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FIELD WATER MANAGEMENT AND N-RATES TO SAVE WATER AND CONTROL IRON TOXICITY IN LOWLAND RICE

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ABSTRACT

Poor level of development of lowlands in West Africa, epitomized with bad water management generates favorable conditions for occurrence of iron toxicity which is responsible for limiting yields of lowland rice. Field trial was conducted in 2009, 2010 and 2011 to evaluate the effect of water and nitrogen management on iron toxicity and yield of lowland rice in the Bida, Niger State, Nigeria. Treatments imposed were: (1) Continuous flooding with 5 cm water head from transplanting to hard dough stage. (2) Alternate 30 days flooding with 5 cm water head – 7 days drainage - 30 days flooding – 7 days drainage – 30 days flooding -7 days drainage and flood up to hard dough stage. (3) Alternate 60 days flood with 5 cm water head - 7 days drainage – 30 days flooding – 7 days drainage and flood up to hard dough stage. (4) Alternate 90 days flooding with 5 cm water head – 7 days drainage – flood up to hard dough stage. The N-rates applied were: 40 (control), 60, 80 and 100 kg N ha^{-1}. Treatments were replicated four times and data obtained were statistically analyzed using SAS statistical package. Results obtained showed that irrigation and N-rates had significant influence ($P<0.05$) on plant height, panicles number, straw and grain yield when compared with the control (farmers practice). There were no significant differences in grain yield between application of 80 kg N ha^{-1} and 100 kg N ha^{-1}. Yields generally increased with increasing levels of nitrogen up to 80 kg N ha^{-1} and declined with further increase in N-level. Nitrogen use efficiency decreased with increasing levels of nitrogen rates and was 25 kg kg^{-1} for application of 40 kg N ha^{-1}. There were also significant differences in plant tissue iron content. Iron concentration was higher in the control than treatments with higher levels of nitrogen. Continuous flooding with 5 cm water head from transplanting to hard dough and the application of 80 kg N ha^{-1} gave the highest yield in the 3 seasons. The average irrigation water applied for the 3 seasons was 1441 mm including rainfall and crop water use. Treatment 2 of water management saved 143 mm and average water use efficiency was 3.80 kg mm^{-1}. This treatment also had a marginal decline in grain yield but there was a tradeoff between yield and drainage. Appropriate water and nitrogen management can reduce the intensity of iron in rice to enhance sustainable yield increases of paddy rice in the lowland soils of Bida area.

Keywords: water management; N-rates; iron toxicity; lowland rice.

INTRODUCTION

Rice is a profligate user of water, it uses 3000-5000 liters to produce 1 kilogram of paddy rice, which is about 2 to 3 times more than the quantity required producing 1 kilogram of other cereals such as maize or wheat (Cantrell, 2002). Nigeria's present and future food security depends largely on irrigated rice production. However, the water use efficiency of rice is low, and growing rice requires large amounts of water. Until recently, the amount of water for irrigated rice has been taken for granted, but now the global water crisis threatens sustainability of irrigated rice production (Gleick, 1993; Postel, 1997). Reasons for this are diverse and location specific, but include decreasing quality

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(chemical, pollution, salinization), decreasing resources (falling groundwater tables, silting of reservoirs), and increased competition from other sectors such as urban and industrial users (Postel, 1997).

Increasing scarcity of water, the costs of its use and resource development are increasing. Therefore, farmers and researchers alike are looking for ways to decrease water use in rice production, increase its use efficiency and increase yield of paddy rice. A fundamental approach for achieving this is to start at the field level, where water and rice interact. For farmers with no control over the availability or distribution of water beyond their farm gates, the crucial question to address is what are the options to cope with the decreasing water supply at the farm or field inlets? To answer this question, we have to look at the flow of water into the rice fields and understand where reductions in water use can be achieved without compromising yield.

Large reduction in water input can be realized by reducing the unproductive seepage and percolation (SP) flows during crop growth and idle periods (Bouman & Tuong, 2001). The idle period is the period when the fields are flooded and allowed to soak before land preparation.

Iron toxicity is one of the main nutritional disorders, which limits yield of lowland rice. Higher concentration of Fe^{2+} in the rhizosphere also has antagonistic effects in the uptake of many essential nutrients (Fageria *et al.,* 2008). Among the toxicities, iron toxicity is acknowledged as a widespread disorder affecting growth of crops, principally lowland rice (Dobermann & Fairhust, 2000; Cheriff *et al.,* 2009). All types of lowlands (mangrove, irrigated, rainfed) with or without water control, can be affected by iron toxicity constraint in tropical zones. The poor level of development of lowlands in West Africa, epitomized with bad water management, generates favorable conditions for occurrence of iron toxicity (Kosaki *et al.,* 1986; Okusami, 1986; Audebert & Sahrawat, 2000). On acid soils it is considered one of the most significant constraints of rice production along with Zn deficiency (Neue *et al.,* 1998; Becker & Asch, 2005).

Iron toxicity in rice is generally associated with excessive quantities of ferrous ion (Fe^{2+}) reduced in the soil (*in situ*) or interflow from adjacent upland. This constraint can occur on large number of soils, but the general character of iron toxicity raises value of reduced iron, low acid pH, low cation exchange capacity (CEC) and low exchangeable K (Kirk, 2004; Kirk *et al.,* 1993; Ottow *et al.,* 1993).These traits can be associated with Zn deficiencies as well as H_2S toxicity.

The yield loss induced by the iron toxicity is frequently associated with low nutritional status. Consequently, iron toxicity can be defined as a multiple nutritive disorder further increased by P, K, and Zn deficiencies through excesses of H_2S (Ottow *et al.,* 1993; Fageria *et al.,* 2008). Symptoms of iron toxicity in rice results from excessive uptake of ferrous ions by the roots and their acropetal translocation through xylem outflow to the aerial parts. The typical symptoms linked to this are the bronzing or yellowing processes of the leaves (Becker & Asch, 2005). Yield losses associated with the occurrence of iron toxicity symptoms generally range from 15-50%. In the case of severe toxicity however; total harvest loss can occur (Abifarin, 1988; Audebert & Sahrawat, 2000).

The objectives of the study were therefore, to study the effect of water regimes and N-rates on iron concentration in lowland rice and to determine the effect of water regimes and N-rates on growth and yield components of lowland rice.

MATERIALS AND METHODS

Experimental Site Location and Description

The experiment was conducted at the National Cereals Research Institute Badeggi, Edozighi research farm (lat. 9^0 06' N and long. 5^0 59' E). Soils of the area were classified as dystric gleysol (FAO/UNESCO), silt-loam and iron-toxic (Narteh & Sahrawat, 1999). The climate is characterized by a distinct wet season from April to November with average rainfall of about 1200mm and dry season from November to March.

Experimental Design

The experimental treatments consisted of four irrigation regimes imposed as in the following sequence:

I. Continuous flooding with 5 cm water head from transplanting to hard dough stage (CF).

II. Alternate 30 days flooding – 7 days drainage – 30 days flooding – 7 days drainage – 30 days flooding – 7 days drainage and flood up to hard dough stage (AF30-7-30-7-30-7).

III. Alternate 60 days flooding – 7 days drainage – 30 days flooding – 7 days drainage and flood up to hard dough stage (AF60-7-30-7).

IV. Alternate 90 days flooding – 7 days drainage and flood up to hard dough stage (AF90-7) and four nitrogen (N) rates: 40 kg N ha^{-1} (control), 60 kg N ha^{-1}, 80 kg N ha^{-1}, and 100 kg N ha^{-1}. Phosphorus and potassium were applied as single super phosphate and K_2O, at 45 kg P_2O_5 ha^{-1} and at 45 kg K_2O ha^{-1} respectively.

The water management (irrigation regimes) was assigned to the main plots while N-rates were assigned to the subplots. The experiment was laid out in a Randomized Complete Block Design with split plot arrangement. Each treatment was replicated four times (Figure 6).

The main plots were 12x5m and the subplots 5x3m in size. The field plots were puddled and kept continuously flooded and drained at determinate intervals from transplanting till 2 weeks before harvest, when the fields were finally drained. Water depth was initially 5 cm in the field plots and gradually decreased to 2 cm when water was again applied to bring the depth to 5 cm for the plots that have standing water. Field plots were drained at intervals for a period of 7 days and again water was applied to bring up the depth to 5 cm. Re-flooding the fields after 7 days was equivalent to soil water potential of -20 cb. This threshold for soil water tension was similar to research in alternately submerged, non-submerged systems conducted by Belder *et al.,* 2004; Bouman & Tuong, 2001. Plastic sheets were installed down to 40 cm in the bunds of all subplots in order to control the mobility of nitrogen from one subplot to another. Irrigation water was supplied to the field plots through orifices of 1m long with a diameter of 7.62cm (PVC pipe). The discharge was calculated as the cross-sectional area of the orifice multiplied by velocity ($Q= 0.61\ A\ \sqrt{2gH}$).

Twenty one-day old seedlings of FARO 35 (susceptible to iron toxicity), 120 days variety of lowland rice were transplanted with two seedlings per hill at a spacing of 20 x 20 cm. Fertilizer N.P.K was applied seven days after transplanting. Phosphorus and potassium were applied as single super phosphate and K_2O, at 45 kg P_2O_5 ha^{-1} and at 45 kg K_2O ha^{-1} respectively. Urea was applied in 3 splits; at 7 DAT, maximum tillering, and at panicle initiation stages. Weeding was done 2 times for the plots with continuous flooding and 3 times for the alternate flooding treatments

Soil and Plant Analysis

Soil samples (20 cm depth) were collected air-dried, crushed with porcelain pestle and mortar and sieved to remove materials greater than 2mm for physical and chemical analysis. Soil pH was determined potentiometrically in water with glass electrode using soil to water ratio of 1:2.5. Particle size analysis was made using hydrometer method (Gee & Bauder, 1986). Organic carbon was determined by the Walkley-Black wet oxidation method (Olsen and Sommers, 1982), and total N was determined by the Kjedahl method as described by Bremmer (1965). Extractable P was determined colorimetrically using spectrophotometer as described by Olsen and Sommers (1982). Exchangeable acidity was determined by titrimetric method using 1N KCl solution and cation exchange capacity (CEC) was estimated by summation method of exchangeable acidity and exchangeable bases as described by Chapman (1965). Exchangeable bases were determined by extraction with neutral 1N ammonium acetate (NH_4 OAc), sodium (Na) and potassium (K) in the extract were determined with flame photometer while calcium (Ca) and magnesium (Mg) were determined using the atomic absorption spectrophotometer (Kundsen *et al.,* 1982). Extractable micronutrients zinc (Zn), iron (Fe) manganese (Mn) were extracted with 0.1N HCl and determined by atomic absorption spectrophotometer (Osiname *et al.,* 1973).

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Sixteen hill/ plant samples were taken at 30, 60, and 90 DAT. from all treatments to determine tissue iron and nitrogen content. The samples were oven dried at 70 ^{0} C and then finely ground to pass through a 0.5 mm sieve. Nitrogen uptake was calculated from the nitrogen concentration of the grains and straw. Grain and straw weight were taken from 12 m^2 in the centre of the plots.

Water Use and Nitrogen Use Efficiencies

Water use efficiency was calculated as the ratio of biological yield (grain + straw) to total water applied. Nitrogen use efficiency is the ratio of nitrogen content in the grain and straw to the nitrogen applied (Bouman *et al*., 2005). Meteorological data collected at the site included rainfall, evaporation, wind speed, minimum and maximum temperatures. Evaporatranspiration (water used) was calculated using class A pan evaporation method: 0.70 x E pan (FAO, 2010). Standard evaluation of rice (IRRI 1988) was used to score iron toxicity, (1- not severe, 9 - severe).

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using the General Linear Model Procedure of SAS (SAS Inst. 2002). Treatment effects were analyzed on yearly basis and pooled where necessary. Where the F-ratios were found to be significant, treatment means were separated using standard error of means (SEM). Regression analyses were performed for relevant soil and plant parameters. Duncan Multiple Range Test (DMRT) was also performed for the separation of means.

RESULTS AND DISCUSSION

Initial Physical Properties of the Soil

Particle Size Distribution

Analysis of particle size distribution showed that the soil contained 44.08% sand, 46.56% silt and 9.36% clay; the texture was loam (Table 1).

Sizes of dominant soil particles (sand and silt) will determine the physical properties of the soil. Clay and silt generally have very fine particle size, while sand particles are considerably larger and would impact high potential for water percolation that could be controlled by puddling to conserve water for lowland rice production.

Silt: Clay ratio

The silt: clay ratio of 4.97 indicated that the soils would be relatively young or the parent materials have undergone low degree of weathering. The sand and silt contents were almost equal. The large silt content would be a reflection of the aeolian origin of their parent material. Soils with silt: clay ratio less than 0.15 are said to be at advanced weathering stage (van Wambeke, 1962). The low clay content may be due to sorting of soil material by biological activities, clay migration or surface erosion (Ojanuga, 1979). Therefore, soils of the study area are rich in silt, which in the presence of clay could provide a suitable lowland condition for lowland rice production (Table 1).

Table 1. Initial Physical properies of the soil

Soil property	Value
Classification	Dystric Gleysol
Sand (%)	44.08
Silt (%)	46.56
Clay (%)	9.36
Texture	Loam
Silt:Clay ratio	4.97
Bulk density (g cm^{-3})	1.42
Total porosity	45%

Bulk Density of the soil

Mean bulk density of the soil was 1.42 g cm^{-3} and is within limits to support easy root penetration (Table 1). Bulk density values exceeding 1.45 g cm^{-3} would severely impede plant root penetration and growth (Ogunwale, 2000). This could result to lodging in rice and consequently low yield.

Total Porosity

Total porosity (calculated from bulk density and particle density) was 45% (Table 1). The low value of soil porosity could impact poor structural condition and low stability of aggregates, which leads to compaction (Kowal, 1970). This may be attributed to puddling activities on the soil.

Chemical Properties of the Soil

Chemical properties of the soil are contained in Table 2. Soil pH in water was 4.50 and in $CaCl_2$ solution were 3.15 to show that the soils were generally acidic in reaction and had net negative charge at the natural soil reaction as indicated by the fall in pH between water and $CaCl_2$. The Implication of acid condition of the lowland soil is that it affects the supply of nutrients to the rice crop and enhances reduction of ferric iron to ferrous which was detrimental to lowland rice growth. At a very low pH (< 4.0) physiological activity of the rice plant decreases drastically and this weakens root functions (Rorison, 1973; Tadano & Yoshida, 1978).

The surface soil was generally moderate in organic matter with a value of 10.69 g kg^{-1}. The reason for the moderate content of organic matter in the lowland was probably due to intensive cultivation and Farmers have the habit of commonly burning rice straw after harvest. For sustainability, rice straw should be incorporated into the soil. . Organic carbon would be moderate for the lowland soil with a value of 6.20 g kg^{-1}, but could be deficient when it is < 5.5 g kg^{-1} (Odunze *et al*., 2012).

The soil had low exchangeable potassium, magnesium and calcium with values of 0.14, 0.80 and 0.23 cmol kg^{-1} respectively. Exchange acidity and Sodium were also low with values of 0.40 and 0.15 cmol kg^{-1} respectively. Exchange acidity value of the lowland was less than 1.0 cmol kg^{-1} and suggests that the soils have no exchange acidity problem (Brady and Weil, 2002). The lowland soil was also low in total nitrogen with value of 0.65 g kg^{-1}.

Cation exchange capacity (CEC) with value of 5.60 cmol kg^{-1} was low. This would suggest that the soils have a dominance of low activity clay (Lombin, 1987). External nutrients had to be added to improve soil fertility for lowland rice production.

The C: N ratio was 9.54:1 suggesting low carbon sequestration. The low carbon stock could be attributed to intensive farming of rice in the area or coupled with the burning of rice straw and the rate of organic matter mineralization due to high tropical temperatures.

Manganese, aluminium and iron with values of 12.17, 76.00 and 342 mg kg^{-1} respectively were well supplied in the soil; Zn was low with a value of 0.20 mg kg^{-1}. Micronutrients in submerged lowlands were abundant due to the reduction process in the soil. Zinc was low probably because of the antagonistic effect with iron (Ponnamperuma, 1972). Where soil pH is higher than 4.3 as it was in this experiment, concentration of Al in soil solution was not toxic to lowland rice as Al became less soluble with rise in pH (Kensuke and Matthias, 2004).

In summary, from the data presented in Table 2 it would be inferred that the lowland soil in Edozighi could be deficient in essential nutrients such as Phosphorus, Potassium, Calcium, Magnesium and Zinc (P 4. 23 mg kg^{-1}, K 0.14, Ca 0.8, Mg 0.8 cmol kg^{-1} and Zn 0.20 mg kg^{-1}). The soil had moderate organic matter with a value of 10.69 g kg^{-1}, low total nitrogen with a value of 0.65 g kg^{-1} and cation exchange capacity of 5.60 cmol kg^{-1}. In order to have sustainable lowland rice production, argumentation of nutrients that are deficient in the soil is necessary. It is a common practice to remove the rice from the field and thresh without returning the straw back to the field and at times burn after threshing. This practice could be partly responsible for the low soil nutrient and organic carbon contents. Incorporation of straw into the soil during land preparation would improve availability of soil nutrients, C.E.C and organic matter contents for sustainable productivity.

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Table 2. Initial Chemical Properties of the soil

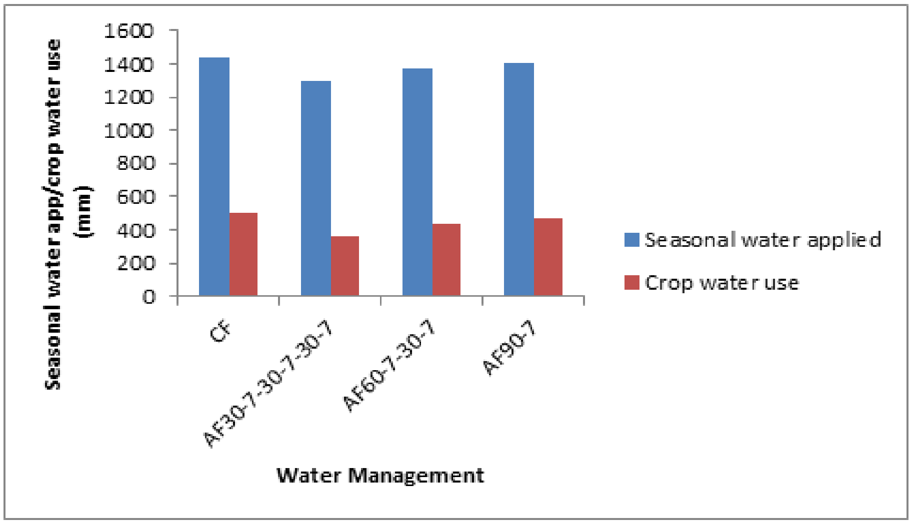
Soil property	Value
pH (H_2O)	4.50
pH ($CaCl_2$)	3.15
O M (g kg^{-1})	10.69
Total N (g kg^{-1})	0.65
Organic C (g kg^{-1})	6.20
C:N ratio	9.54;1
CEC (cmol kg^{-1})	5.60
P Bray1 (mg kg^{-1})	4.23
Fe (mg kg^{-1})	342
Mn (mg kg^{-1})	12.17
Zn (mg kg^{-1})	0.20
Al (mg kg^{-1})	76.00
K (cmol kg^{-1})	0.14
Ca (cmol kg^{-1})	0.80
Mg (cmol kg^{-1})	0.23
Na (cmol kg^{-1})	0.15
H+Al (cmol kg^{-1})	0.40

Water Management in Lowland Rice

The total water applied to the crop was 1441 mm; including rainfall and crop water use was 507 mm for treatment 1 that had continuous flooding. The treatment that was drained three times during the crop life cycle (treatment 2) had the least water input of 1297 mm and the water used was 365 mm (Fig. 1). Irrigation water applied to treatment 3 (draining the field twice) was 1369 mm and the water used by the rice crop was 439 mm. Also, the water applied to treatment 4 (draining the field once) was 1404 mm; the water used was 473 mm. This means that draining at thirty day-interval for seven days, three times in the crops life cycle saved 144 mm when compared with continuous flooding.

The advantages of draining the waterlogged soil are enormous. Firstly, it saves water, oxidizes the soil and precipitates Fe^{2+} to Fe^{3+} which is insoluble. Iron oxidization allows microbes to gain energy. The ferric ion produced, physically protects the microorganisms. Iron is a good electron acceptor; oxygen and nitrate suppress iron reduction (Mullilab, 2008).

Increasing water scarcity during the off-season and increasing adverse subsoil water levels necessitates the development of techniques that require less water than traditional flooded rice. Researchers are developing water saving technologies, such as alternate wetting and drying (Bouman & Tuong, 2001; Belder *et al.*, 2004; Tinh, *et al.*, 2000), and continuous saturation (Borell *et al.*, 1997) to reduce water losses and improve its productivity. This will also reduce methane emission a greenhouse gas that is responsible for global warming,



CF continuous flooding, AF alternate flooding with number of days of flooding and drainage

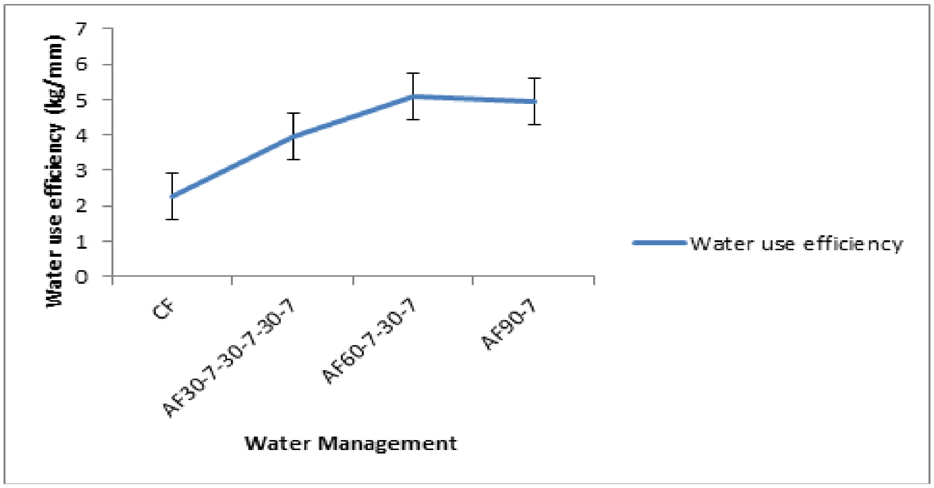
Figure 1. Irrigation water applied and crop water use in lowland rice. Average data for 3 years

Water use efficiency

Water used efficiency was 2.26 kg mm^{-1} for treatment 1, and 3.90 kg mm^{-1} for treatment 2. Treatments 3 and 4 had water use efficiencies of 5.09 and 4.88 kg mm^{-1} respectively. Treatment 3 had the highest water used efficiency (Figure 2).

Water management had actually increased yield. Treatment 1 of the main plot with continuous standing water to harvest and the application of 80 kg ha^{-1} of N, treatment 3 of the subplot had the highest yield of 3.05 t/ha. This was not significantly different from treatment 4 of the main plot which had irrigation water drained once and the N applied was 100 kg ha^{-1}. There was however a decline in yield when the field plots were drained more than 2 times as in treatment 2 with values of 2.05 t/ha, the yield loss was 7%.

Drainage saved water however, this was followed by yield reduction but there was a tradeoff between drainage and yield. This was also reported by Ethan *et a*l., (2011) and Bouman *et al*., (2005) in their studies. Tanaka *et al.*, (1965) in his studies observed that drainage treatments increased yield to about 10% in soils with high N availability, but decreased yield more than 10% in soils with low N, because withdrawal of water and irrigation treatments enhanced denitrification and nitrate leaching.



1-flood field till harvest; 2-drain field 3 times; 3-drain field 2 times; 4-drain field once

Figure 2. Water use efficiency of lowland rice

Effect of water management and N-rates on plant height

Table 3 presents data on the effect of water management and N-rates on plant height. Continuous flooding (CF) treatment had plant height value of 74.19 cm in 2009. In 2010 and 2011 plant height values were 76.62 and 76.31 cm respectively and average value for the 3 years was 75.71cm. There were no significant differences ($P< 0.05$) in plant height in the 3 years under this water regime.

Alternate flooding AF30-7-30-7-30-7 treatment had plant height values of 74.13, 76.31, and 76.50 cm in 2009, 2010 and 2011 respectively and average value for the 3 years was 75. 65 cm. Similarly, AF60-7-30-7 had plant height values of 74.13, 76.60, and 76.31 respectively in the 3 seasons under the same water regime and also had average value of 75.68 cm. The AF90-7 treatment had plant height values of 74.19, 76.31 and 76.43 cm respectively in the 3 seasons and average plant height value of 75.64 cm. There was no significant difference ($P< 0.05$) across all the alternate flooding treatments in plant height.

Application of 40 kg N ha^{-1} (farmers practice) treatment had the shortest plant height values of 52.00, 56.00 and 56.00 cm in the first, second and third year respectively. This was closely followed by application of 60 kg N ha^{-1} that had values of plant height as 65.75 cm, 68.75 cm and 68.75 cm respectively for the 3 seasons. This was significantly different ($P<0.05$) from application of 40 kg N ha^{-1}. Similarly, application of 80 kg N ha^{-1} had its plant height as 89.25cm, 91.25cm and 90.50 cm in the first, second and third year respectively. This was not significantly different from application of 100 kg N ha^{-1} with plant height values of 89.50cm, 90.50cm and 90.00 cm respectively in the 3 seasons. Rice plant height increased with increase in nitrogen rates but appeared to level off at 100 kg N ha^{-1}. The results corroborated with findings by Fageria & Baligar, (2001); Sahrawat (2005) who observed increase in plant height with increase in nitrogen rate.

In summary, findings on the effect of water management and N-rates on plant height suggest that water management did not interact significantly with N-rates to influence plant height. Also, there was no significant difference in plant height between 80 or 100 kg N ha^{-1} rates. Hence, 80 kg N ha^{-1} rate is preferred as it would conserve cost and mitigate nitrogen pollution of groundwater and sustain improved soil quality.

Table 3. Effect of water management and N-rates on plant height

Treatments	Water Management			
	Plant height (cm)			
	2009	2010	2011	Average
CF	74.19a	76.62a	76.31a	75.71a
AF30-7-30-7-30-7	74.13a	76.31a	76.50a	75.65a
AF60-7-30-7	74.13a	76.60a	76.31a	75.68a
AF90-7	74.19a	76.31a	76.43a	75.64a
Mean	74.16	76.46	76.39	
SEM	0.36	0.39	0.47	
N-Rates (NR)				
40 kg N ha^{-1}	51.56c	54.21c	55.62b	53.83c
60 kg N ha^{-1}	66.00b	68.19b	68.81b	67.67b
80 kg N ha^{-1}	89.31a	90.56a	90.31a	90.06a
100 kg N ha^{-1}	89.50a	90.37a	90.37a	90.08a
Mean	74.09	75.79	76.28	
SEM	0.29	0.28	0.25	
WM*NR	Ns			

Ns- not significant, means followed by same letter in a column are not significantly different ($P< 0.05$).

Effect of water management and N-rates on shoot tissue iron content

Table 4 presents data on the effect of water management and N-rates on shoot tissue iron content. Continuous flooding treatment (CF) had shoot tissue iron concentration of 253.31, 265.81 and 255.69 mg kg^{-1} in the first, second and third year respectively and average for 3 years was 258.27 mg kg^{-1}. One of the intervention measures for reducing iron toxicity in lowland soils is continuous flooding (IRRI, 2002), where iron is washed and drained from the field by flooding water. Contrary to the report, our results indicated higher iron concentrations in shoot tissues under continuous flooding treatments when compared with alternate flooding. The reasons could be poor drainage network of the irrigation scheme.

The alternate flooding treatments (AF30-7-30-7-30-7) had shoot tissue iron concentration of 250.86 mg kg^{-1} in 2009. The 2010 and 2011 shoot tissue iron concentration was 254.81 and 254.69 mg kg^{-1} respectively and the average was 253.45 mg kg^{-1}. This was significantly different ($P< 0.05$) from the continuous flooding treatment. Similarly, AF60-7-30-7 had shoot tissue iron concentration of 250.75, 255.12 and 254.44 mg kg^{-1} in the first, second and the third cropping seasons respectively. The AF90-7 treatment had shoot tissue iron concentration of 253.06, 253.87 and 255.12 mg kg^{-1} respectively and the average was 254.01 mg kg^{-1}. There was no significant difference ($P< 0.05$) in the alternate flooding treatments AF30-7-30-7-30-7, AF60-7-30-7 and AF90-7 in iron content in the shoots of the lowland rice.

Application of 40 kg N ha^{-1} had the highest iron concentration in the shoot tissues with values of 287.25, 298.75 and 297.12 mg kg^{-1} and the average was 294.37 mg kg^{-1} in the 3 seasons. This was closely followed by application of 60 kg N ha^{-1} with shoot tissue values of 264.12, 278.87 and 278.69 mg kg^{-1} respectively and average of 273.89 mg kg^{-1} in the 3 years. There was significant ($P < 0.05$) reduction in shoot tissue iron concentration when 80 and 100 kg N ha^{-1} was applied. This demonstrated that increasing application of nitrogen rates could lower the uptake of ferrous iron by the rice plant. The result could support the findings of Fageria & Baligar, (2001), who reported increase in rice grain yield with increase in N-rates in iron toxic soils. Perhaps, this was due to the reduction in iron concentration in the shoots. Table 10 therefore confirms that water management interacted significantly to nitrogen rates to reduce iron toxicity in the rice plant.

Iron toxicity in the vegetative stage causes a reduction in height and dry matter (Abu *et al.,* 1989). Aerial biomass can be more affected by iron toxicity constraint than root biomass (Fageria, 1988) while tiller formation and a number of productive tillers can be drastically reduced (Cheema *et al.,* 1990). When iron toxicity occurs at the end of vegetative stage, or at the beginning of reproductive stage, number of panicles drops (Singh *et al.,* 1992), and spikelet sterility increases (Virmani, 1977) and the flowering and maturity stages can be delayed by 20-25 days. For some cultivars highly susceptible to iron toxicity, no flowering takes place (Ayotade, 1979).

Table 4. Effect of water management and N-rates on shoot tissue iron content

Treatments	**Water Management (WM)**			
	Shoot tissue iron content (mg kg^{-1})			
	2009	**2010**	**2011**	**Average**
CF	253.31a	265.81a	255.69a	258.27a
AF30-7-30-7-30-7	**74.13a**	254.81b	254.69b	253.45b
AF60-7-30-7	250.75b	255.12b	254.44b	253.43b
AF90-7	253.06a	253.87b	255.12a	254.01b
Mean	251.99	257.40	254.98	
SEM	2.04	0.08	1.77	
	N-Rates (NR)			
40 kg N ha^{-1}	287.25a	298.75a	297.12a	294.37a
60 kg N ha^{-1}	264.12b	278.87b	278.69b	273.89b
80 kg N ha^{-1}	228.06c	222.69c	222.81c	224.52c
100 kg N ha^{-1}	228.55c	219.93c	219.88c	222.79c
Mean	251.99	255.01	254.63	
SEM	1.25	0.91	1.30	
WM*NR*				

* Significant at ($P< 0.05$), means followed by same letter in a column are not significantly different ($P< 0.05$).

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Effect of water management and N-rates on straw weight of lowland rice

Table 5 presents data on the effect of water management and N-rates on straw weight of lowland rice. Continuous flooding treatment (CF) had straw weight values of 3.22, 3.21 and 3.23 t ha^{-1} respectively in the first second and third year and the average was 3.22 t ha^{-1}. The AF30-7-30-7-30-7 treatment had the following values of straw weight 3.22, 3.21 and 3.23 t ha-$^{-1}$ respectively in the 3 seasons and the average was 3.22 t ha^{-1}. Similarly, AF60-7-30-7 and AF90-7 had non-significant values of straw weight. There was no significant difference (P<0.05) in straw weight under water management regimes across the treatments (contiuous flooding and alternate flooding). This was probably because we had low water head of 5 cm in the field plots. Bouman & Tuong (2001) reported low straw weight values in treatments that had higher water head (10 cm) in field plots.

Application of 40 kg N ha^{-1} had straw yield values of 2.04, 2.03 and 2.03 t ha^{-1} in the first, second and third year respectively and was the lowest. Application of 60 kg N ha^{-1} had higher values of rice straw weight of 3.02, 3.04 and 3.03 t ha^{-1} in the 3 seasons which was significantly different (P<0.05) from application of 40 kg N ha^{-1} . However, there was no significant difference in straw weight when 80 kg N ha^{-1} was applied with values of 3.94, 3.83 and 3.94 t ha^{-1} in the first, second and third year and application of 100 kg N ha^{-1} with values of 3.90, 3.82 and 3.91 t ha^{-1} respectively (Table 13). Application of 40 kg N ha^{-1} had the lowest straw weight and the highest straw yield was obtained from application of 80 kg N ha^{-1}. This was not significantly different from application of 100 kg N ha^{-1} meaning production of nearly equal amounts of biomass irrespective of 80 or 100 kg N ha^{-1} application rates. The average values of straw weight for the 3 years indicate no significant differences at the application of 80 kg N ha^{-1} and 100 kg N ha^{1}. This suggests that 80 kg N ha^{-1} could be the optimum N-rate for lowland rice production in Edozighi. The interaction between water management and nitrogen rates showed no significant difference (P<0.05). Table 5 therefore suggests that water management did not interact significantly with the N-rates to influence straw weight yield.

Iron toxicity is related to multiple nutritional stresses, which leads to reduced metabolites and in a period of intense metabolic activities such as tillering, these results in an increased rhizosphere population, which in turn leads to increased demand for electron acceptors (Dobermann & Fairhust, 2000). The application of optimal N increases oxidation power of the roots and enhances nutrient uptake which eventually increases biomass. Low oxidation power of roots lead to more ferrous iron uptake that causes iron toxicity (Fageria & Baligar, 2001).

Table 5. Effect of water management and N-rates on rice straw weight

Treatments	Water Management			
	Straw weight (t ha^{-1})			
	2009	2010	2011	Average
CF	3.22a	3.21a	3.23a	3.22a
AF30-7-30-7-30-7	3.22a	3.21a	3.23a	3.22a
AF60-7-30-7	3.22a	3.21a	3.23a	3.22a
AF90-7	3.22a	3.21a	3.23a	3.22a
Mean	3.22	3.21	3.23	
SEM	0.09	2.14	0.03	
N-Rates (NR)				
40 kg N ha^{-1}	2.04c	2.03c	2.03c	2.03c
60 kg N ha^{-1}	3.02b	3.04b	3.03b	3.03b
80 kg N ha^{-1}	3.94a	3.83a	3.94a	3.90a
100 kg N ha^{-1}	3.90a	3.82a	3.91a	3.88a
Mean	3.22	3.18	3.23	
SEM	0.30	1.05	1.02	
WM*NR	Ns			

Ns- not significant, means followed by same letter in a column are not significantly different (P< 0.05).

Effect of water management and N-rates on panicles number of lowland rice

Table 6 presents data on the effect of water management and N-rates on panicles number of lowland rice. Continuous flooding treatment (CF) had panicles number values of 263.25, 273.12 and 271.62 respectively and the average was 269.12 in the 3 seasons. The AF30-7-30-7-30-7 alternate flooding treatment had the following number of panicles 263.25, 271.06 and 272.37 in the 3 seasons respectively and the average was 268.89. This was not significantly different from AF60-7-39-7 and AF90-7 alternate flooding treatments. There were no significant differences between the continuous flooding treatments and the alternate flooding. Panicles number is an important factor that influences rice grain yield (Fageria & Baligar, 2001).

Application of 40 kg N ha^{-1} had values of 201.56, 210.12 and 211.00 number of panicles in the 3 seasons respectively and was the lowest. Panicles number is an important factor in grain yield which was significantly affected ($P<0.05$) by the N-rates treatments. Application of 60 kg N ha^{-1} had higher values of 251.06, 259.56 and 259.00 numbers of panicles in the 3 planting seasons. This was significantly different from application of 40 kg N ha^{-1}. However, application of 80 kg N ha^{-1} had values of 301.62, 310.31 and 310.31 number of panicles in the first, second and third year. This was not significantly different from application of 100 kg N ha^{-1} with values of 300.56, 308.25 and 309.50 number of panicles. The results of the analysis suggest that application of 80 kg N ha^{-1} is the optimal N-rate. Interaction between water management and N-rates was not significant on the number of panicles. Table 6 therefore suggests that water management did not interact significantly with N-rates to influence panicles number.

Iron toxicity disrupts rice plant physiology to affect tillering and eventually reduces panicle number that latter translates into reduced grain yield. Application of N fertilizer had significantly increased the number of panicles per m^2 in iron-toxic environment (Fageria *et al*., 2008). Fertilizer N uptake tends to minimize the toxic effect of excess iron on panicle number and other yield components (Audebert *et al.,* 2006).

Table 6. Effect of water management and N-rates on panicles number

Treatments	Water Management			
	Panicles number (m^2)			
	2009	2010	2011	Average
CF	263.62a	272.12a	271.62a	3.22a
AF30-7-30-7-30-7	263.25a	271.06a	272.37a	3.22a
AF60-7-30-7	264.06a	272.68a	272.56a	3.22a
AF90-7	263.87a	272.50a	272.50a	3.22a
Mean	263.67a	272.09a	272.26a	
SEM	0.29	0.27	1.86	
N-Rates (NR)				
40 kg N ha^{-1}	201.56c	210.12c	211.00c	207.56c
60 kg N ha^{-1}	251.06b	259.56b	259.00b	256.54b
80 kg N ha^{-1}	301.62a	310.31a	310.00a	307.31a
100 kg N ha^{-1}	300.56a	308.25a	309.50a	306.96a
Mean	263.70	272.29	272.35	
SEM	0.30	0.25	0.80	
WM*NR		Ns		

Ns- not significant, means followed by same letter in a column are not significantly different ($P< 0.05$).

Effect of water management and N-rates on rice grain yield

Table 7 presents data on the effect of water management and N-rates on rice grain yield. Continous flooding treatment (CF) had the following values of rice grain yield 2.37, 2.43 and 2.44 t ha^{-1} in the 3 seasons respectively and the average was 2.41 t ha^{-1}. This treatment had the highest rice grain yield across water management treatments. This agrees with the findings of Tabbal *et al.*, (2002) and Bouman & Tuong (2001) who reported increased in grain yield under continous flooding water regime. Alternate flooding treatment (AF30-7-30-7-30-7) had these values as rice grain yield 2.02, 2.02 and 2.04 t ha^{-1} respectively in 3 seasons; the average was 2.03 t ha^{-1}. This was not significantly different ($P< 0.05$) from the AF60-7-30-7 and AF90-7.alternate flooding treatments. Studies have shown that prolonged drainage of the fields (alternate flooding treatments) witnessed decline in rice grain yield (Bouman & Tuong, 2005) when compared with continous flooding as it was in this experiment. Water saved from the alternate flooding could be used for another round of irrigation.

Application of 40 kg N ha^{-1} (farmers practice) had rice grain yield values of 1.24 t ha^{-1} in the first year, 1.32 t ha^{-1} in the second and 1.33 t ha^{-1} in the third year . Higher yields were obtained when 60 kg N ha^{-1} was applied in the 3 seasons with values of 2.04, 2.09 and 2.12 t ha^{-1} respectively. Application of 80 kg N ha^{-1} had grain yield values of 3.05, 3.10 and 3.11 t ha^{-1} respectively in the 3 seasons. Similarly, application of 100 kg N ha^{-1} had 3.02, 3.07 and 3.07 t ha^{-1} grain yields in the 3 seasons respectively. There was a marginal decline in grain yield when 100 kg N ha^{-1} was applied though this was not significantly different ($P<0.05$) from application of 80 kg N ha^{-1}. Average grain yield values followed the same trend across the treatments.

Grain yield was significantly increased by increasing the nitrogen levels and declined when the N-rates were more than 80 kg ha^{-1}.This implies that 80 kg N ha^{-1} application rate, irrespective of the water management was optimal for rice grain yield in the Edozighi area of Nigeria. Across the water management and N-rate treatments, continuous flooding till hard dough combined with 80 or 100 kg N ha^{-1} fertilizer resulted in significantly higher rice grain yield than the other treatments. This finding supports the positive interaction effect between water management (WM) and nitrogen management (NR); thus suggesting that flooding field till hard dough enhanced significant rice yield better than the other alternate flooding regimes. However, under each water management treatment 80 kg N ha^{-1} enhanced rice grain yield better than the other N-rate treatments.

Grain yield in rice is a function of panicles per unit area, number of spikelets per panicle and filled spikelets (Fageria *et al,* 1997). Data on the effect of water and nitrogen management on rice grain yield supported a large body of literature that confimed the effect of nitrogen (balance nutrition) and water management on reducing iron concentration in lowland soils, improved growth and increased rice grain yield.

Table 7. Effect of water management on N-rates on rice grain yield

Treatments	**Water Management**			
	Grain yield (t ha^{-2})			
	2009	**2010**	**2011**	**Average**
CF	2.37a	2.43a	2.44a	2.41a
AF30-7-30-7-30-7	2.02b	2.02b	2.04b	2.03b
AF60-7-30-7	2.04b	2.02b	2.03b	2.03b
AF90-7	2.09b	2.05b	2.07b	2.07b
Mean	2.13	2.13	2.14	
SEM	0.07	0.03	0.05	
N-Rates (NR)				
40 kg N ha^{-1}	1.24c	1.32c	1.33c	1.30c
60 kg N ha^{-1}	2.04b	2.09b	2.12b	2.15b
80 kg N ha^{-1}	3.05a	3.10a	3.11a	3.09a
100 kg N ha^{-1}	3.02a	3.07a	3.07a	3.05a
Mean	2.34	2.39	2.41	
SEM	0.06	0.02	0.03	
WM*NR *				

* Significant at ($P< 0.05$), means followed by same letter in a column are not significantly different.

Effect of water management and N-rates on Nitrogen use efficiency (NUE) of lowland rice

Application of 40 kg N ha^{-1} had the following values of nitrogen use efficiencies (NUE) 20, 21 and 23 kg kg^{-1} in the first, second and third year respectively (Figures 3 and 4). This treatment had the highest nitrogen use efficiency under this N treatment. The lowest nitrogen use efficiency was however obtained from the application of 100 kg N ha^{-1} with values of 16, 15 and 16 kg kg^{-1} in the 3 seasons. The application of 60 kg N ha^{-1} had the following values 20, 19 and 21 kg kg^{-1} in the 3 seasons and application of 80 kg N ha^{-1} had nitrogen use efficiencies values of 18, 18 and 19 kg kg^{-1} in the first, second and third year respectively.

Average for the 3 seasons were as follow: application of 40 kg N ha^{-1} had value of 25 kg kg^{-1} as nitrogen use efficiency; application of 60 kg N ha^{-1} had 20 kg kg^{-1}; similarly application of 80 kg N ha^{-1} had 18 kg kg^{-1} and application of 100 kg N ha^{-1} had 16 kg kg^{-1} as nitrogen use efficiency. Nitrogen use efficiency in lowland rice in the tropics was reported to be in the range of 15-25 kg grain produced per kilogram of applied N (Yoshida, 1981). Results of our study were within this range.

The results suggest that under lowland conditions increase in N dosage has as consequence decrease in recovery. This implies that increasing N-rates results in decreasing NUE probably due to losses encountered through denitrification, volatilization and leaching. Bronson *et al.,* (2000) did not observe any differences in fertilizer use efficiency between split applications at different times. Our study of split application of urea resulted in increased nitrogen use efficiency; this was not in agreement with Bronson *et al.,* (2000) observation. For irrigated rice cropping, high yields were achievable when plant N uptake (PNU) is adequate to maintain dry matter production and sink formation throughout the growing period (Cassman *et al*. 1994). The N supply environment is governed by availability of N from indigenous soil resources and from applied fertilizer inputs, and the capacity of the root system to take up available N (Cassman *et al*. 1994).

Recent research in fertilizer N efficiency has nonetheless, demonstrated considerable opportunity to improve the efficiency of N fertilizer use in farmers' fields, through improved timing, split application and reduced quantity of N fertilizer applied per unit increase in grain yield (Dobermann & Fairhust, 2000).

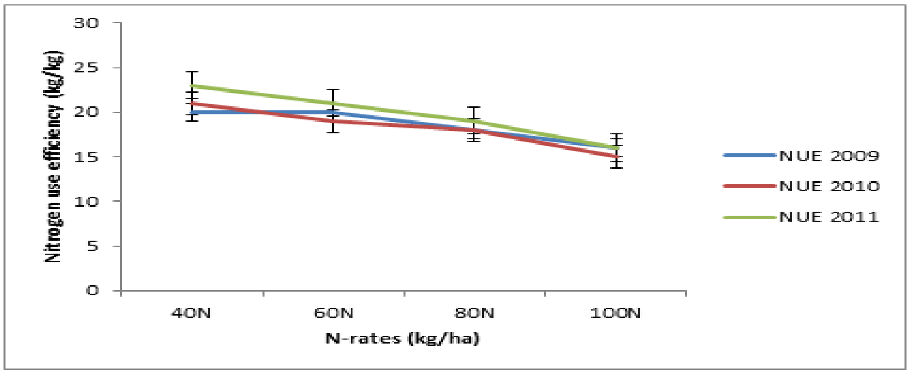

Figure 3. Nitrogen use efficiency of lowland rice

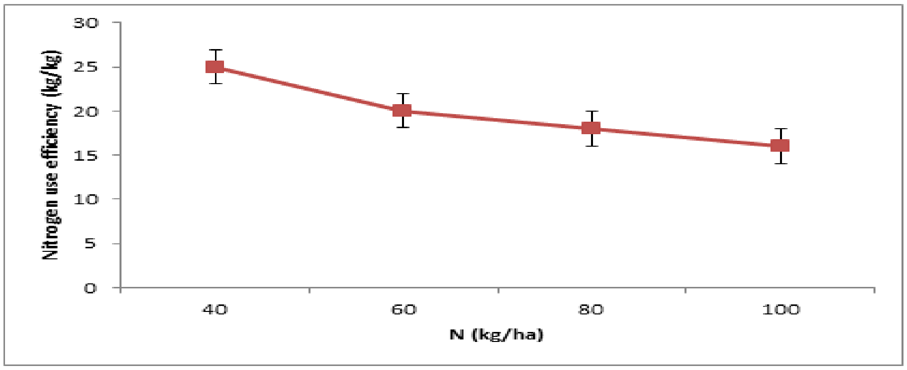

Figure 4. Nitrogen use efficiency of lowland rice. Average data for 3 years

Effect of water management and N-rates on iron toxicity score of lowland rice

Table 8 presents data on the effect of water management and N-rates on iron toxicity score. Continuous flooding treatment (CF) had the following iron toxicity scores 4.00, 4.00 and 4.00 in the first second and third seasons respectively. Alternate flooding treatments values were also the same with the continuous flooding treatment values. This suggests that water management treatments did not influence iron toxicity scores.

Application of 40 kg N ha^{-1} had the highest iron toxicity score with values of 6 in the first, second and third year respectively. It was closely followed by application of 60 kg N ha^{-1} with value of 4. This was significantly different from application of 40 kg N ha^{-1}. Similarly, application of 80 and 100 kg N ha^{-1} had values of 2 as iron toxicity score in the first, second and third year. This was the lowest score and was significantly different ($P<0.05$) from the control (40 kg N ha^{-1}) and the application of 60 kg N ha^{-1}. This observation suggests that application of 60, 80 and 100 kg N ha^{-1} significantly ($P<0.05$) reduced effect of iron toxicity on the rice plant. However, application of 40 kg N ha^{-1} (Farmers practice) showed higher effect of iron toxicity by bronzing that translated into reduced grain yield. Visual iron toxicity score using a scale of 1 to 9 indicated that the treatments were significantly different ($P<0.05$). Iron toxicity score defines the severity of damage by ferrous iron concentration on lowland rice. It also predicts the yield that would be obtained from the field because low score predicts high yield and *vice versa.*

Table 8 shows that, water management did not significantly affect iron toxicity differently. However, nitrogen rates application differed significantly on their effects with iron toxicity. The best iron toxicity reduction was recorded under 80 and 100 kg N ha^{-1} and suggests that iron toxicity is least at 80 kg N ha^{-1} under lowland rice production in the study area.

Table 8. Effect of water management and N-rates on iron toxicity score

Treatments	Water Management			
	Iron toxicity score			
	2009	2010	2011	Average
CF	4.00a	4.00a	4.00a	4.00a
AF30-7-30-7-30-7	4.00a	4.00a	4.00a	4.00a
AF60-7-30-7	4.00a	4.00a	4.00a	4.00a
AF90-7	4.00a	4.00a	4.00a	4.00a
Mean	4.00	4.00	4.00	4.00
SEM	0.03	0.03	0.03	
	N-Rates (NR)			
40 kg N ha^{-1}	6.00a	6.00a	6.00a	6.00a
60 kg N ha^{-1}	4.00b	4.00b	4.00b	4.00b
80 kg N ha^{-1}	2.00c	2.00c	2.00c	2.00c
100 kg N ha^{-1}	2.00c	2.00c	2.00c	2.00c
Mean	3.50	3.50	3.50	
SEM	0.25	0.25	0.25	
	WM*NR	Ns		

Ns- not significant, means followed by same letter in a column are not significantly different ($P< 0.05$).

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Objectives of this trial were to study the effect of water regimes and N-rates on iron concentration in lowland soils for rice production and to determine the effects on growth and yield components. In relation to this a split plot design with water management in the main plot and N-rates in the suplots were arranged in a randomized complete block (RCBD).

Physical properties of the lowland soil indicated that the soils were loam in texture and suitable for lowland rice production. Particle size analysis showed that the soil contained 44.08% sand, 46.56%

silt and 9.36% clay. The silt: clay ratio of 4.97 indicated that the soils are relatively young or the parent materials have undergone low degree of weathering. Mean bulk density of the soil was 1.42 g cm^{-3} and is within limits to support easy root penetration. There was a tendency for high water percolation rate due to high percentage of sand, that was cotrolled by puddling the soil to enable the lowland have standing water. The soil under study showed low water stable aggregates ratio under irrigated rice cultivation.

Chemical properties showed that the soil had moderate organic carbon (6.20 g kg^{-1}) and high extractable iron (342.00 mg kg^{-1}), low exchangeable bases (K 0.14cmol kg^{-1}), pH 4.5 and cation exchange capacity (CEC 5.6 cmol kg^{-1}) and was deficient in crop nutrients P, K, and Zn (4.23 mg kg^{-1}, 0.14 cmol kg^{-1}, and 0.20 mg kg^{-1} respectively). Manganese and aluminum (12.17 mg kg^{-1} and 76.00 mg kg^{-1}) were well supplied in the lowland soil. Flooding affected electrochemical and chemical processes which in turn affected soil fertility in dynamic manner. The main electrochemical changes that affected soil fertility include decrease in redox potential and changes in soil solution pH during submergence.

Continuous flooding treatment (CF) had plant height value of 75.71 cm while AF30-7-30-7-30-7 alternate flooding had 75.65 cm. Similarly, continuous flooding had rice straw weight of 3.22 t ha^{-1} and AF 30-7-30-7-30-7 had 3.22 t ha^{-1}. Also, continuous flooding treatment had 269.12 m^2 numbers of panicles and AF30-7-30-7-30-7 had 268. 89 m^2. The analysis showed no significant differences in plant height, rice straw weight, and number of panicles due to water management treatments in the 3 seasons. However, continuous flooding treatment had shoot iron content of 258.27 mg kg^{-1} while alternate flooding AF30-7-30-7-30-7 had 253.95 mg kg^{-1}. Similarly, continuous flooding treatment had 510.77 mg kg^{-1} iron plaque and AF30-7-30-7-30-7 alternate flooding had 510.90 mg kg^{-1}. Also, continuous flooding had rice grain yield value of 2.41 t ha^{-1} and AF30-7-30-7-30-7 had 2.03 t ha^{-1}. Iron concentration in the rice shoots, root iron plaque and grain yield were significantly different ($P<0.05$) by water management practices in the 3 seasons.

Application of 80 kg N ha^{-1} had average plant height value of 90.00 cm in 3 years while application of 40 kg N ha^{-1} had value of 53.83 cm. Similarly, application of 80 kg N ha^{-1} had straw weight value of 3.90 t ha^{-1} and application of 40 kg N ha^{-1} had 2.03 t ha^{-1}. Also, application of 80 kg N ha^{-1} had rice grain yield value of 3.09 t ha^{-1} and the application of 40 kg N ha^{-1} had 1.30 t ha^{-1}. Therefore, application of 80 kg N ha^{-1} significantly decreased iron concentration in rice shoots, increased root iron plaque and increased rice grain yield but was not significantly different from application of. 100 kg N ha^{-1}. Application of 80 and 100 kg N ha^{-1} treatments did not significantly influenced yield components differently, but were significantly higher than 40 and 60 kg N ha^{-1} treatments.

Water and nitrogen management minimized toxic effect of excess iron concentration on grain yield. Continuous flooding from transplanting to hard dough and the application of 80 kg N ha^{-1} had the highest grain yield. There was grain yield decline beyond 80 kg N ha^{-1} however; this was not significantly different from 100 kg N ha^{-1}. Application of 40 kg N ha^{-1} had the lowest grain yield value of 1.30 t ha^{-1}.

Nitrogen fertilizer application in the iron-toxic lowland rice soils, showed significant differences ($P<0.05$) in plant height, panicles number, straw and grain yield as reported above, that manifested into increased grain and straw yields. There was also a decrease in iron concentration in the rice plant tissue with increase in N-level. Continuous flooding from transplanting to hard dough and application of 80 kg N ha^{-1} had the highest grain yield. Alternate flooding treatment AF30-7-30-7-30-7 and application of 40 kg N ha^{-1} had the lowest grain yield.

Nigerian farmers, especially those living in the study area; though resource poor, could adopt application of 80 kg N ha^{-1},45kg P_2O_5 ha^{-1} and 45 kg K_2O ha^{-1} as economic N rate to ensure sustainable lowland rice production. Application of nitrogen fertilizer beyond the recommended rate could lead to pollution of groundwater, economic waste and possible reduction in rice yield overtime. Similarly, continuous flooding from transplanting to hard dough stage is recommended as the water management that gave the highest grain yield. However, where there is scarcity of water, fields could be drained at least twice during a cropping season though there would be a decline in yield with this water regime. The water saved could be used for another round of irrigation. Temporary aeration of lowland fields will also reduce emission of methane; a greenhouse gas responsible for global warming from the lowland rice soils.

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