inland valley swamps or inland flood plains (The *fadama* in Hausa). The inland valley swamps are characterized by seasonal flooding at the peak of the rainy season, high residual moisture regimes in the dry season and variable but shallow ground water table depths. The agricultural potentials of tropical inland valley swamps or flood plains can be harnessed via the effective management of its soil and water resources. Field experiments were conducted in order to examine pattern of water use, growth and yield of four varieties of rice grown in the dry season in an inland flood plain (fadama) under irrigation management strategies. The aim was to evaluate varietal yield potential and related traits under variable soil moisture regimes, and to examine the value of the measured traits to yield potentials and genotypic adaptation among the tested rice varieties.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The study was conducted at the Teaching and Research Farm of the Federal University of Technology, Akure, a humid rainforest zone of southwest Nigeria (Latitude 7°14'N and Longitude 5°08'E) and at 35 m above sea level. The mean annual rainfall range between 1300-1600 mm and with average temperature of 30ºC. The relative humidity ranges between 85 % during the rainy season and less than 60 % during the dry season.

The experiment was carried out between December, 2010 and May, 2011 to determine the effects of soil water management strategies on water use, yield and yield components of four varieties of rice grown in the dry season in an inland valley swamp (fadama). \rice seeds were grown in December, 2010 on soil water reserve until peak vegetative growth (date of first flowering) after which irrigation was imposed during reproductive growth (flowering to crop maturity: Growth on residual soil moisture at the vegetative stage supplemented with irrigation at the reproductive stage and growth under full irrigation throughout) and in Janaury 2011 for which seedlings were drip-irrigated from planting to harvest. The varieties evaluated are two upland (Ekpoma local and upland Nerica 4) and two lowland (Nerica 1 and 2). Seeds of four varieties of rice consisting of two upland (Ekpoma local and upland Nerica 4) and two lowland (Nerica 1 and 2) The NERICA genotypes were obtained from the African Rice Centre, Ibadan while Ekpoma local was obtained from the Edo State Agricultural Development project, Benin City. Rice seeds were sown on soil water reserve until peak vegetative growth (date of first flowering) after which irrigation was imposed during reproductive growth (flowering to crop maturity), and between Janaury and May 2010). Seeds were sown on the field at 90 by 20 cm spacing along the row and at three row-replications per treatment. The experimental site consisted of two blocks of 14 by 90 m dimension. The land was manually cleared, packed, and

Force-Up herbicide was applied at the rate of 3 liters per hectare to further prevent weed competition on the plots.

At maturity, six uniform plants of 0.3 m^2 in each plot were measured for plant height and sampled by cutting the plants from the bottom (right above the soil surface). The plants sampled from each plot were put into a paper bag and were then oven-dried at 75°C for 3 days. The dried samples were then measured for total grain yield and its components, including biomass, 100-seed weight and panicle and spikelet weights.

2.2 Plant Measurements

Data were collected on root and shoot biomass, leaf area development, flowering and fruiting characters and grain yield of rice. Photographs of various operations were also taken on the field. Data were collected on pattern of soil moisture storage and depletion, and agronomic parameters of root and shoot biomass, leaf area and fruit yield characters of rice. Agronomic characters of root and shoot biomass, leaf area, seed yield and yield components were monitored from ten plants per row. Root and shoot biomass were oven-dried at 80ºC for 48 h and dry weights were recorded.

2.2.1 Soil physical and chemical properties

Soil moisture was estimated by gravimetric method (oven-dried moist soil samples at 105°C for 24 h). Core samples were taken at surface soil (10 cm depth) while bulk density determined for the samples were employed in the conversion of gravimetric soil moisture content to volumetric (cm^3. cm^{-3}). From the experimental field, ten points were sampled weekly starting from planting to crop physiological maturity. Soil moisture depletion (SWD) was obtained from the differences in soil moisture contents measured at the beginning and at the end of weekly cycle.

Accumulated heat units (thermal time) was calculated from temperature coefficient for individual crops. Thermal time (TT °Cd) for the phenological phases were calculated from the daily maximum (T_{max}) and minimum (T_{min}) temperatures measured at the Meteorological Observatory of the Department of Meteorology, FUT, Akure. Average daily temperature was used to calculate thermal time (TT) for each growth phase. Cardinal temperatures [15,12], namely base temperature (T_b 8°C), optimum temperature (T_{opt} 32°C), and maximum temperature (T_{max} 42°C), were assumed in the calculation of heat unit accumulation measured as growing degree days (GDD) using equation of McMaster and Wilhelm [26].

$$GDD = \frac{T\max + T\min}{2} - Tbase \quad (1)$$

$$ThermalTime(TT) = \frac{T\max 1 - x - To}{2 - Tb} \quad (2)$$

T_{max} is the maximum temperature, T_o is optimum temperature and T_b is the base temperature, 1-x represents the time interval during which measurements were made (day one to the last day). Thermal time requirements (TT^{o}Cd) for the different growth phases can also be obtained from the sum of the calculated growing degree days summed over the growing season length (days). Weather variables at the site of experiment during crop growth cycle (soil and air temperatures, vapour pressure deficit (vpd), solar radiation, wind speed were monitored from Meteorological observatory, 500 meters from site of experiment.

2.2.2 Irrigation strategies

In the first experiment (December, 2010), adequacy of soil moisture from planting to date of first flowering was assumed. Rice seedlings were therefore grown on residual soil water (soil water reserve) until date of first flowering (2 to 7 weeks after planting, WAP). Thereafter irrigation was imposed weekly during reproductive growth (flowering to crop maturity: 8 to 16 WAP). In another set, second planting (January, 2011), rice seedlings were drip-irrigated weekly from planting to harvest. For both experiments, irrigation regimes consisted of water application at weekly intervals using drip irrigation system. In both experiments, irrigation was imposed using low-head (gravity) drip system weekly and fortnightly and 1.38 liters of water per plant at each irrigation. Irrigation water was applied using the gravity-drip irrigation system while water was delivered to plants via point source emitters of 2 $l.h^{-1}$ discharge rate. The emitters were installed on laterals per row of crop and were spaced 1 by 1 m apart. Irrigation buckets were suspended on 1 – 1.5 m high stakes to provide the required hydraulic heads. Drip irrigation was applied using point source emitters and the emitters (2 $l.h^{-1}$ discharge rate) were installed on laterals per row of crop. Irrigation buckets were suspended on 1 – 1.5 m (hydraulic heads) high stakes [25].

Data collected were subjected to analysis of variance (ANOVA) while significant treatment means were separated using the Least Significance Difference (LSD) test at 5% level of probability. Simple correlation and regression analysis was performed between some of the measured growth and seed yield characters of rice and weather factors during rice growth. Three functional forms of regression models (exponential, power, logarithmic) were fitted to into these relationships.

The second year experiments (December, 2011 and May, 2012) were set up following the identical treatments and procedure of December, 2010 and May, 2011 experiments. There were no significant differences in the results obtained from year to year, and due to the similar yearly pattern of response of pepper to the soil moisture management strategies, the data for the 2 years of study were pooled and a 2-factor analysis of variance was carried out. Therefore, data collected o for the two-years of study (2010 - 2012) were averaged and means are presented in tables and figures.

3. RESULTS

3.1 Weather Conditions of the Site of Study During Rice Growth

An experiment was carried out during the dry season (December 2010 and May, 2011). The growing environmental condition of the dry season is characterized by high solar radiation intensities and temperatures (air and soil) and low relative humidity and high vapor pressure deficits and open water evaporation (Fig. 1a). The trends weather conditions during period of study (December 2010 and May, 2011) is presented in Figs. 1b and 1c. The figures showed that during the course of rice growth and at different stages in the respective sowing dates December 2010 and January, 2011), rice plants were subjected to concurrent stresses of soil moisture and vapor pressure deficits and high air temperatures.

3.2 Soil Moisture Storage (Replenishment) and Depletion

The values of soil moisture taken at 10 cm depth differed for the first (residual soil moisture plus supplementary irrigation at reproductive growth) and second (irrigated crop from planting to harvest) sowing dates (Figs. 2a and 3a).

For the December sown crop, the initial soil moisture contents were high possibly from the late rains of the second modal rainfall pattern which terminates about November and residual effects of the receding flood. The sequence of depletion and replenishment of soil moisture under first and second sowing dates (supplementary and full irrigation) are shown in Figs 2b and 3b. During the establishment and vegetative growth stages, differences in soil moisture storage (replenishment via irrigation) were found. In general, high soil moisture storage was observed within the first to the five weeks after sowing before the attainment of anthesis/heading dates. Thereafter, lower moisture was stored in the soil at reproductive phase (heading and seed filling period). The site of the experiment is a flood plain (Fadama) characterized by shallow water table depths, capillary rise from the water table in addition to the residual moisture from the rainfall-enhanced floods can have influenced the soil moisture content (storage) within the rice plant root zone.

3.3 Growth, Yield and Yield Components of Rice

Significant differences were observed for growth and yield parameters of rice in the different sowing dates (December and January). Among the rice varieties, differences were obtained in other growth phases such as 50 % flowering date to seed filling and physiological maturity of seeds (Tables 1 and 2). The selected rice varieties also had different maturity dates in particular, differences in the duration of reproductive growth phase.

Table 1. Physical and chemical properties of soil of site of experiment

Soil properties	
Sand (%)	40.9
Silt (%)	30.8
Clay (%)	28.3
Textural Class	Sandy clay loam
Bulk density ($g.cm^{-3}$)	1.24
Porosity (%)	51
Infiltration rate ($mm.s^{-1}$)	3.18
Saturation (%)	40.1
Field capacity moisture (%)	27.9
1500 kPa mositure (%)	17.2
Water holding capacity (%)	21
Organic matter $mg.g^{-1}$)	4.23

Based on the parameters measured in this study, the Ekpoma (upland) variety is superior to the others (Upland Nerica 4 and lowland Nerica 1 and 2). Over other the Nerica varieties, significantly higher values of root dry weight, number of roots, root length, shoot dry weight, length and breadth of the flag leaf, flag leaf, number of tillers, panicle and seed weight were produced by the Ekpoma variety. However, the lowland Nerica varieties produced similar (non-significant differences) in plant height, number of leaves, spikes / panicle and spikelets / panicle, panicle and seed weight / panicle and harvest index (HI). The inherent potentials of the four varieties appeared to be remarkably expressed under full irrigation (January sowing date) than growth on residual soil moisture plus supplementary irrigation during reproductive growth phase (December sowing date). In the January sowing when rice plants were irrigated from planting to maturity, significant higher ($P \leq 0.05$) values of most of the parameters considered in this study were obtained.

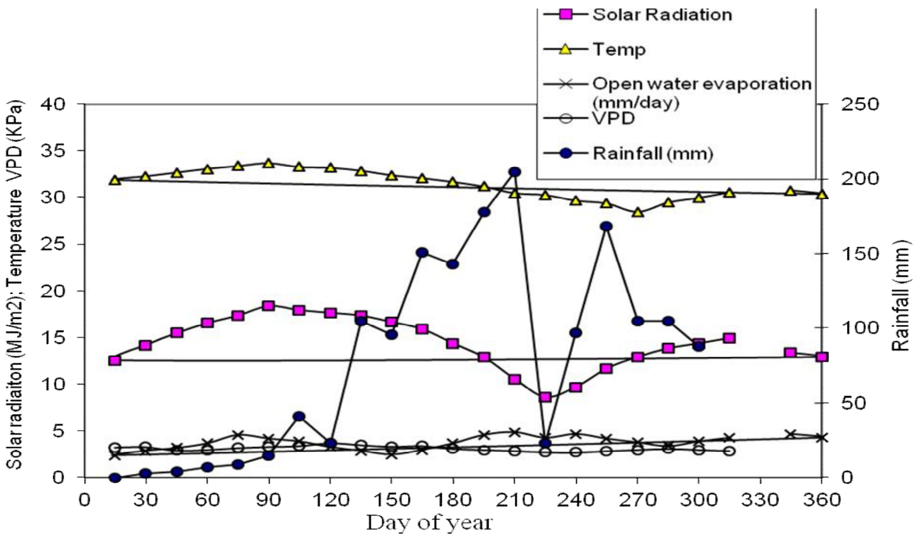

Fig. 1a. Some meteorological variables at site of experiment

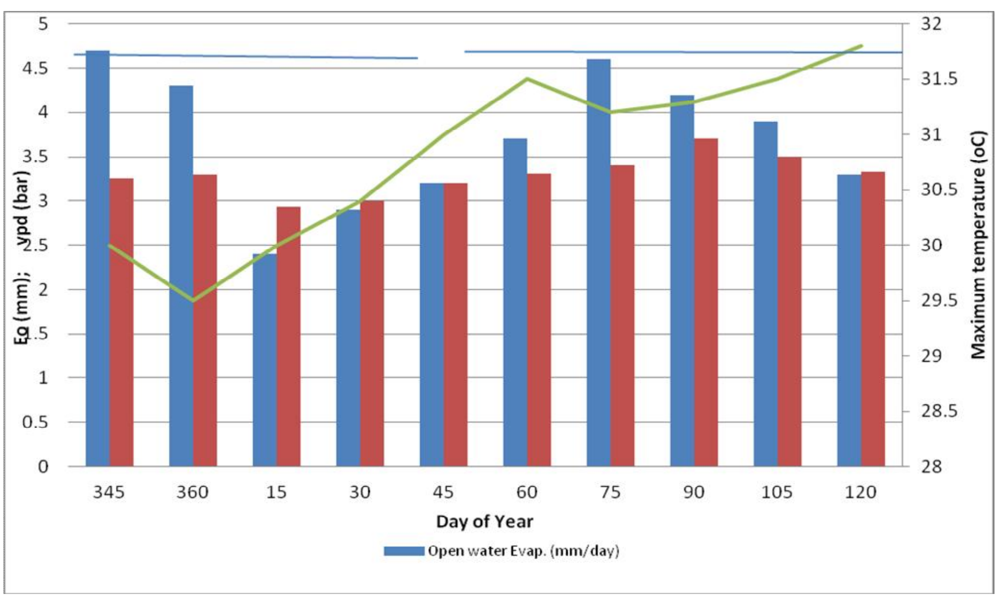

Fig. 1b. Pattern of Eo, vpd & temperature during rice growth (rainfed crop)

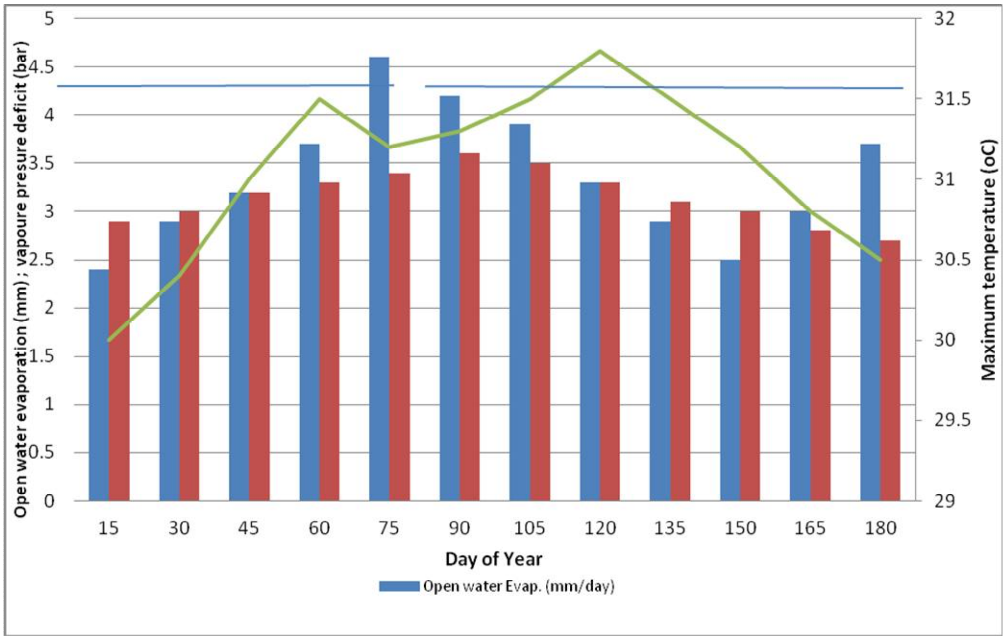

Fig. 1c. Pattern of Eo, vpd and Temperature during rice growth (full irrigated crop)

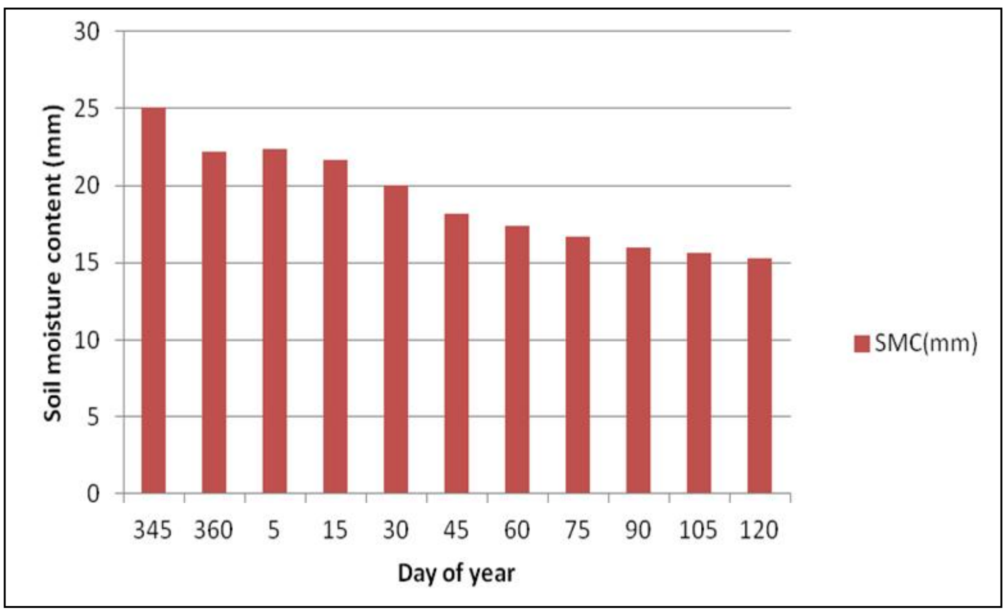

Fig. 2a. Pattern of soil moisture contents during rice growth (Rainfed Expt)

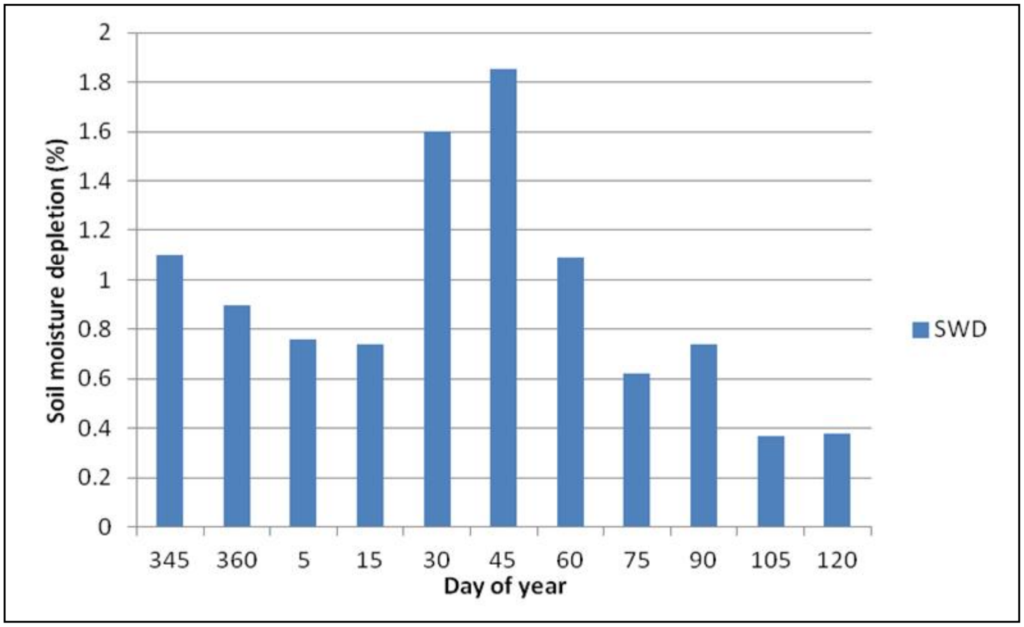

Fig. 2b. Pattern of soil moisture depletion during rice growth (Rainfed Expt)

Table 2. Growth and yield parameters of rice varieties grown in residual soil moisture in the dry season in an inland valley swamp (December 2010 - May 2011)

Plant parameters	Rice varieties				
	Ekpoma Upland)	Nerica 4 (Upland)	Nerica 1 (Lowland)	Nerica 2 (Lowland)	LSD (0.05)
Root dry weight (g)	3.07	0.94	0.74	0.57	0.40
Total number of roots	145.5	100.4	73.8	71.5	15.21
Total root length (cm)	723.04	291.17	382.22	288.18	43.24
Shoot dry weight (g)	4.17	1.55	1.20	1.08	0.54
Plant height (cm)	80.24	75.17	77.05	74.91	3.62
Stem girth (cm)	0.45	0.37	0.32	0.30	0.02
Number of leaves @ 50% flowering	6.2	4.6	5.6	5.0	1.42
Leaf area/plant (cm^2)	70.3	53.9	41.0	42.3	9..6
Width of flag leaf (cm)	1.82	1.53	1.39	1.26	0.08
Number of productive tillers/plant	4.1	3.6	2.7	2.6	0.21
Heading date (@ 50% flowering)	100	65	65	65	---
Number of spikes/panicle	10.7	10.4	10.5	8.9	1.52
Number of spikelets/panicle	111.6	83.5	67.6	63.5	18.7
Panicle weight (g)	173	157	163	141	21.03
Seed weight/panicle	3.40	2.46	1.91	2.10	0.36
Seed yield (t/ha)	1.70	1.23	0.96	1.05	0.21
100 seed weight (g)	3.55	2.99	3.41	3.31	0.06
Harvest index (HI)	5.3	5.7	8.2	7.6	2.03

There was considerable variation between the two groups of rice tested for growth and seed yield characters (Table 3). For example, the two best lines (Upland Ekpoma and Nerica 4), had similar yield performance when grown under irrigation from planting to maturity (harvest) but differed significantly in their trait combinations. The significantly improved performance of upland varieties (Ekpoma and Nerica 4) for the respective first and second sowing date (Table 3), was associated with for example higher seed weight (2.9 and 7.6g compared with 2.0 and 5.1 g) and leaf area (68 and 96 m^2 compared with 42 and 52 m^2).

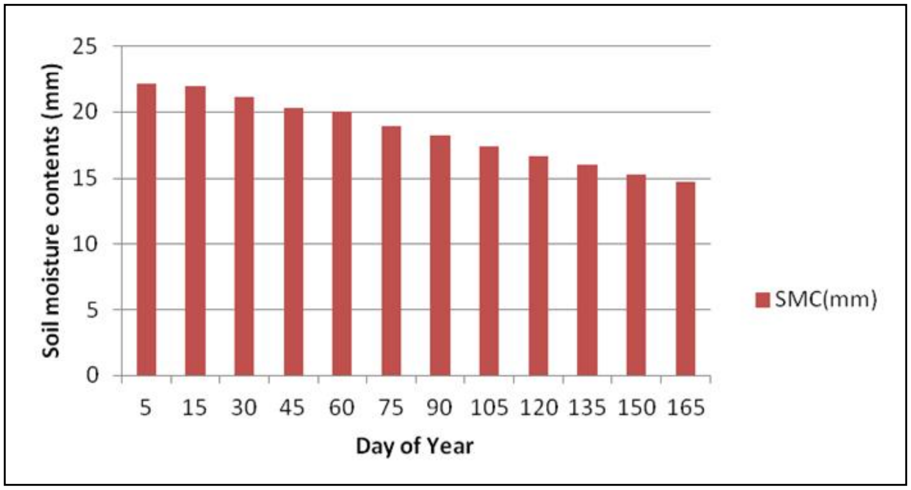

Fig. 3a. Pattern of soil moisture contents during rice growth (irrigation Expt)

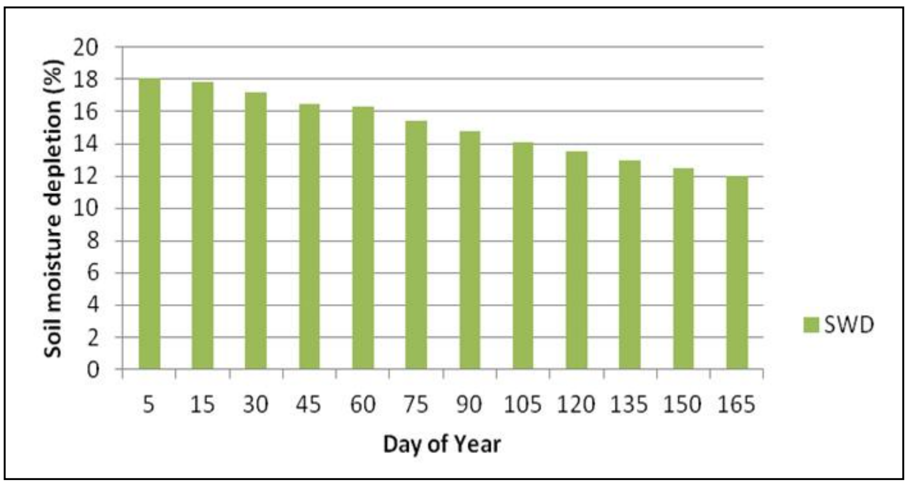

Fig. 3b. Pattern of soil moisture depletion during rice growth (irrigation Expt)

Genotypic potential can explain the variation for most of the measured traits (root and shoot, panicle and seed weights and harvest index). The results indicate that for most of the traits measured (root and shoot weight, leaf area, plant height, number of tillers, panicle and seed weight, 100 seed weight and harvest index), these parameters were significantly different between December (first) and January (second) sowing dates (Tables 4 and 5). Over December sowing, the yield advantage of the January sowing under irrigation throughout growth is associated with taller plants (103.4 and 76.8 cm), leaf area (76 and 52 m^2), and shoot biomass (103.7 and 79 g), panicle weight (0.30 and 0.20 kg) and harvest index (8.9 and 6.7). In addition, the seasonal sum of soil moisture depletion within crop root zone and efficiencies of water use (186 and 223 mm; 0.031 and 0.053 $t.ha^{-1}.mm^{-1}$) were higher for the January sown crop (Table 5).

Some of the measured growth and seed yield characters of rice were related with the prevailing weather conditions of the respective sowing (December and January) and regression equations (exponential, power, logarithmic) were fitted to into these relationships. The regression coefficients (R^2) which were mostly negative for these relationships differed for the two sowing dates differed, R^2 values were higher for the December sowing date for and higher for January sown rice for minimum temperatures (Table 6).

Table 3. Growth and yield parameters of four rice varieties under full irrigation in the dry season in an inland valley swamp (January 2011 – May 2011)

Plant parameters	Rice varieties				
	Ekpoma (Upland)	Nerica 4 (Upland)	Nerica 1 (Lowland)	Nerica 2 (Lowland)	LSD (0.05)
Root dry weight (g)	13.0	3.0	5.81	5.17	0.40
Total number of roots	400.1	352.3	208.9	209.3	15.21
Total root length (cm)	1680.9	1030.2	1079.8	1064.8	43.24
Shoot dry weight (g)	14.0	3.49	6.58	6.08	0.54
Plant height (cm)	127.9	106.9	88.8	70.2	11.9
Stem girth (cm)	0.50	0.42	0.27	0.28	0.02
Number of leaves @ 50% flowering	15.43	14.95	10.48	11.10	1.42
Leaf area/plant (cm^2)	112.5	78.5	57.8	55.6	24.62
Width of flag leaf (cm)	40.74	35.36	30.36	31.74	2.74
Number of productive tillers/plant	4.4	3.9	3.8	3.8	0.21
Heading date (@ 50% flowering)	100	73	70	71	----
Number of spikes/panicle	13.4	11.6	12.4	10.7	1.55
Number of spikelets/panicle	155.6	110.1	94.5	93.8	28.7
Panicle weight (g)	275.4	233.7	268.2	236.8	23.4
Seed weight/panicle	9.21	6.1	5.2	5.0	0.36
Seed yield (t/ha)	4.61	3.05	2.59	2.50	0.43
100 seed weight (g)	3.50	3.22	3.22	3.09	0.30
Harvest index (HI)	8.6	9.1	9.3	8.8	1.17

Shoot biomass (tiller number and leaf area) correlated strongly with crop water satisfaction/stress index (CWSI; $1\text{-}ET_a/ET_o$), accumulated heat units/thermal time and evaporative demand and minimum temperatures. Similarly, seed yield were negatively and highly associated with evaporative demand and thermal time and minimum temperatures.

Exponential and power functions which had highest coefficients (R^2 > 0.80) were the lead equations on the basis of statistical properties. These equations best described the relationships between weather factors and measured growth and seed yield characters of rice for the two sowing dates.

4. DISCUSSION

Among four rice varieties, genotypic tolerance of the soil and air temperatures, soil and air moisture deficits of the dry season was evaluated and the value of genotypic tolerance attributes to seed yield production was discussed. The soil moisture management strategies adopted (soil moisture replenishment via supplementary and full irrigation regimes) produced changes in soil moisture storage, plant water extraction/depletion in the root zone. Panicle weight and panicle contribution to seed yield (productive spikes and spikelets) appeared to be affected by root zone soil moisture status and growing weather conditions at heading (anthesis) and seed filling period.

Over supplementary irrigation, full irrigation throughout crop growth (January sowing) enhanced soil moisture status and the growth and yield characters of rice. Irrigation is known to ameliorate the hydrothermal regimes of soil. Plant biomass (root and shoot dry weight) and leaf area were better under full drip irrigation strategy and the improved growth was accompanied by high grain yield and water use efficiency (WUE) [26,27,12]. In addition, the tested rice varieties responded differently to supplementary and full irrigation strategies which is attributable to genetic characteristics. The dry season is characterized by negligible rainfall, low relative humidity, and high soil water evaporation and solar radiation (high climatic demand). These environmental conditions are known to affect biomass accumulation and seed setting and yield of rice [13,12].

Drought is the most important factor limiting rice productivity under rainfed system worldwide and especially in the humid tropics. In this study, four varieties of rice were field evaluated their yield performance and related traits under variable soil moisture regimes (residual soil moisture at the vegetative stage supplemented with irrigation at the reproductive stage and full irrigation schemes throughout growth phases in the dry season in an inland flood plain (fadama).

Table 4. Growth and yield of the upland and lowland rice varieties for December and January sowing dates

Sowing dates	Root biomass (g)	Shoot biomass(g)	Leaf area (cm^2)	Plant height(cm)	Number of tillers per stand	Panicle weight (g)	100 seed weight (g)	Seed weight per plant (g)	Harvest index
December sowing date									
Upland varieties	2.1	2.8	68	79	3.8	223.3	3.3	2.9	6.95
Lowland varieties	1.3	1.7	42	76	2.6	195.4	3.4	2.0	7.40
LSD (0.05)	0.42	0.46	7.6	4.1	0.54	21.7	0.43	0.46	0.35
January sowing date									
Upland varieties	9.0	9.5	95.3	118.2	4.2	215.6	3.3	7.6	8.75
Lowland varieties	5.5	6.8	58.2	79.7	3.8	189.7	3.2	5.1	8.21
LSD (0.05)	2.7	2.3	17.7	22.6	0.33	14.8	0.31	1.63	0.71

Table 5. Growth and yield of rice for December (first) and January (second) sowing dates

Sowing	Shoot biomass (g)	Plant height (cm)	Leaf area (cm2)	Panicle weight (g)	Seed weight per panicle (g)	Number of seeds per panicle	100 seed weight (g)	Seed yield (t/ha)	Harvest index	Total water applied (mm)	Seasonal sum of soil moisture storage (mm)	Water use efficie-ncy (mm/Kg)
First	79.30	76.84	51.9	0.15	2.47	10.8	3.32	1.24	6.7	40	186	0.031
Second	103.74	103.42	76.1	0.26	6.37	11.4	3.26	3.19	8.9	60	223	0.053
LSD (0.05)	9.31	12.42	9.7	0.05	0.8	0.04	0.03	0.67	1.43	----	----	0.003

Table 6. Association of some weather factors with growth and yield characters of rice during its growth

Parameters	Time of sowing	Regression equations	R^2
Seed weight and CWSI:	First	$y = -13.28x+6.4$	0.94
	Second	$y = -3.93\ln(x) + 1.31$	0.92
100-seed weight and CWSI:	First	$y = -37.9x + 21.6$	0.95
	Second	$y = 3.754x^{-0.72}$	0.81
Seed weight and vpd:	First	$y = -4.251x + 6.4$	0.94
	Second	$y = 1403.5e^{-0.02x}$	0.64
100-seed weight and vpd:	First	$y = 5182.x^{-5.36}$	0.92
	Second	$y = -21.08e^{0.412x}$	0.40
Panicle weight and vpd:	First	$y = 123.7e^{-1.93x}$	0.90
	Second	$y = -2353\ln(x) + 179$	0.57
Leaf area and Thermal time:	First	$y = 0.103x^2-29.14x+1472$	0.90
	Second	$y = 855.8e^{-0.22x}$	0.73
Seed weight and T minimum:	First	$y = -110\ln(x) + 347.8$	0.53
	Second	$y = 0.01x^2-2.23x+150.7$	0.64
Panicle weight and T minimum:	First	$y = -110\ln(x) + 347.8$	0.40
	Second	$y = 0.01x^2-2.23x+150.7$	0.71

The study established the relationship between drought tolerance and yield potential among the tested rice varieties and possible mechanisms that functioned together to contribute to their improved drought tolerance and seed yield potentials. When compared with upland varieties, lowland rice had significantly lower biomass and seed yields in addition to lower harvest indices However, differences were not significant between the groups in terms of biomass and seed yields under full irrigated conditions. A possible mechanism is dehydration avoidance, characterized by significantly higher growth attributes and biomass accumulation across varieties and groups under stress and profound biomass accumulation under full irrigated conditions [1,26,28]. Under full irrigated conditions all varieties were characterized by improved harvest index signifying efficient biomass partitioning, resulting primarily from heavier panicle and seed weight. These ascertions were true and can explain the high biomass accumulation and seed yield production in the Ekpoma variety, the best performing line. Considerable variation in the measured traits among the lowland and upland varieties implies differences in the degree of drought tolerance and yield potential.

The most important mechanism contributing to drought tolerance of the improved upland and lowland Nerica lines was inferred to be dehydration avoidance, characterized by their significantly higher biomass under stress. This mechanism was reflected by their better abilities to maintain a high biomass accumulation under stress. The measured drought tolerant-related traits in the tested rice varieties which presumably are the underlying mechanisms functioned together and contribute to their improved drought tolerance and seed yield potentials. However, the contributions of these traits to drought tolerance and seed yield production in the upland and lowland rice varieties appeared to vary depending on specific period (growth phase) during growth which drought stress was experienced [28,29].

The measured drought tolerant-related traits in the tested rice varieties which presumably are the underlying mechanisms functioned together and contribute to their improved drought tolerance and seed yield potentials. However, the contributions of these traits to drought tolerance and seed yield production in the upland and lowland rice varieties appeared to vary depending on specific period (growth phase) during growth which drought stress was experienced.

Efficient biomass partitioning characterized by high harvest index (HI) can be attributed as the mechanism that contributed to drought tolerance and yield potential among rice varieties. characterized by higher harvest index (HI). This was consistent with previous reports that the maintenance or improvement of HI is of critical importance for drought tolerance (for grain yield) under terminal drought stress [27,30,31,32]. The increase in HI under drought condition was most probably associated with a higher remobilization of assimilates to fill the grains. Previous studies showed that the contribution of dry matter partitioning from stems and leaves to grain filling increased with the severity of drought stress [33,34,28]. The full irrigation applied in this study had greater effects on shoot biomass size (source supply) traits (plant height, leaf area, number of tillers), whereas supplementary irrigation greatly affected traits related to sink size and partitioning (panicle and seed weight, total number of seeds and harvest index).

The environmental conditions after the initiation of reproductive growth can change floral development, alter pollination, or prevent seed filling and ultimately seed yield in crops [35,36,37]. In crops cereals in particular, unfavourable growing environment condition such as drought imposes assimilate limitation, restricts pollination and decreases kernel set [38,36]. In addition to the prevention of pollination presumably by low water potentials during grain filling can arrest ovary growth and cause embryo abortion [33,39,34].

Traits such as biomass accumulation, leaf area development (duration of canopy), capacity for assimilate reserve and mobilization to reproductive structures (grain) are important to crop yield under variable soil water and thermal regimes [40,31]. Plants possess traits which are important to the survival and productivity parameters, these traits are also involved in setting tolerance limit to and confer increased productivity under variable weather conditions [13,12,41]. The identification and understanding of the values of these traits is important in the strategies to improve genotypic adaptation of crops in areas and seasons when varying degrees of soil moisture deficits and temperature extremes are encountered at some stages of crop growth cycle. The tested varieties exhibited differences in their sensitivity to the growing season environmental conditions. The greatest sensitivity occurred in the lowland Nerica varieties.

Regression equations were worked out between some growth parameters of cowpea and some weather variables. These relationships were characterized by variable regression coefficients (R^2) in the different sowing dates. The regression coefficients (R^2) show that on the average, about 40% of shoot biomass and seed yield production in rice is determined by minimum temperatures, open water evaporation, atmospheric dryness (vapor pressure deficit) and accumulated thermal time requirements during the growing period.

5. CONCLUSION

Four varieties of rice were evaluated for beneficial responses to multiple abiotic stress factors (soil and air moisture deficit and temperature stresses) via phenotyping cultivar attributes. The results of this study demonstrated that the tested rice varieties (upland and lowland) differed for most of the phenotypic traits measured between the December and January sowing dates. Total seed yield (3.2 t ha^{-1}) was higher in January over December (1.24 t ha^{-1}) sowing in addition to higher water use efficiencies (0,053 & 0.031 $t.ha^{-1}.mm^{-1}$). The reductions in yield for December sowing is associated with reductions in leaf area, shoot weight panicle and 100 seed weight and harvest index across all tested lines. The two groups of rice tested differed in their growth and seed yield characters. For example, the two best lines (Upland Ekpoma and Nerica 4), had similar yield performance in both sowing dates) but differed in their trait combinations. The improved performance of upland over the lowland varieties for the respective first and second sowing was associated with an increased shoot biomass (6.5 and 4.5 g), increased seed weight (5.5 and 3.5 g) and HI (8.5 and 7.5). Over the lowland varieties, upland Ekpoma and Nerica 4 exhibited superior ability to produce tillers, panicle and seed weights. Some of the measured growth and seed yield characters of rice were related with the prevailing weather conditions of the respective sowing (December and January). The regression coefficients (R^2) which were mostly negative for these relationships differed for the two sowing dates differed. The strong negative association of CWSI with seed yield indicates the inability of soil moisture storage to satisfy rice water requirements (ET_a). The indigenous or land races of rice from the tropics have wide adaptability and excellent grain quality, but moderate yield potential (low productivity). The growth and yield potential (adaptation) of these indigenous varieties may be related to ability to tolerate multiple and concurrent abiotic stresses of soil and air moisture deficits.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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