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Effects of Deficit Irrigation Regime and Interval on Chemical Properties and Paddy Rice Yield in Sudan Savanna of Nigeria

S.T. Abu and W.B. Malgwi
Department of Soil Science, Faculty of Agriculture/Institute for Agricultural Research,
Ahmadu Bello University, P.M.B. 1044, Zaria, Kaduna State, Nigeria

Abstract: Strategies to improve water use efficiency of irrigated crops are among others deficit irrigation, precision irrigation technologies soil and water conservation practices. The study evaluates the effects of deficit irrigation regime and interval on soil chemical properties and performance of paddy rice in Sudan Savanna agroecosystem. The treatments include water application depths of 100, 85, 70, 55 and 40% of Total Available Water (TAW) capacity and 4, 8, 12 and 16 days irrigation intervals. Water was conveyed from field ditches into each basin through a pair of polyvinyl chloride pipes using surface irrigation method. Routine methods of chemical analysis were employed. Results showed that the highest organic carbon was recorded in treatments irrigated with water depth of 85% TAW at 4 days interval. Significantly higher total nitrogen, cation exchange capacity, sodium, pH (H_2O) and pH ($CaCl_2$), exchangeable sodium percentage and sodium adsorption ratio were recorded with TAW and 4 days interval treatments. Treatments irrigated at 40% TAW and 16 days interval got higher available P, Ca, Mg and potassium as well as base saturation. Treatments with 85% TAW (4772.0 kg ha^{-1}) and 8 days interval (4442.3 kg ha^{-1}) gave the highest yield. Based on stepwise regression analysis, potassium, organic carbon and cation exchange capacity were the major determinants of the yield. Hence, sustainable utilization of such land under irrigation requires regular application of organic matter and 85% of total available water at 8 days interval for more efficient use of irrigation water and acquisition of high paddy rice yield.

Key words: Irrigation regime, irrigation interval, soil chemical properties, paddy rice yield, water saving and Nigerian Sudan savanna

INTRODUCTION

The Nigerian savanna is made up of four ecological zones namely: Southern Guinea (SG), Northern Guinea (NG), Sudan (Su) and Sahel (Sa) Savanna. These agro-ecological zones cover an area of about 700,000 km^2. The whole of the Savanna covers about three quarters of Nigeria's total land area (Iloeje, 2001). The soils are characterized by low activity clay with kaolinite and sesquioxides (FeOH) forming 80-90% of clay fraction (Moberg and Esu, 1991) and highly weathered with soil types ranging from loamy sand to sandy loam in the top. The greater amount of kaolinite and sesquioxides leads to the lower CEC of the soils (Enwezor *et al*., 1990). Sudan and Sahel savanna are located in the semi-arid and arid part of Nigeria where water is becoming economically scarce resource (IPCC, 2001).

In order to cope with the problems of aridity, rainfall variability and the lack of food self sufficiency. Irrigation is acknowledged of great importance in sub-Saharan Africa already since colonial times (Kolawole, 1991). One of the biggest irrigation schemes in Nigeria is the Bakolori irrigation scheme located about 70 km south east of Sokoto in the Sokoto River Valley. The idea to develop the Sokoto basin is based on a Food and Agricultural Organization (FAO, 1969) soil and water resources study from 1969. FAO recommended a relative modest dam and irrigation scheme (12,000 ha) at Talata Mafara on the River Sokoto as part of a comprehensive basin development plan (FAO, 1969). The Bakolori irrigation scheme was commissioned in 1979 and construction of a major portion of the scheme was completed by 1983. In total, 23,000 hectares were developed, of which 15,000 ha were planned for pump irrigation and 8000 ha for irrigation by gravity. Sprinkler systems installed in the area developed for pump irrigation (15,000 ha) are no longer operational. The area with functioning irrigation is therefore limited to 7,500 ha, irrigated by gravity (Kebbeh *et al*., 2003).

More than 80% of the total cultivated irrigated area is used for irrigated rice production. Farmers

Corresponding Author: Department of Soil Science, Faculty of Agriculture/Institute for Agricultural Research, Ahmadu Bello University, P.M.B. 1044, Zaria, Kaduna State, Nigeria Tel: +234 (0) 7034761406

(mainly small-scale) own 90 percent of the Bakolori Irrigation Project (BIP) land and grow rice in more than 80% of the irrigated area while suffering from declining yields over the years (Kebbeh *et al*., 2003). Operation and management of the water facilities is very poor, resulting amongst others in environmental and ecological problems, like waterlogging, salinity and weed infestation. They negatively affect more than 50% of the available area under surface irrigation and are capable to turn the BIP into a barren land in the foreseeable future (Kolawole, 1993). Strategic options for achieving sustainable agriculture include alternate cropping patterns (cultivating low water-demand crop), water conserving irrigation scheduling, developing stress/drought tolerant crop varieties (Qadir *et al*., 2003) and employing management practices that sequester (store) soil organic carbon (matter) (Brahim *et al*., 2009).

Because rice receives more irrigation water than other grain crops, water-saving irrigation technologies for rice are seen as a key component in any strategy to deal with water scarcity (Li and Barker, 2004). The need to produce more food with less water poses vast challenges to reassign existing water supplies, encourage more efficient use and promote natural resource protection (Hussain *et al*., 2007). Successful rice production under full or partial irrigation at Talata Mafara and other irrigation schemes, therefore, require an effective irrigation scheduling which minimizes or eliminates percolation of water beyond root zone and satisfy water requirement of the crop. This study was aimed at (1) determining the effects of deficit irrigation regime and interval on soil chemical properties (2) investigating the impact of the deficit irrigation regime and interval on yield of paddy rice and (3) to establish the relationship between rice paddy yield with the soil nutrient availability.

MATERIALS AND METHODS

The experiment was conducted for 2 consecutive dry seasons (2008/2009 and 2009/2010) at the Irrigation Research Farm of the Institute for Agricultural Research, Talata Mafara, Nigeria (12° 37.212′ N and 06° 1.382′ E and 309 m above sea level). The location is in the northern Sudan savanna ecology, in an environment described as semi-arid. Tropical wet and dry climate prevails in the area. Rainfall distribution is monomodal and most rains fall from June to September with an annual precipitation of about 650 mm. The main wet season crops are millet, guinea corn, cowpea, groundnut and cotton. During the dry season, rice, maize, wheat, sweet potatoes, cowpea, groundnut and vegetables are the major crops. Sandy loam soils are dominant on the slopes. In some years, rainfall may be prolonged while there may be delayed onset in some other years. Maximum and minimum annual mean temperatures are 34 and 16°C. The area is geomorphologically plain and nearly flat with gentle slope and characterized by sparse vegetation of Sudan savanna types (Kebbeh *et al*., 2003).

Field study: The treatments include five levels of regulated deficit irrigation [water application depths of 100, 85, 70, 55 and 40% of total available water capacity equivalent (TAW = 91.7 mm/600 mm depths), referred to as TAW, 85% TAW, 70% TAW, 55% TAW and 40% TAW, respectively] and four irrigation intervals (4, 8, 12 and 16 days intervals). The treatments were laid out in Randomized Complete Block Design (RCBD) with split plot arrangement and three replications. The total available water capacity of the soil was determined before imposing irrigation regime treatments. For this purpose, soil samples were collected at the experimental site to 60 cm depth at 15 cm interval. Field water capacity (FC), Permanent Wilting Point (PWP), bulk density (ρ) and Available Water (AW) capacity were then determined thus: the soil moisture of dry Weight (W) at field capacity (W_{FC}) and permanent wilting point (W_{PWP}) were converted to volumetric (Θ) moisture content at same field capacity (Θ_{FC}) and permanent wilting point (Θ_{PWP}) by multiplying the former values by ρ at the corresponding soil depths. The soil Total Available Water (TAW) across the Rooting Depth (RD) was computed using the following Equation:

$$\Theta_{FC} = W_{FC} * \rho * d; \qquad (1)$$

$$\Theta_{PWP} = W_{PWP} * \rho * d \qquad (2)$$

$$TAW = \sum_{i=0}^{n} [(\Theta_{FCi} = \Theta_{PWPi})RDi] \qquad (3)$$

where, d = depth of soil layer; Θ_{FCi} =Volumetric moisture content at field capacity within ith layer; Θ_{PWPi} = Volumetric moisture content at permanent wilting point within ith layer; RD_i = soil layers within rooting depth

Surface irrigation method was used in conveying water into each basin. A pair of 5 cm diameter polyvinyl chloride pipes of 40 cm length was used to let water from field ditches into each basin. These pipes were installed to give a free orifice flow. Stage guages were placed at the water inlet of each basin to measure the depth of water flowing through the pipes. Thus the discharges through the pipe into the basins were quickly computed and the depth of water applied was monitored using a stop watch. Soil moisture status was determined one day before and after 4, 8, 12 and 16 days intervals using soil moisture resistance devices (gypsym blocks) installed at 0-30 cm depth for determination of water deficit.

The irrigation regimes were assigned to the main plot (block) whereas irrigation intervals were placed in the subplots. Soil samples were collected at the experimental site to 30 cm depth from each treatment for laboratory analysis.

Laboratory study

Organic carbon: Organic carbon was determined by Walkley-Black method (Nelson and Sommers, 1982). Total nitrogen was determined by regular Kjeldahl digestion-distillation method (Bremner, 1965). Soil available P was determined by using Bray-1 (ascorbic acid molybdate) method (Rodriguez *et al*., 1994). Soil pH (Soil Reaction) was determined potentiometrically by a pH meter (Pye Unicam); Exchangeable bases were extracted out by the neutral IM NH_4OAc saturation method (Lanyon and Heald, 1982). Calcium and magnesium were determined by the Atomic Absorption Spectrophotometer (AAS), while sodium and potassium were determined with the flame photometer. The cation exchange capacity was determined by the ammonium acetate method (Chapman, 1965). Percentage base saturation (% B.S), Exchangeable Sodium Percentage (ESP) and Sodium Absorption Ration (SAR) were computed as follows:

$$\%\,BS = \frac{Na^{+} + K^{+} + Ca^{2+} + Mg^{2}}{CEC} \times 100 \quad (4)$$

$$ESP = \frac{Exchangeable\,Na^{+}}{CEC} \times 100 \quad (5)$$

where, CEC is the cation exchange capacity:

$$SAR = \frac{Na}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (6)$$

Statistical analysis: The data collected were subjected to factorial Analysis of Variance (ANOVA) using SPSS 16.0 computer statistical program. Significant differences among treatments were compared using the Tukey-Kramer Multiple Comparison Test.

RESULTS

Soil organic carbon, total N, C: N ratio, available P and cation exchange capacity: Table 1 shows results on Soil Organic Carbon (SOC), Total N (TN), Available P (AP) and Cation Exchange Capacity (CEC). As shown in the Table 1, the investigated irrigation regimes and intervals significantly affected the soil organic carbon/matter (SOC/SOM) content. Treatments with water application depths of 85% TAW, 70% TAW and 55% TAW were statistically at par in SOC with one another and with those irrigated at TAW but significantly differed from those irrigated with water depths of 40% TAW. Regarding irrigation interval, treatments irrigated at 8 days interval got significantly higher SOC (7.22 g kg^{-1}) than those irrigated at the other intervals. Significant TN differences were found among the treatments with various water application depths and intervals. The highest mean values were recorded in treatments with water application depths of TAW and 4 days interval. The TN contents consistently decreased with decrease in the depth of applied water and with increase in irrigation interval. The influence of the irrigation regimes and intervals on the distribution of TN among the plots followed similar trend as SOC.

Significant differences were observed in C/N ratio between treatments with water application depths of TAW and 55% TAW but the treatments supplied with the other water application depths were statistically at par. The ratio ranged from 48.4 to 82.0 with the highest value being recorded in treatments with water application depths of 55% TAW. All plots irrigated at the studied intervals did not significantly differ in the ratio, though the highest mean value was observed in plots irrigated at 8 days interval.

Mean AP values across irrigation regime ranged between 5.13 and 7.02 mg kg^{-1} while it was between 5.43 and 6.61 mg kg^{-1} when averaged across irrigation intervals. Mustapha (2007) reported a mean value of 7.63 mg kg^{-1} in fadama (paddy) soils elsewhere in Bauchi State, Nigeria. Treatments with deficit water application depths contained significantly higher available P (AP) than those with water application depths of TAW. The AP content consistently increased with increase in water application deficit. Similarly, irrigation at longer intervals favored concentration of higher AP in the soil than those irrigated at shorter intervals.

Mean CEC values across irrigation regimes was significantly higher in plots irrigated with water depth of TAW (13.9 cmol (+) kg^{-1}) and lower in those receiving water depths of 40% TAW (9.2 cmol (+) kg^{-1}) compared to the other regimes. Plots with water application depth of 55% TAW and 40% TAW were not significantly different in the CEC. Considering irrigation intervals, plots irrigated at 4 days interval had significantly higher CEC mean value (12.8) while the value was significantly lower in those irrigated at 16 days interval. Plot irrigated at 4 and 8 days intervals were statistically similar in the value.

Table 1: Effects of irrigation regime and interval on soil organic carbon, total nitrogen, available phosphorus and cation exchange capacity in Talata Mafara, Nigeria

Treatment	Organic carbon (g kg^{-1})	Total N (g kg^{-1})	C: N ratio	Available P (mg kg^{-1})	CEC cmol (+) kg^{-1}
Irrigation regime					
TAW	5.85^{ab}	0.121^{a}	48.4^{b}	5.13^{d}	13.9^{a}
85% TAW	6.26^{a}	0.102^{ab}	61.2^{ab}	5.64^{c}	12.7^{b}
70% TAW	5.99^{a}	0.092^{bc}	65.2^{ab}	5.91^{c}	11.0^{c}
55% TAW	5.96^{a}	0.083^{bc}	82.0^{a}	6.54^{b}	9.5^{d}
40% TAW	4.07^{b}	0.076^{c}	56.0^{ab}	7.02^{a}	9.2^{d}
SE	0.4525	0.0063	7.872	0.0709	0.2184
p (0.05)	0.010	0.000	0.049	0.000	0.000
Irrigation interval					
4 days	6.26^{b}	0.117^{a}	56.3^{a}	5.43^{d}	12.8^{a}
8 days	7.22^{a}	0.105^{ab}	74.7^{a}	5.86c	11.8^{ab}
12 days	4.98^{bc}	0.085^{bc}	61.4^{a}	6.30^{b}	10.7^{c}
16 days	4.06^{c}	0.072^{c}	58.4^{a}	6.61^{a}	9.8^{d}
SE	0.4048	0.0056	6.980	0.0634	0.1955
p (0.05)	0.000	0.000	0.247	0.000	0.000

TAW: Total available water equivalent; All means followed by the same letter within a column are not significantly different at 5% probability level using the Tukey-Kramer Multiple-Comparison Test

Table 2: Effects of irrigation regime and interval on exchangeable bases and base saturation in Talata Mafara, Nigeria

Treatment	Ca cmol (+) kg^{-1}	Mg cmol (+) kg^{-1}	K	Na	BS% cmol (+) kg^{-1}
Irrigation regime					
TAW	2.70^{d}	1.61^{d}	0.60^{e}	0.205^{a}	36.8^{e}
85% TAW	3.03^{bc}	1.84^{c}	0.65^{d}	0.182^{ab}	46.3^{d}
70% TAW	3.20^{b}	2.08^{b}	0.71^{c}	0.160^{bc}	57.1^{c}
55% TAW	3.34^{a}	2.11^{b}	0.79^{b}	0.137^{cd}	68.5^{b}
40% TAW	3.43^{a}	2.38^{a}	0.87^{a}	0.100e	75.8^{a}
SE	0.0592	0.0536	0.0095	0.0073	1.0596
p (0.05)	0.000	0.000	0.000	0.000	0.000
Irrigation interval					
4 days	2.71^{d}	1.67^{c}	0.64^{d}	0.197^{a}	42.9^{d}
8 days	3.02^{c}	1.92^{b}	0.69^{c}	0.171^{b}	51.9^{c}
12 days	3.30^{b}	2.13^{a}	0.76^{b}	0.138^{c}	61.4^{b}
16 days	3.53^{a}	2.30^{a}	0.79^{a}	0.120^{c}	71.4^{a}
SE	0.0539	0.0480	0.0085	0.0065	0.9478
p (0.05)	0.000	0.000	0.000	0.000	00.000

TAW: Total available water equivalent; All means followed by the same letter within a column are not significantly different at 5% probability level using the Tukey-Kramer Multiple-Comparison Test

Hassannezhad *et al.* (2008) reported CEC value ranges between 10 and 40 cmol (+) kg^{-1} in paddy soils they investigated depending on the amount and the type of clay minerals.

Exchangeable bases and base saturation: Results on exchangeable bases and base saturation are presented in Table 2, showing that plots irrigated at 55 and 40% TAW got significantly higher Ca^{2+} (3.34 and 3.43 cmol (+) kg^{-1}, respectively) than the other plots receiving different water depths. Exchangeable Ca^{2+} was significantly higher in plots with water application at 16 days interval (3.53 cmol (+) kg^{-1}). The values consistently decreased with increase in the amount of applied water up to TAW equivalent and with decrease in irrigation interval to 4 days.

Significantly higher exchangeable Mg^{2+} and K^{+} were also observed in plots with water application depths of 40% TAW (2.38 and 0.87 cmol (+) kg^{-1}) and at 16 days interval (2.30 and 0.79 cmol (+) kg^{-1}, respectively), while the lowest value was recorded in plots irrigated with water depth of TAW (1.61 and 0.6 cmol (+) kg^{-1}, respectively) and 4 days interval (1.67 and 0.64 cmol (+) kg^{-1}, respectively).

The exchangeable Na^{+} content averaged across irrigation regime ranged between 0.100 and 0.205 cmol (+) kg^{-1} while the mean across irrigation interval was between 0.120 and 0.197 cmol (+) kg^{-1}. Plots irrigated with water depth of TAW and at 4 days interval got significantly higher values than those irrigated with other water depths and intervals.

Base Saturation (BS) significantly differed among the irrigation regimes and intervals with the lowest value (36.8%) recorded in plots supplied with water application depth of TAW and consistently increased with deficit irrigation. The highest BS value of 75.8% was recorded on application of water depth of 40% TAW which consistently decreased with increase in water application depth. Similarly, the highest (71.4%) and lowest (42.9%) BS was recorded on irrigation at 16 and 4 days intervals, respectively.

Soil reaction and salinity status: Table 3 shows the results on pH measured in water (pH (H_2O)) and salt (pH ($CaCl_2$), Exchangeable Sodium Percentage (ESP), Electrical

Table 3: Effects of irrigation regime and interval on pH, electrical conductivity, exchangeable sodium percentage, sodium adsorption ratio and paddy rice yield in Talata Mafara, Nigeria

Treatment	pH (H_2O) (cmol (+) kg^{-1})	pH ($CaCl_2$)	EC (dS m^{-1})	ESP (%)	SAR	Yield (kg ha^{-1})
Irrigation regime						
TAW	6.21^{a}	5.04^{a}	0.0554^{d}	2.230^{a}	0.1216^{a}	4039.7^{b}
85% TAW	5.97^{ab}	4.87^{ab}	0.0670^{c}	1.889^{b}	0.1117^{ab}	4772.0^{a}
70% TAW	5.88^{bc}	4.56^{bc}	0.0713^{bc}	1.463^{c}	0.1002^{bc}	3404.6^{c}
55% TAW	5.58^{cd}	4.51^{d}	0.0789^{ab}	1.068^{d}	0.0292^{d}	2675.3^{d}
40% TAW	5.36^{d}	4.28^{e}	0.0821^{a}	0.706e	0.0697^{cd}	2080.2^{e}
SE	0.0620	0.0534	0.0020	0.0679	0.0051	49.112
p (0.05)	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation interval						
4 days	6.08^{a}	5.06^{a}	0.0834^{a}	1.640^{a}	0.1326^{a}	4068.0^{b}
8 days	5.94^{a}	4.81^{b}	0.0745^{b}	1.559^{ab}	0.1086^{b}	4442.3^{a}
12 days	5.63^{b}	4.52^{c}	0.0673^{c}	1.380^{bc}	0.0832^{c}	2691.7^{c}
16 days	5.49^{b}	4.38^{c}	0.0585^{d}	1.307^{c}	0.0696^{c}	2375.5^{d}
SE	0.0555	0.0477	0.0083	0.0607	0.0045	43.927
p (0.05)	0.000	0.000	0.000	0.000	0.000	0.000

TAW: Total available water equivalent; All means followed by the same letter within a column are not significantly different at 5% probability level using the Tukey-Kramer Multiple-Comparison Test

Table 4: Stepwise regression coefficient[d] showing chemical properties making the greatest contribution to yield variation

		Unstandardized coefficients		Standardized coefficients			
Model		B	Std. Error	Beta	t	Sig.	R
1	(Constant)	10258.4	636.7		16.1	0.000	0.820^{a}
	K	-9504.8	870.4	-0.820	-10.2	0.000	
2	(Constant)	8055.5	837.5		9.6	0.000	0.857^{b}
	K	-7961.5	897.5	-0.687	-8.9	0.000	
	OC	193.3	53.1	0.282	3.6	0.001	
3	(Constant)	2161.6	1942.2		1.1	0.270	0.882^{c}
	K	-3682.7	1536.0	-0.318	-2.4	0.020	
	OC	194.6	49.0	0.284	4.0	0.000	
	CEC	248.4	75.1	0.423	3.3	0.002	

a: Predictors in the Model: (constant) K, b: Predictors in the Model: (constant) K, SOC, c: Predictors in the Model: (constant) K, SOC, CEC

Conductivity (EC) and Sodium Adsorption Ratio (SAR). The significant influence of the irrigation regimes and intervals on both pH (H_2O) and pH ($CaCl_2$) is apparent in Table 3. The highest mean value (pH = 6.21 and 5.04, respectively) was recorded in treatments with water application depth of TAW which consistently increased as the depth of applied water decreased to 40% TAW (pH = 5.36 and 4.28, respectively). With respect to irrigation interval, the highest pH values (6.08 and 5.06, respectively) were recorded with plots irrigated at 4 days interval, thus decreasing with increase in the interval.

The ESP and SAR values followed the same trend with exchangeable Na, the highest values being observed on irrigation at the depth of TAW (2.23% and 0.122) and 4 days interval (1.64% and 0.133, respectively). Significant differences were found among the irrigation regimes and intervals in Electrical Conductivity (ECe) values. The highest ECe value was recorded in plots irrigated at the depth of TAW (0.082 dS m^{-1}) and 4 days interval (0.0834 dS m^{-1}) which were far below 4 dS m^{-1} considered the upper limit of tolerable (critical) value.

Paddy rice yield: The irrigation regimes and intervals investigated significantly affected grain yield. Irrigation at the depth of 85% TAW gave the highest yield of 4772.0 kg ha^{-1} (Table 3), significantly exceeding values recorded on irrigation at water depths of TAW, 70% TAW, 55% TAW and 40% TAW by 15.5, 25.5, 35.7 and 48.5%, respectively. Considering irrigation interval, plots irrigated at 8 days interval gave the highest yield of 4442.3 kg ha^{-1}, 8.4% higher than the yield obtained on irrigation at 4 days interval and 39.4 and 46.5% higher than those irrigated at 12 and 16 days intervals, respectively.

Stepwise regression analysis: Stepwise regression analysis (Table 4) indicates that K significantly (p = 0.000) and most highly correlated with yield than the other mineral elements since it has the largest absolute standardized coefficient (B = -0.820) and coefficient of determination (R = 0.820). Despite the fact that CEC had the highest Beta In compared to SOC (Table 5, model 1), the next most significantly (p = 0.001) correlated property to yield is SOC as confirmed by its highest record of partial correlation (0.434). The results (Table 5, model 2) also showed that CEC significantly correlated (Beta In = 0.423; R = 0.404) to yield thus occupying the third place. Model 3 (Table 5) showed that the other chemical properties insignificant correlated to yield.

Table 5: Regression models showing the relationship between paddy rice yield and soil chemical properties

	Model 1			Model 2			Model 3		
Parameters	Beta in	Sig.	Partial correlation	Beta in	Sig.	Partial correlation	Beta in	Sig.	Partial correlation
SOC	0.282[a]	0.001	0.434	-	-	-	-	-	-
pHw	0.325[a]	0.007	0.345	0.171[b]	0.181	0.178	-0.087[c]	0.552	-0.080
pHCa	0.365[a]	0.005	0.363	0.184[b]	0.199	0.171	-0.121[c]	0.466	-0.099
Ca	-0.158[a]	0.202	-0.169	-0.033[b]	0.784	-0.037	0.090[c]	0.440	0.104
Mg	-0.076[a]	0.594	-0.071	0.063[b]	0.642	0.062	0.094[c]	0.452	0.102
Na	0.116[a]	0.134	0.198	0.078[b]	0.274	0.146	0.115[c]	0.084	0.231
BS	-0.406[a]	0.044	-0.264	-0.238[b]	0.216	-0.165	0.365[c]	0.149	0.193
CEC	0.419[a]	0.005	0.361	0.423[b]	0.002	0.404	-	-	-
EC	0.208[a]	0.007	0.349	0.111[b]	0.168	0.184	0.066[c]	0.387	0.117
TN	0.278[a]	0.002	0.389	0.197[b]	0.027	0.290	0.051[c]	0.629	0.065
AP	-0.417[a]	0.012	-0.327	-0.245[b]	0.137	-0.197	0.021[c]	0.907	0.016
SAR	0.116[a]	0.125	0.202	0.076[b]	0.277	0.145	0.104[c]	0.109	0.215
ESP	0.079[a]	0.407	0.110	0.030[b]	0.737	0.045	0.138[c]	0.107	0.216
C:N	0.016[a]	0.838	0.027	-0.240[b]	0.006	-0.358	-0.139[c]	0.141	-0.198

SOC: Soil organic carbon, pHw: pH measured in water, pHCa: pH measured in $CaCl_2$, BS: Base saturation, CEC: Cation exchange capacity, ECe: Electrical conductivity, TN: Total nitrogen, AP: Available phosphorus, SAR: Sodium adsorption ratio, ESP: Exchangeable sodium percentage, a: Predictors in the Model: (constant) K, b: Predictors in the Model: (constant) K, SOC; c: Predictors in the Model: (constant) K, SOC, CEC

DISCUSSION

Soil organic carbon, total N, C: N ratio, available P and cation exchange capacity: The plots irrigated at various depths and intervals generally had low SOC/SOM (<10/17.2 g kg^{-1}). The low level of SOC/SOM is in agreement with data reported for savanna soils by Esu (1983 and 1989). This also agrees with the report by Loveland and Webb (2003).

According to Esu (1991), ratings for soil fertility classes in the Nigerian Savanna, the site had generally very low (< 1.5 g kg^{-1}) TN. The low values of TN contents in the soil could be attributed to low SOC/SOM. The observed C:N ratio ranging from 48.4 to 82.0 in all the plots in this study suggests non-ideal conditions for plant growth. This is due to the fact that mineralization of SOC under such conditions is expected to be is less than its immobilization. However, plots supplied with water depth of TAW and at 4 days interval formed a better plant growth condition compared to those supplied with water at other depths regimes. This is supported by reports of some researchers that higher C:N ratios greater than 23 (Goma, 2003) favor slow degradation of residues by the associated micro-organisms (Eiland *et al*., 2001), higher immobilization effects (Goma, 2003) and limited N in the soil that may lead to reduced crop yields (Uriyo *et al*., 1979).

Based on Esu (1991) fertility rating for savanna soils, all the plots had low AP content (<10 mg kg^{-1}) thus falling within categories of soils with P deficiency. The observed low values of P could partly be attributed to fixation in Fe or Al complexes which is confirmed by Uyovbisere (1994).

All the plots irrigated at the investigated irrigation regimes and intervals had CEC values between 9.19 and 13.94 cmol (+) kg^{-1}. According to National Soil Service (NSS, 1990) staff, almost all the plots fell within the category of soils considered poor (low to medium) in CEC (6.0-12.0 cmol (+) kg^{-1}). This could be related to low soil organic carbon and consequently organic matter of this soil. This agrees with the reports of Van Dijk (1971) and Oades (1988) which showed that SOM was responsible for 25-90% of the total CEC of surface horizons of mineral soils they studied.

Exchangeable bases and base saturation: Low to very low levels of Ca^{2+} was observed in all the plots which portend higher bondage of Ca^{2+} to P. This was based on the recommended threshold level of Ca^{2+} is 5 cmol (+) kg^{-1} proposed by Marx *et al*. (1996).

The critical Mg^{2+} and K^{+} values for most arable crops in Nigeria are 0.2 and 0.15 cmol (+) kg^{-1}, respectively (FPDD, 1989). Based on these, the result of the present study indicated that irrigation at 70, 55 and 40% TAW equivalent, as well as at 12 and 16 days intervals enabled provision of Mg^{2+} in optimum amount since the values were above the recommended. All the plots irrigated at the investigated regimes and intervals had high amount (0.60-0.87 cmol (+) kg^{-1}) of K^{+} above the critical values. This portends adequate provision of crops with Mg^{2+} and K^{+}. Irrigation at TAW and 85% TAW negatively affected Mg^{2+} availability in the soil.

The values of Na^{+} obtained in all the plots were higher than the critical value of 0.05 cmol (+) kg^{-1} suggested by Tinker (1969) which portends adequate supply of the element to crops and no sodium hazard.

The result suggests that application of higher volume of water, either imposed by irrigation regime or interval, promoted leaching of some basic cations from the topsoil, hence the lower base saturation in such treatments.

The entire site had values below the minimum value of the normal pH range suggested by Sanchez *et al.* (2003) (6.0-7.5) for optimal mineral elements availability for most crops. Plots irrigated with water depth of TAW and 85% TAW as well as 4 days interval were slightly acidic. Plots irrigated with water depth of 70% TAW were moderately acidic (pH = 5.88) while those irrigated with water depth of 55 and 40% TAW were strongly acidic.

The critical values of ESP above which most crops are affected are established at 15. The ESP values in all the plots treated with various irrigation regimes and intervals were less than the critical values of 15 proposed by Lebron *et al.* (2002). Electrical conductivity values were also low indicating low content of total dissolved salts in the site. According to Ayers and Tanji (1981), soil may have severe infiltration problem when saturation extract or water has SAR values ranging between 0 and 3 and EC value of <0.2 dS m^{-1}. Being the case with the study site, management techniques that improve water infiltration need to be employed.

Paddy rice yield: The high yield recorded in treatments irrigated with water depth of 85% TAW could be explained by the relatively favorable soil moisture condition and nutrient supply formed. Baloch *et al.* (2004) reported paddy yield ranging from 2160 to 4560 kg ha^{-1}depending on the availability of resources, management of crop and socio-economic status of farmers. Stepwise regression coefficients showed that K, Soil Organic Carbon (SOC) and Cation Exchange Capacity (CEC) were the main determinants of yield in the study site (Table 4). Exchangeable K, being the most highly correlated to yield, to a greater extent determined the yield, followed by SOC and then CEC. Yield was negatively affected by K and positively affected by SOC and CEC, indicating that lower K and higher SOC and CEC levels than the current status would favor yield increase of paddy rice. The other parameters made insignificant contribution to yield formation (Table 5), indicating that they more depended on SOC, CEC and K to impact on yield hence their under-performance in determining yield. The implication of the high exchangeable K recorded in the site is that it could lead to displacement of Ca and Mg from the soil exchange complex. This may consequently result to their leaching from the soil and low total exchangeable bases. This is in agreement with the reports of Ranade-Malvi (2011). The low SOC/SOM in the present study also might have resulted to low CEC of the soil which could have adversely affected the yield. This is supported by Oades (1988) who showed that SOM is responsible for 25 - 90% of the total CEC of surface horizons of mineral soils and by Sanchez and Logan (1992) who indicated that low CEC is implicated with low crop yield.

CONCLUSION

The soil chemical properties and the paddy rice yield were significantly affected type of irrigation regimes and irrigation intervals imposed. The K, SOC and CEC status of the soil as influenced by the treatments to a greater extent determined the yield level. The K, SOC and CEC status of the study site determined the influence of the other exchangeable bases, AP and TN on the yield of the paddy rice. It is, therefore, apparent that there is a need to replenish the organic matter using resources such as crop residues and manure for maximum paddy rice yields through its influence on structural stability, porosity, mineral elements availability (N, P and S), ion-exchange capacity and soil moisture holding capacity which also has great impact on improving irrigation efficiency for sustainable land productivity.

REFERENCES

Ayers, R.S. and K. Tanji, 1981. An application from Ayers and Westcot's, 1985 "Use of treated municipal wastewaters for irrigation. " FAO Irrigation and Drainage Paper No. 29 Rev. 1. Originally published as an ASCE 1981 Water Forum Conference Proceedings.

Baloch, M.S., I.U. Awan, G. Hassan, M.A. Khan, K. Ahmad and M.Z. Sulemani, 2004. Quantitative assessment of social and some input variables relating to rice production in Dera Ismail Khan, Pakistan. Pak. J. Agron., 3: 52-58.

Brahim, N., T. Gallali and M. Bernoux, 2009. Effects of agronomic practices on the soil carbon storage potential in Northern Tunisia. Asian J. Agric. Res., 3: 55-66.

Bremner, J.M., 1965. Total Nitrogen. In: Methods of Soil Analysis Part 2, Black, C.A. (Ed.). American Society of Agronomy, Madison, WI., USA., pp: 1149-1178.

Chapman, H.D., 1965. Cation Exchange Capacity. In: Methods of Soil Analysis, Black, C.A. (Ed.). Part 2. American Society Agronomy, Madison, WI., ISBN-10: 0891180729, pp: 891–901.

Eiland, F., M. Klamer, A.M. Lind, M. Leth and E. Baath, 2001. Influence of initial C/N ratio on chemical and microbial composition during long term composing of straw. Microbial. Ecol., 41: 272-280.

Enwezor, W.O., E.J. Udo, K.A. Ayotade, J.A. Adepelu and V.O. Chude, 1990. Literature review on soil fertility investigation in Nigeria (in five volumes). Federal Ministry of Agriculture and Natural Resources, Lagos, Nigeria.

Esu, I.E., 1983. Characterization and classification of dark clay soil of Biu plain. Nig. J. Soil Sci., 4: 80-91.

Esu, I.E., 1989. A pedological characterization of the soil of the Hadejia alluvial complex of the semi-arid region of Nigeria. Pedologic, 39: 171-190.

Esu, I.E., 1991. Detailed soil survey of NIHORT farm at Bunkure Kano State. Nigeria.

FAO, 1969. Soil and water survey of Sokoto Valley, Nigeria. Final Report, Six volumes, Rome.

FPDD, 1989. Literature on soil fertility investigation in Nigeria. Produced by the Federal Ministry of Agriculture and Natural Resources, Lagos.

Goma, H.C., 2003. Potential for Changing Traditional Soil Fertility Management Systems in the Wet Miombo Woodlands of Zambia: The Chitemene and Fundikila Systems. In: Soil Fertility Management in Africa: A Regional Perspective, Gichuru, M.P., A. Bationo, M.A. Bekunda, H.C. Goma and P.L. Mafongoya *et al*., (Eds.). Academy Science Publishers, Nairobi, Kenya, pp: 187-218.

Hassannezhad, H., A. Pashaee, F. Khormali and M. Mohammadian, 2008. Effect of soil moisture regime and rice cultivation on mineralogical characteristics of paddy soils of mazandaran province, Northern Iran, Amol. Int. J. Soil Sci., 3: 138-148.

Hussain, I., H. Zakir, M.H. Sial, A. Waqar and M.F. Hussain, 2007. Optimal cropping pattern and water productivity: A case of Punjab canal. J. Agron., 6: 526-533.

IPCC, 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Cambridge University Press, New York, USA.

Iloeje, N.P., 2001. A New Geography of Nigeria. Longman Nigeria Ltd., Nigeria, pp: 200.

Kebbeh, M., S. Haefele and S.O. Fagada, 2003. Challenges and opportunities for improving irrigated rice productivity in Nigeria. West Africa Rice Development Association, Abidja.

Kolawole, A., 1991. Water resources development projects in Nigeria: Farmers' responses. Int. J. Water Resour. Dev., 7: 124-132.

Kolawole, A., 1993. Monitoring and evaluation of Nigeria's irrigation systems: the case of Bakolori Irrigation Project. Int. J. Water Res. Develop., 9: 75-85.

Lanyon, L.E. and W.R. Heald, 1982. Magnesium, Calcium, Strontium and Barium. In: Methods of Soil Analysis. Agronomy Monograph Part 2, Page, A.L., R.H. Miller and D.R. Keeney (Eds.). 2nd Edn., Agronomy Society of America and Soil Science Society of America, Madison, WI., pp: 247-262.

Lebron, I., D.L. Suarez and T. Yoshida, 2002. Gypsum effect on the aggregate size and geometry of three sodic soils under reclamation. Soil Sci. Soc. Am. J. 6: 92-98.

Li, Y. and R. Barker, 2004. Increasing water productivity for paddy irrigation in China. Paddy Water Environ., 2: 187-193.

Loveland, P. and J. Webb, 2003. Is there a critical level of organic matter in the agricultural soils of temperate regions: A review. Soil Tillage Res., 70: 1-18.

Marx, E.S., J.M. Hart and R.G. Stevens, 1996. Soil Test Interpretation Guide. Oregon State University Extension Services, Corvallis, pp: 7-7.

Moberg, J.P. and I.E. Esu, 1991. Characteristics and composition of some savanna soils in Nigeria. Geoderma, 48: 113-129.

Mustapha, S., 2007. Physico-chemical properties and fertility status of some haplic plinthaquults in Bauchi Local Government area of Bauchi State, Nigeria. Int. J. Soil Sci., 2: 314-319.

NSS, 1990. Laboratory Procedures for Routine Soil Analysis, 3rd Ministry of Agriculture and Livestock Development, National Soil Service, ARI, Mlingano..

Nelson, D.W. and L.E. Sommers, 1982. Total Carbon, Organic Carbon and Organic Matter. In: Methods of Soil Analysis. Part 2 Chemical and Microbiological Properties Agronomy, Page, A.L., R.H. Miller and D.R. Keeney (Eds.). 2nd Edn., ASA-SSSA, Madison, Wisconsin, USA., pp: 539-579.

Oades, J.M., 1988. The retention of organic matter in soils. Biogeochemistry., 5: 35-70.

Qadir, M., Th.M. Bores, S. Schubert, A. Ghafoor and G. Murtaza, 2003. Agricultural water management in water-starved countries: Challenges and opportunities. Agric. Water Manage., 62: 165-185.

Ranade-Malvi, U., 2011. Interaction of micronutrients with major nutrients with special reference to potassium. Karnataka J. Agric. Sci., 24: 106-109.

Rodriguez, J.B., J.R. Self and N.P. Soltanpour, 1994. Optimal conditions for phosphorous analysis by the ascorbic acid-molybdenum blue method. Soil Sci. Soc. Am. J. 58: 866-870.

Sanchez, P.A. and T.J. Logan, 1992. Properties and Management of Soils in the Tropics. John Wiley and Sons, New York, pp: 618.

Sanchez, P.A., C.A. Palm and W. Buol, 2003. Fertility capability soil classification a tool to help assess soil quality in the tropics. Geoderma, 114: 157-185.

Tinker, P.B.H., 1969. Soil chemistry and fertility. Proceedings of International Society of Soil Science, (ISSS'69), Aberdeen, UK., pp: 223-231.

Uriyo, A.P., H.O. Mongi, M.S. Chowdhury, B.R. Singh and J.M.R. Semoka, 1979. Introductory Soil Science. TPH Ltd., Dares Salaam.

Uyovbisere, E.O., 1994. Phosphorus studies in three typical soils of Nigeria. Ph.D. ABU, Zaria. Nigeria.

Van Dijk, H., 1971. Colloid Chemical Properties of Humic Matter. In: In: Soil Biochemistry, A.D. McLaren, J. Skujins, (Eds.). Marcel Dekker, New York, pp: 16-35.