Response of upland rice agronomic parameters to variable water supply

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Abstract: Rice response to water application is necessary for increased productivity; hence, this study was aimed at establishing the agronomic responses of rice crop to differential water supplies. A two-year dry season experiment was conducted on the research farm of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Two upland rice varieties (NERICA 2 and NERICA 4) were planted on a 5 m×5 m plot in a randomized complete block design with four treatments and two replicates based on different water application. Irrigation scheduling was designed as 100%ET, 75%ET, 50%ET and 25%ET for the treatments weekly. Agronomic parameters such as plant height, root depth, canopy shading (CS), leaf area index (LAI), panicle and tiller configuration, biomass and grain yield in relation to crop water use were obtained and the results were subjected to statistical analysis. Average values of highest plant height (89.0 and 100.3 cm), deepest root depth (22.1 and 23.8 cm), panicle diameter (3.9 and 4.5 cm), panicle length (26.1 and 25.7 cm), LAI, 3.27 and 3.95, CS, 0.22 and 0.99 were obtained for both NERICA 2 and NERICA 4 respectively. Leaf width (1.3 and 1.4 cm), total tillers (14 and 12) and leaf length (36.9 and 38 cm) were also observed for the two varieties respectively. The highest total grain and biomass yields of 1.94 t/ha and 1.95 t/ha were observed in 100%ET treatment for NERICA 2 while the least values of 0.29 t/ha and 1.09 t/ha were observed in 25%ET treatment. As for NERICA 4, the highest values (1.90 t/ha and 2.27 t/ha) were from 100%ET and the least (0.38 t/ha and 2.29 t/ha) in 25%ET. The result of ANOVA showed significant differences in biomass and grain yield, LAI, CS, plant height and root depth among treatments (P<0.05) stressing the domineering influence of water in agronomic response of rice.

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1 Introduction

Rice (*Oryza sativa L*) constitutes one of the most important staple foods of over half of the world's population. Globally, it ranks third place after wheat and maize in terms of production[1]. Food security in the world is challenged by increasing food demand and threatened by declining water availability. More recently, the increase in area under biofuel crops at the cost of food crops is also threatening[2]. In Nigeria, rice is the sixth major crop in cultivated land area after sorghum, millet, cowpea, cassava and yam[3,4]. It is the only crop grown nationwide and in all agro-ecological zones from Sahel to the coastal swamps. Rice could be cultivated in about 4.6-4.9 million ha of land in Nigeria, but the actual area under cultivation is only 1 million ha representing 22% of the total potential available area[5]. Before the oil boom of the 1970s, Nigeria had been largely self sufficient in rice production with negligible imports to take care of the

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taste of small European population in the country. The resultant buoyant foreign exchange earnings of the country from the oil boom of 1970-80 raised the general standard of living and taste, which resulted in massive importation of all kinds of manufactured goods and commodities, including rice. Local rice production was no longer encouraged and therefore national self-sufficiency declined from over 99% from 1961 to 1973 to about 23% in 1984[6]. Rice importation rose from 7 000 tons in the 1960s to 657 000 tons in the 1990s[7,8]. Although, Nigeria is West Africa's largest producer of rice, producing an average of 3.2 million tons of paddy rice in the past five years[9], the country is also the World's second largest rice importer, spending over US$300 million on rice imports annually which rose to US$1 billion in 2010[10]. This had created serious drain on Nigeria's foreign exchange reserve and also raised a big question: Why should the country continue to spend that much on rice imports when it has the capacity to become self sufficient in rice production? The answer could lie in increasing productivity using irrigation. Despite large research efforts to lift rice yields, there are large gaps between biologically achievable potential yields at research stations and on farm yields[11].

Water is essential for rice cultivation and its supply in adequate quantity is one of the most important factors in rice production. In Asia and other parts of the world, rice crop suffers either from too little water (drought) or too much (flooding or submergence). Most studies on constraints to high rice yield showed that water is the main factor for yield gaps and yield variability from experiment stations to farm[12]. Irrigated agriculture is the dominant use of water, accounting for about 80 % of global and 86% of developing countries water consumption as in 1995[13]. By 2025, global population will likely increase to 7.9 billion, more than 80% of whom will live in developing countries and 58% in rapidly growing urban areas[14]. About 250 million ha, representing 17% of global agricultural land, is irrigated worldwide today, nearly five times more than at the beginning of the 20th century. This had contributed about 40% of the global production of cereal crops. Irrigated rice was responsible for about 75% of the world's total rice production[15,16]. Irregular water application often leads to high amount of surface runoff, seepage and percolation which accounts for about 50%-80% of the total water input into the field[17]. Therefore, the water crisis being experienced today is not about having too little water to satisfy our needs especially in agriculture but a crisis of proper management[18]. The objective of this study therefore, was to investigate the effect of this important factor of production on the agronomy of rice crop under variable water supply.

2 Materials and methods

The study was carried out at the farmyard of the International Institute of Tropical Agriculture (IITA), Ibadan, the Oyo State capital, Nigeria. Located between latitude 3°54'E and 7°30'N, at elevation of 200 m above the mean sea level, it has an annual rainfall range between 1 300 mm and 2 000 mm while its rainfall distribution pattern is bimodal. The annual mean temperature is 27.2^{o}C during dry season and 25.6^{o}C during the rainy season. The soil class is *oxic paleustaff* which belongs to Egbeda Series and is described as Alfisol (Apomu Sandy loam). The vegetation is humid rain forest with an average relative humidity of between 56% and 59% during the dry season and 51%-82% during the wet season[19].

Field experiment were conducted for two dry seasons to ascertain the crop's water use under irrigated conditions, between November 2005 and March 2006 (first trial) and November 2006 to March 2007 (second trial). The experimental design was a Randomized Complete Block Design (RCBD) with four treatments and two replicates. NERICA 2 and 4 were planted on all the plots and irrigation water was delivered through an overhead sprinkler systems. There were four treatments based on the level of irrigation water application. Plot A (first treatment) received water daily at full irrigation capacity (100%ET) and plot B (second treatment) received water six days in a week at moderate irrigation capacity (75%ET). The third treatment (plot C) received water five days in a week at medium irrigation capacity (50%ET) and the fourth treatment (plot D) received water four days in a week at low irrigation capacity (25%ET). A controlled experiment to monitor the behaviour of rice on the field was carried in a lysimeter situated in a screen house located 50 metres away from the field[18]. Weekly measurements of plant height of rice were made using the measuring rule from two weeks after planting (i.e. from emergence) to maturity stage (i.e. fifteen weeks after planting) in order to monitor the crop growth response to the variability of water supplied. Canopy Analyzer [Li Cor 2000] was used in measuring the Leaf Area Index (LAI) and Canopy Shading (CS) non-destructively. Other agronomic parameters determined included, the grain yield, grain size, leaf length and width, number of leaves panicle length, tillering ability, root depth, flowering and maturity days using convectional equipment such as weighing balance, measuring rule and vernier caliper. The field weight of grain yield was corrected to 12% moisture content before storage. Results obtained during field experimentation were subjected to statistical analysis using SAS 9.1 version.

3 Results and discussion

3.1 Root depth response to water use

The root depths of the crop throughout the entire growing season were as shown in Figure 1. The average maximum root depths of 22.6 cm and 23.8 cm were recorded in Plot A in the 2 varieties (i.e. N2 and N4) while the lowest was recorded in Plot C (17.3 cm) and predictably in plot D, (18.1 cm) in field observations respectively during the first trial. Similar results were obtained for the second trial with root depths of 23.5 cm in A and 19.4 cm in D respectively (Table 1). The variation in the root depth within the treatments may be due to differential water application as a result of deficit irrigation experienced in D using low irrigation. This agreed with the findings of[20, 21] which remarked that a relationship existed between water location and root depth during rice development. This was a clear indication that the length of roots of rice has a direct bearing on the water application and use of water in all the treatments considered.

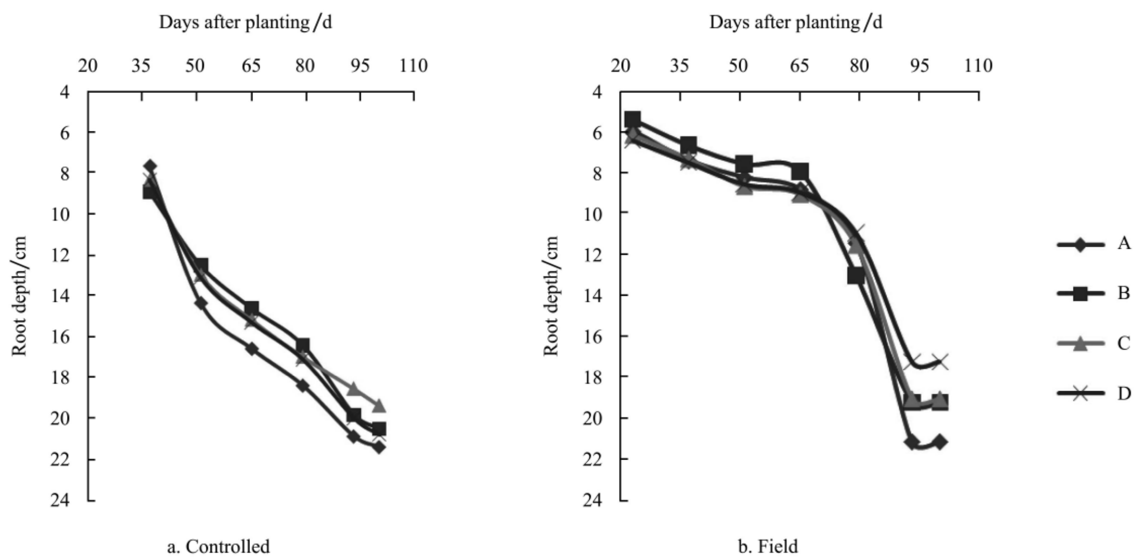
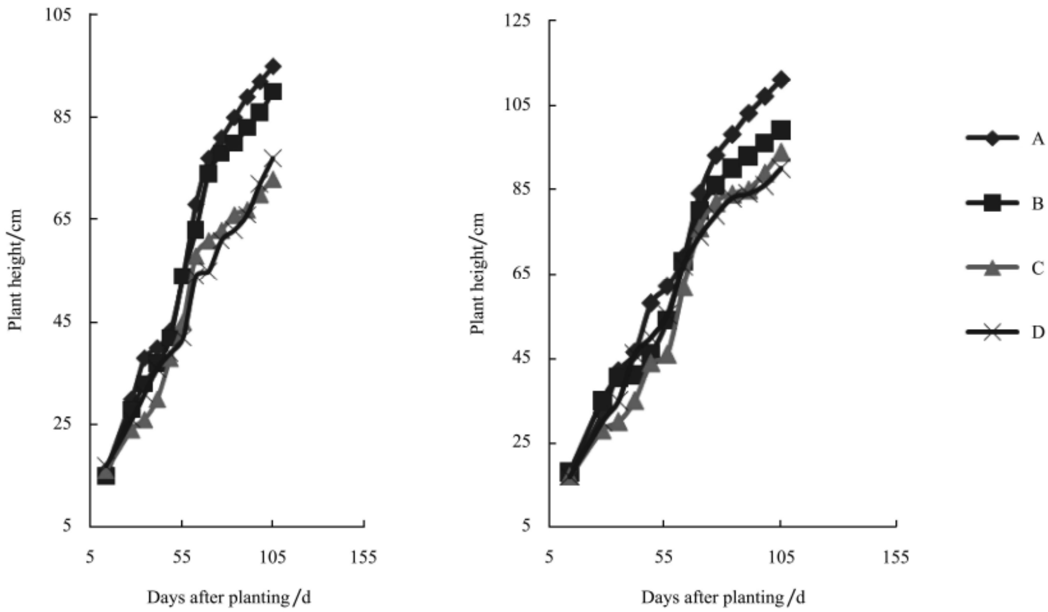


Figure 1 Variations in Root Depths versus Days after Planting in controlled and field experiments

3.2 Plant height response to water use

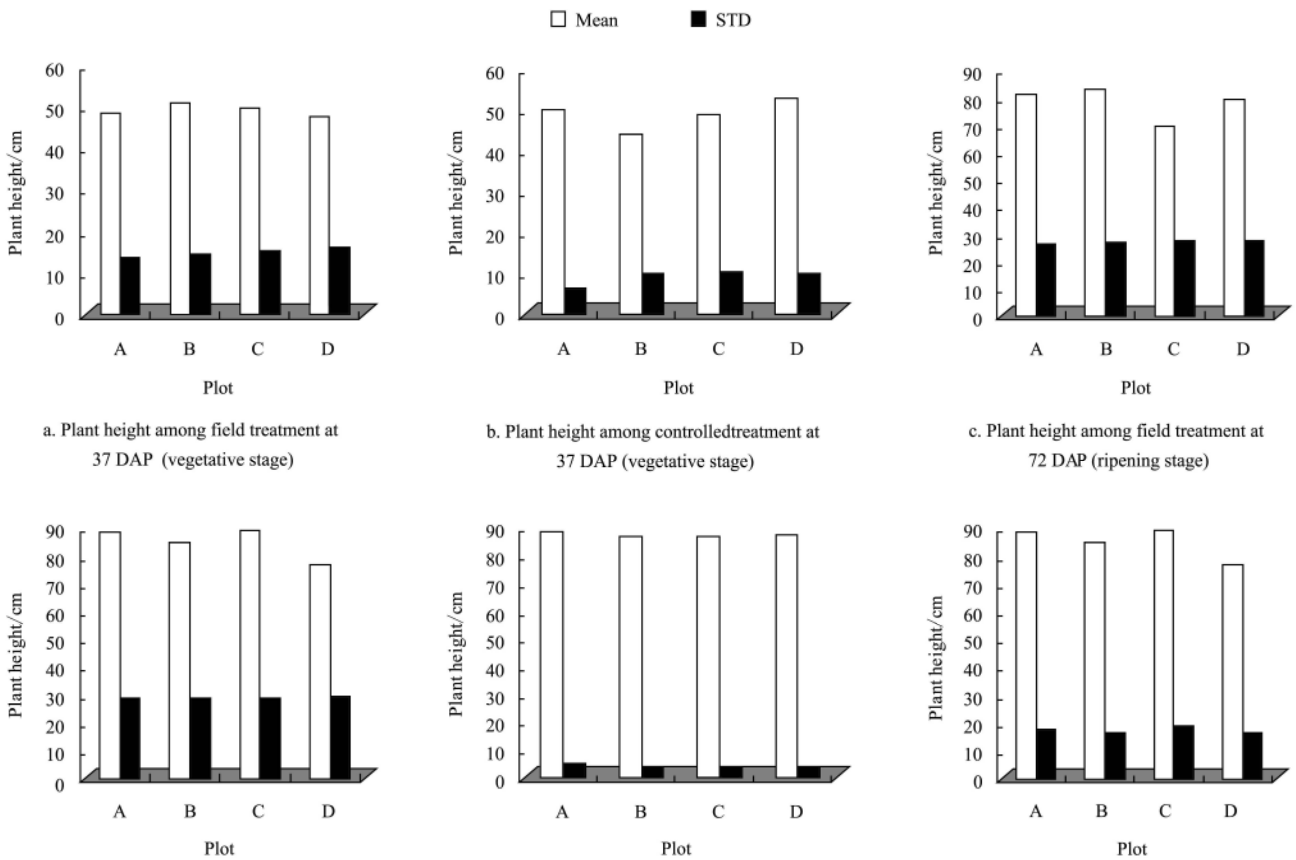
The heights of rice during the vegetative, ripening and maturity stages for the four treatments were given in Figure 2 and illustration of mean heights and the standard deviation of each of the treatments are in Figure 3. N2 had average maximum plant height of 89 cm while N4 had an average height of 100.3 cm during the first trial (Figure 2). This was similar in values recorded in the second experimental trial indicating reliability in the methods adopted and quantity of water applied. This agreed with the findings of[22,23] which in separate instances confirmed the observations of WARDA[24] that N2 is shorter than N4.



a. Plant height for N2

b. Plant height for N4

Figure 2 Plant height versus Days after Planting (DAP) for N2 and N4 on all the plots



a. Plant height among field treatment at 37 DAP (vegetative stage)

b. Plant height among controlledtreatment at 37 DAP (vegetative stage)

c. Plant height among field treatment at 72 DAP (ripening stage)

d. Plant height among controlledtreatment at 72 DAP (vegetative stage)

e. Plant height among field treatment at 93 DAP (maturity stage)

f. Plant height among controlledtreatment at 93 DAP (maturity stage)

Figure 3 Plant height among treatments in field and controlled experiment at different stages of growth

The steady and consistent rise in the crop's height was attributed to the quantity of irrigation water applied, which was a reflection of the glaring differences in the parameters for the different plots. Several researchers[25-27] agreed with this fact that crop's behaviour was due to the quantity of irrigation water scheduled per given time which varied from soil, weather and the crop's genetically-modified variety. There were differences in the plant height at ripening (72 DAP) and maturity (93 DAP) stages among treatments at 5% level of significance (Figure 3). It was evident that differences in plant height among field treatments were obvious as the controlled treatments especially at 37 DAP. At vegetative stage, the monitored soil effect was evident as crop emergence were mostly soil and water dependent. At 72 DAP (ripening stage), the combined effect of soil and weather was more visible hence, the little variation in the plant height (particularly in field experiment). At 92 DAP; the weather effect was more evident hence, the pronounced variation in the mean plant height and deviation. These observations were similar to the ones reported by[28] in his research.

3.3 Leaf Area Index (LAI) response to water use

The correlation between LAI and DAP in all the treatment plots were as shown in Figure 4. The values of LAI were found to be highest in treatment A and lowest in treatment D. In the first trial, LAI was found to be 1.78 in N2 variety but in the second experiment, N2 has a LAI of 3.27 while N4 was measured to be 3.95 (Figure 4). The changes noticed in the same variety but different season may be associated with soil's moisture content and climate change variability which has been reported of the increase in daytime temperature[29]. These readings were observed during the mid season/ripening stage in both N2 and N4 varieties (65 to 85 DAP). However, the values were nearly equal particularly at the maturity stage. This behaviour followed the water distribution pattern which is a function of %ET of water applied, since any effect on LAI would definitely affect yield. The data confirmed that the variable pattern in water applied affected the LAI and subsequently yields in the treatment plots. The observation was also an indication of increased water application resulting in decreased crop water use since water stress had been eliminated hence the leaves orientation during the ripening stage. This also agreed with the findings of[30] and [20,21] who stressed that the leaf area orientation is a function of water application. At 5% level of significance, the difference in values of LAI between the treatments was significant.

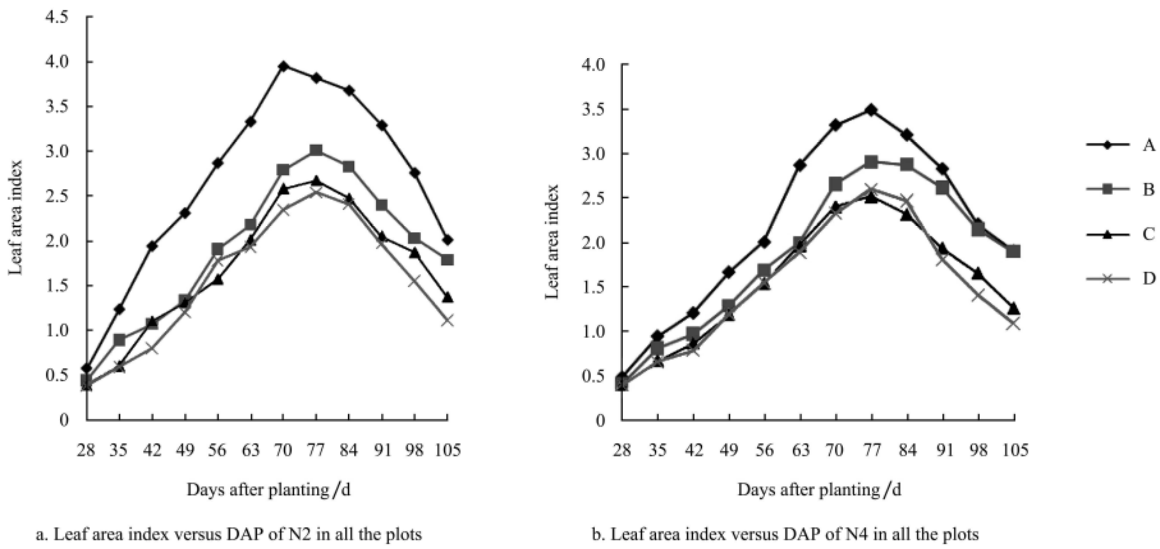
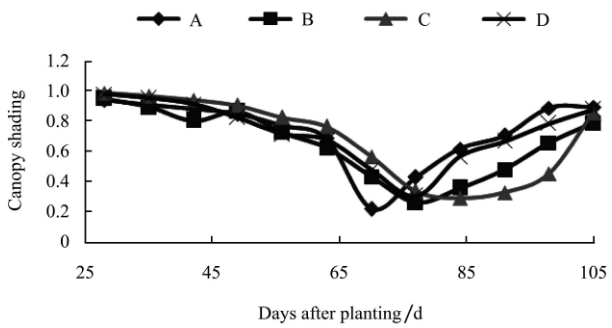


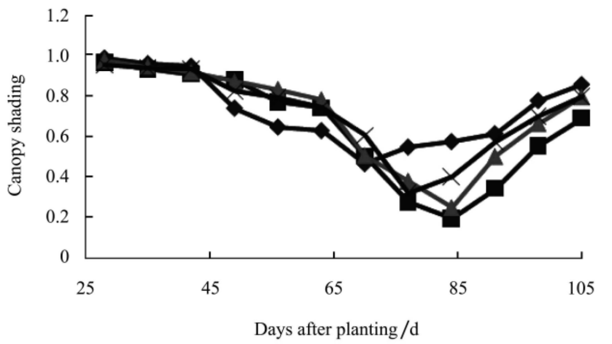
Figure 4 Leaf Area Index (LAI) versus Days after Planting (DAP) of N2 and N4 in all the plots during the second experimental trial

3.4 Canopy Shading (CS) response to water use

Canopy shading (CS)'s response to variation with days after planting (DAP) for the second trials were shown in Figure 5. It was observed that the highest CS (0.2) was during the mid season stage (heading, booting, flowering and milky phases of the ripening stage) i.e. between 60-79 DAP. By 105 DAP, CS has dropped to between 0.8 and 1.0 among the treatments. This was due to the fact that at maturity, leaves coloration changed from lush green to brown and the canopy had collapsed in readiness for grain harvesting. This behaviour was similar to LAI as the highest CS was observed during the ripening stage; the same time LAI was at the maximum on all the plots. Similar observations were recorded for the first trial and in both varieties. LAI had maximum values (3.95 for N4 and 3.27 for N2) during ripening stages (65-85 DAP) in both varieties. This implied that increased water application increased LAI as well as CS indicating the need for irrigation scheduling at a certain stage of crop growth. It must be noted that irrigation water was increased by 100% (full ET) during the mid season/ripening stage in all the treatments and trials. This was to cater for increased metabolic activities of the crop at this stage. Similar trends in behaviour was observed and recorded for LAI vs DAP and CS vs DAP in the first trials.



a. Canopy shadingfor N2



b. Canopy shadingfor N4

Figure 5 Canopy Shading (CS) versus Days after Planting (DAP) for N2 and N4 in all the plots

3.5 Post-harvest parameters

Post harvest agronomic parameters such as the panicle length, panicle diameter, total tiller, grain length, width and diameter and 100 grain weight were all measured in both experiments. The results presented in Tables 2 and 3 conformed to the standard frequently quoted by the Africa Rice Institute (ARI) and West Africa Rice Development Authority (WARDA) for upland NERICA 2 and 4 rice varieties. The maximum plant height and leaf length were 89 and 37 cm respectively. Panicle length and diameter were 26 and 3.9 cm respectively. Leaves number, width and total tillers were 11, 1.4 cm and 14 respectively. Similar observations were recorded in Table 2 for N4 variety; maximum plant height and leaf length were 100.3 and 38 cm respectively. Panicle length and diameter were 25 and 4.5 cm respectively while leaves number, width and total tillers were 12, 1.3 cm and 12 respectively at 5% least square difference (LSD) and agreed with the findings of[4,21,23,24]. These were indicative of definite behaviour to water application at different stages of crop development. Further increase in water application may not result in any pronounced change(s) in these parameters.

Table 1 Average Root Depth measurements at various Days after Planting (DAP) in all the treatment plots during the second experimental trial

DAP	A/cm	B/cm	C/cm	D/cm
23	5.92	5.34	6.12	6.36
37	7.34	6.6	7.28	7.44
51	8.18	7.5	8.62	8.5
65	8.76	7.88	9.02	8.9
79	11.38	12.98	11.5	10.9
93	21.12	19.2	19	17.2
100	23.45	20.32	20	19.35
103	23.5	20.33	20	19.35

Table 2 Results of measured plant parameters (N2) after harvest from field experiment

Plots	Plant height/cm	Root depth/cm	No of leaves	No of tillers	Leaf length/cm	Leaf width/cm	Panicle diameter/cm	Panicle length/cm
A	88.8	22.6	11	15	36.89	1.44	3.92	26.08
B	85.6	19.2	9	13	35.94	1.30	3.76	25.50
C	88.8	19.1	11	8	32.30	1.28	4.50	25.60
D	76.4	17.2	8	10	29.46	1.24	3.34	23.84

Note: LSD (*P*>5%).

Table 3 Results of measured plant parameters (N4) after harvest from field experiment

Plots	Plant height/cm	Root depth/cm	No of leaves	No of tillers	Leaf length/cm	Leaf width/cm	Panicle diameter/cm	Panicle length/cm
A	100.33	23.80	12	15	37.98	1.28	4.55	24.65
B	87.33	21.51	11	12	34.97	1.43	4.10	25.97
C	86.63	20.38	12	12	30.33	1.32	3.48	24.48
D	85.75	19.78	10	12	29.25	1.35	4.03	25.75

Note: LSD (*P*>5%).

3.6 Grain and biomass yield

The values of grain yield, biomass and total yield in t/ha were given for the first trial in Table 4 and second trial in Table 5. These parameters were highest in treatment A and lowest in treatment D. The variation in the yield per treatment was due to the quantity of water received and days assigned for irrigation per plot which varied tremendously. The crop in treatment A received water, 7 days a week while treatment D received water 4 days a week. Increased irrigation water application resulted in increase in soil moisture availability for crop use since no water stress was allowed on the crop. Reduced crop water stress would result in reduction in crop water use and increase in crop growth. This was the summary of the findings of[15, 17, 22, 30] under identical conditions. This was a clear indication that increased irrigation water applied does not increase crop water use but decreased water application increases crop water use. Similar observations were recorded for irrigation water applied and total ET for rice in plots C and D. This trend also affected all agronomic parameters including biomass and grain yield as there were noticeable reduction in all the plots as water use increases (Tables 4 and 5). The grain yield was highest in plot A (1.36 and 1.94 t/ha) in the two trials and steady but gradual decline was observed in all other plots (B and C). In plot D, the grain yield was minimum (0.16 and 0.29 t/ha) indicating that water has a yield-limiting influence on the rice crop. One major factor that limit the yield was the emergence of whiteheads on all the four plots during milky and flowering stages of ripening (78 DAP) in the first trial. Table 6 showed variation of the whiteheads, an indication of water deficit at that stage. The lowest was in Plot A, 7.4% while the highest expectedly was found in plot D 16.6%. This may have affected the final outcome of the grain yield. This was the resultant effect of the introduction of temporal deficit irrigation towards the later part of ripening stage. The emergence of whiteheads was a clear indication that deficit irrigation during mid season stage of crop development was not healthy for an optimum growth. However, this does not imply that deficit irrigation was not possible during rice growing season but its introduction during the mid season/ripening stage will greatly affect the crop development and yield. The findings of[20,22,30] agreed with the observation in yield variation as a result of differential irrigation among the treatments. The statistical analyses using SAS and excel for the four major parameters selected were as shown in Tables 7a and 7b. The four parameters considered were the quantity of water applied, plant height, root depth and number of leaves from the experiment. It was shown from the Pearson's coefficient that at the relationship between root depth and number of leaves was highly significant (0.92), a moderate significance was observed between number of leaves and plant height and plant height and quantity of applied water while plant height and root depth were merely significant. The implications of all these was that the relationship between root depth, with its accessibility to water uptake is significantly felt on the number of leaves the crop would produce and similar explanations for plant height and water applied.

Table 4 Grain yield, biomass and total yield of rice for N2 in the 2005/2006 experiment

Plot	Grain yield/t · ha^{-1}	Biomass yield/t · ha^{-1}	Total yield/t · ha^{-1}
A	1.36	1.84	3.2
B	0.81	2.39	3.2
C	0.30	2.30	2.6
D	0.16	1.64	1.8

Table 5 Grain yield, biomass and total yield for N2 and N4 in the 2006/2007 experiment

Treatment plots	Rice type	Grain yield /t • ha^{-1}	Biomass yield /t • ha^{-1}	Total yield /t • ha^{-1}
A	N2	1.94	1.95	3.89
	N4	1.90	2.27	4.17
B	N2	1.25	2.70	3.95
	N4	1.43	2.55	3.98
C	N2	0.66	2.15	2.81
	N4	0.91	2.22	3.13
D	N2	0.29	1.09	1.38
	N4	0.38	2.29	2.67

Table 6 Number of whiteheads in the N2 plots at 78 DAP in the 2005/2006 trial

Plot	Whiteheads	% Composition per plot
A	47	7.4
B	81	15.7
C	94	16.1
D	98	16.6

Table 7a Simple statistical parameters of the four variablesfor field experiment

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
Qwapplied	40	55.42650	11.76035	2217	32.20000	88.80000
Pltht	40	51.43375	28.94265	2057	5.12000	89.40000
Rtdepth	34	10.68353	4.80388	363.24000	3.00000	21.12000
Nolf	26	10.69231	6.88633	278.00000	3.00000	31.00000

Note: N = 20.

Table 7b Pearson correlation coefficients for the four variables for field experiment

	Qwapplied	Pltht	Rtdepth	Nolf
Qwapplied	1.00000	-0.51943**	0.21129	-0.03215
Pltht		1.00000	0.33956*	0.55850**
Rtdepth			1.00000	0.91242***
Nolf				1.00000

Note: * Significant; ** moderately significant; *** Very significant.

4 Conclusions and recommendations

A two year field experiment to evaluate differential water application of upland NERICA rice as it relates to increased productivity was carried out at the farmyard of the International Institute of Tropical Agriculture, (IITA) Ibadan, Nigeria. The choice of upland rice was informed by the fact that the irrigated upland ecology has very high potential for rice production but contributes between 10 and 15 % to national production. Adopting strict water conservation measures will lead crop failure at a certain stage, indicating that the effect of water stress leads to corresponding increase in water use at certain stages such as midseason/ripening stage of crop growth and development. The emergence of whiteheads was an indication of shortfalls in water requirements at this stage. There were corresponding responses of all agronomic parameters of the rice crop observed to changes in water application, indicating the dominant effect of water to growth and development.

The recommendations are:

1) Interspecific cross hybridization of the very good traits of other local rice varieties such as Ofada, Igbimo, Aroso with NERICA cultivars for replication and multiplication is encouraged. This is to complement farmers' efforts with their increased yield production while maintaining some of its very good African traits.

2) Research should be conducted into using modern technologies for bird scaring to reduce considerable yields of rice being lost annually and also to ensure reliable yield data. The age long, primitive method of human bird scaring is effective only on small fields. However, the use of nets as temporary measures to prevent rice invasion by birds (small or medium fields) is suggested. Similarly, chicken wire mesh should be placed around the field to prevent rodents and grass cutters invasion. This is useful where human efforts (bird scarer) may not be enough to prevent birds from attacking rice fields.

3) Application of Alternate Wetting and Drying (AWD) technique to upland rice cultivar in Nigeria should be carried out. This is to investigate its effect on the yield and other agronomic parameters while considering water saving as one of the mitigating strategies against impact of climate change on food and agriculture productivity.

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