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INFLUENCE OF WATER MANAGEMENT, RICE VARIETIES AND COW DUNG RATES ON PHYSICAL QUALITY INDICATORS OF A SANDY CLAY LOAM IN SOKOTO, NIGERIA

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ABSTRACT

Adoption of appropriate soil and water management practices is needed for enhancing or maintaining soil physical quality in savanna regions of northern Nigeria. It is against this background that this study was undertaken to assess the impact of four irrigation methods (AWD1, AWD2, AWD3 and CF), two rice varieties (FARO 44 and TOFA), and four cow dung rates (0, 5, 10 and 15 t ha^{-1}) on soil physical quality in northern Nigeria's savanna region. The treatments were arranged in a split-split plot design over two growing seasons (2020 and 2021). Results showed that water management and rice varieties had no significant impact on soil physical quality. However, cow dung rates notably affected bulk density, total porosity, and plant available water significantly. Rates of 5, 10, and 15 t ha^{-1} cow dung improved soil physical quality compared to no cow dung application. The study therefore, concluded that specific irrigation methods (AWD1, AWD2, AWD3 or CF), rice varieties (FARO 44 or TOFA), and cow dung rates (5, 10 or 15 t ha^{-1}) are better management options in enhancing the soil physical quality. It is moreover suggesting that similar research should be extended to 3-4 years to evaluate their medium-term effects.

Key words: Soil quality, physical quality indicators, Irrigation regimes, rice varieties, cow dung rates

INTRODUCTION

Soil quality (SQ) is considered a key element of sustainable agriculture and commonly defined as 'the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, to maintain or enhance water and air quality, and to support human health and habilitation' (Doran *et al.* 1996). The interactions of soil chemical, physical, and biological properties define a particular soil's quality and determine how effectively the soil performs ecosystem functions such as: (1) retention and release of nutrients and other chemical constituents, (2) partitioning of rainfall at the soil surface into runoff and infiltration, (3) holding and release of soil water to plant, streams, and groundwater, (4) resisting water and wind erosion, and (5) buffering against the concentration of potentially toxic materials (Karlen *et al*. 1997). However, improper management practices could lead to deleterious changes in soil functions that define SQ.

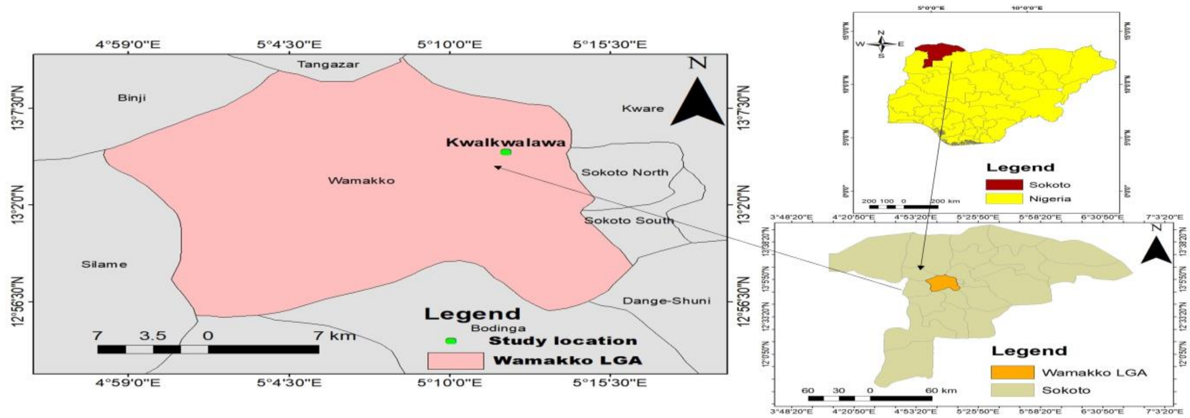
Because improper management can lead to deleterious changes in soil function, the need for tools and methods to assess and monitor SQ was recognized (Doran and Jones 1996). Measurement of SQ requires identification of specific parameters or 'indicators' that can be quantitatively measured over time and compared to reference conditions or judged against some common standards (Seybold *et al.* 1998). Indicators of SQ can be defined loosely as those soil properties and processes that have greatest sensitivity to changes in soil function (Andrews *et al.* 2004). Physical indicators of SQ include soil texture, depth of topsoil or rooting depth, infiltration rate, soil bulk density, water-holding capacity, available water content, aggregate stability at a depth of 0.30 m, drainage, slope, and land form (Doran and Parkin 1994; Eswaran *et al.* 1998; Hseu *et al.* 1999).

On the other hand, the soils of the savanna region of northern Nigeria are physically fragile due to large proportion of sand in topsoil, weak aggregation and low level of organic matter. Also, the particle size distribution indicates that water retention is low while the infiltration rate is high (Salako, 2003). These soil physical constraints could further be worsened by adoption of improper soil and water management practices. Therefore, adoption of appropriate soil and water management practices is needed for enhancing or maintaining soil physical quality in the savanna regions of northern Nigeria. It is against this background that this study was undertaken to assess the influence of irrigation regimes, rice varieties and cow dung rates on the physical quality of a sandy clay loam paddy soil of Sokoto, northwestern Nigeria.

MATERIALS AND METHODS

Study Area

The experiment was conducted near the Usmanu Danfodiyo University Teaching and Research Fadama Farm, Kwalkwalawa, about 5 km from Sokoto, located at Latitude 13° 01' 1'' N and longitude 5° 15' 1'' E using GPS and at an altitude of 300 meters above sea level (Lukman *et al*., 2016). Soil of the study area is classified as Inceptisol (Noma, 2005). The location is in the northern Sudan Savanna ecology of Nigeria, in an environment described as semi-arid. Tropical wet and dry climate prevails in the area. The area is characterized by scattered trees and fewer grasses. Rainfall distribution is monomodal with an average annual rainfall of 629 mm. Minimum and maximum temperature ranges between 15 and 40°C, respectively (SERC, 2013).



Map of the study area showing the study location

Treatments and Experimental Design

The experiment was established as split-split plot design consisting of four (4) irrigation regimes {3 alternate wetting and drying regimes: AWD1, AWD2, AWD3 and 1 conventional flooding (CF)}, two (2) rice varieties (FARO 44 and local variety TOfA/Zakkama) and four (4) cow dung manure rates (0 t ha^{-1}, 5 t ha^{-1}, 10 t ha^{-1} and 15 t ha^{-1}) giving 4 x 2 x 4 (32 treatments) replicated thrice (total of 96 treatment plots). Irrigation regimes were assigned to the main plot, variety as sub-plot, while cow dung rates were allocated to the sub-sub plots respectively. The conventional flooding (CF) practice involved keeping the soil flooded throughout the growing season which is the common practice by rice farmers in the area, while alternate wetting and drying (AWD) consisted of intermittent irrigation using observation wells. The observation wells consisted of PVC pipes of 12 cm diameter and 40 cm height perforated to a height of 20 cm. Trials were conducted for two (2) consecutive growing seasons (2020 and 2021). The gross plots for each treatment were 3m x 2m ($6m^2$). Full description of the treatments, cow dung composition and weather conditions in the study area are contained in Appendix 1, 2 and 3 respectively.

Determination of physical quality indicators of the soil

Soil samples were collected before commencement of the research and after harvest of each growing season. Eight composite soil samples were taken at 0-20 cm depth with the aid of an auger and used for determination of textural composition and routine analysis of the soil (initial soil properties), while samples for determination of soil physical properties after harvest of each season were collected at 0-15 cm and 15-30 cm soil depths. Undisturbed core samples were used for the determination of soil physical quality indicators while composite samples were used for soil textural composition determination. A total of 96 samples at each soil depth, for each parameter in each season were taken and used for the determinations of soil physical quality indicators. The initial chemical properties of the soil before commencement of the research were measured using methods of Page *et al.* (1982). pH using pH meter, electrical conductivity by conductivity meter, organic carbon by wet oxidation method, total nitrogen using kjeldahl method, available phosphorus was determined by Bray-1 method while exchangeable bases (calcium: Ca, magnesium: Mg, sodium: Na and potassium: K) were extracted using 1N neutral ammonium acetate. Ca and Mg were determined by Atomic Adsorption Spectrophotometry (AAS) while Na and K were read using flame photometer. The complete description of the treatments is found in appendix 3.

The soil physical quality indicators were measured using undisturbed core samples collected at 0-15 cm and 15-30 cm soil depths (a total of 96 samples for each depth and season). The textural composition of the soil was measured using the hydrometer method (Gee and Bauder, 1986) while bulk density was determined by the core method (Blake and Hartge, 1986). Air capacity (AC) was measured using relations as described by White (2006) while total porosity (TP) and plant available water (PAW) were determined as described by Ball-Coellho *et al.* (1998) and Abu and Malgwi (2012) using the following relations:

$$AC\ (m^3m^{-3}) = \Theta S\ (\Psi=0) - \Theta FC\ (\Psi= -1m);\ 0 \leq AC \leq \Theta S \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{eq. 1}$$

Where:
ΘS (m^3m^{-3}) = saturation water content; ΘFC (m^3m^{-3}) = field capacity water content; Ψ (m) = pore water pressure head

$$TP\ (\%) = 1 - \frac{Bd}{Pd} x\ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. 2}$$

Where:
Bd = Bulk density (g cm^{-3})
Pd = Particle density (g cm^{-3}) which is assumed to be 2.65 g cm3

$$PAW\ (\%) = \Theta FC\ (\%) - \Theta PWP\ (\%) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{eq. 3}$$

Where:
ΘPWP = water content (%) at permanent wilting point
ΘFC = water content (%) at field capacity

RESULTS AND DISCUSSIONS

Characterization of the study site and cow dung used

The physical and chemical properties of soil of the study area before commencement of the research are presented in Table 1. Characterization of the study site revealed that the soil of the study area is sandy clay loam, slightly acidic, low in organic carbon (OC), available phosphorus (AP) and exchangeable calcium (Esu, 1991). The site is further medium in magnesium (Mg), high in sodium (Na), potassium (K), total nitrogen (TN) and cation exchange capacity (Esu, 1991). Thus, response of the soil to organic amendments is expected due to low organic carbon (OC) content, while pH of the study site is within the range (5.5-7.-0) characterized as good for crop production and nutrient availability (Landon, 1991; Chude *et al.*, 2011).

Climatic conditions of Sokoto across the study years

Appendix 1 shows the climatic conditions of the study area (Sokoto, Nigeria). Appendix 1 revealed that the minimum temperature of the area (January to June) ranged from 16.7 -27.6 ° C for 2020 and 2021 growing seasons respectively. Maximum temperatures around Sokoto ranged between 31.6-41.8° C for 2020 and 2021 growing seasons while rainfall around the study area (January to June) across the two seasons (2020 and 2021) ranged between 0-112.1 mm, as sunshine hours are between 6.3-9 across 2020 and 2021 growing seasons.

Chemical properties of the cow dung manure used

The obtained results on the chemical properties of the cow dung manure used for the study across the two seasons (2020 and 2021) as revealed in Appendix 2, showed that the manure is rich in organic matter and mineral elements (Esu, 1991; Landon 1991) and thus, good for use as organic amendment.

Effects of irrigation regimes, varieties and cow dung rates on textural composition of the soil

The effects of irrigation regimes, rice varieties, and cow dung rates on textural composition (sand, silt and clay contents) of the soil are presented in the following paragraphs.

Results that represent the influence of different irrigation regimes, rice varieties, and cow dung rates on textural composition of the soil in 2020 and 2021 seasons across 0-15 cm and 15-30 cm soil depths are presented in Tables 2 and 3. The results revealed that on average, irrigation

Table 1. Initial soil properties before commencement of the research

Parameter	Value
Ph	6.30
EC (dSm^{-1})	0.07
OC (%)	0.35
OM (%)	0.61
TN (%)	0.05
AP (mg kg^{-1})	0.78
Ca (cmol kg^{-1})	1.00
Mg (cmol kg^{-1})	0.98
Na (cmol kg^{-1})	0.52
K (cmol kg^{-1})	0.59
CEC (cmol kg^{-1})	14.8
Sand (%)	64.9
Silt (%)	13.7
Clay (%)	21.4
Textural class	Sandy Clay Loam

EC- electrical conductivity, OC- organic carbon, OM- organic matter, TN- total nitrogen, AP- available phosphorus, Ca- calcium, Mg- magnesium, Na- sodium, K- potassium, CE C- cation exchange capacity regimes, rice varieties and cow dung rates of application had no significant effects on the textural composition (percentage sand, silt and clay contents) of the soil across the two seasons and depths of measurement. There were also no significant ($p>0.05$) interactions of treatments tested on the textural composition of the soil (Tables 2 and 3). Moreover, taking main effects into consideration, sand, silt and clay contents of the soil in this study ranges from 477.70-631.30 g kg^{-1}, 147.20-260.00 g kg^{-1} and 182.10-262.30 g kg^{-1}across treatments, years of experimentation and depths of measurement respectively showing the dominance of sand particles over silt and clay. The non-significant effects of irrigation regimes on textural composition of the soil could be related to the fact that textural composition of a soil is an inherent property that is not subject to radical changes due to imposed management practices such as irrigation, rice varieties and cow dung rates of application. The results are in accord with findings of Ya'u *et al.* (2022) and Omenihu and Opara-Nadi (2015) who observed no significant ($p>0.05$) effects of cultivation practices on textural composition of soils after periods of cultivation.

Effects of irrigation regimes, varieties and cow dung rates on bulk density (BD), total porosity (TP) and air capacity (AC) of the soil

The results obtained revealed no significant effects of irrigation regimes (AWD1, AWD2, AWD3 and CF) on soil bulk density (BD) across 2020 and 2021 seasons at both 0-15 cm and 15-30 cm soil depths although the CF treatment maintained relatively higher BD (Tables 4 and 5). Similar irrigation regimes effects as that of the BD was observed for total porosity (TP) of the soil although in opposite direction. Moreover, the water management practices had no significant effects on air capacity of the soil across the two seasons and two depths of measurement except in 2021 season at 15-30 cm depth were AWD1 had the highest AC (0.16 m^3 m^{-3}) followed by AWD2 (0.11 m^3 m^{-3}) while least AC (0.08 m^3 m^{-3}) was obtained in AWD3 and CF treatments (Tables 4 and 5). Additionally, taking the main treatments effects into consideration, BD, TP and AC values in this study ranged between 1.37-1.58 g cm^{-3}, 40.51-48.40 % and 0.08-0.16 m^3 m^{-3} respectively across all treatments, seasons and depths of measurement.

Similarly, the two rice varieties (FARO 44 and TOFA) also had no significant effects on the bulk density (BD), total porosity (TP) and air capacity (AC) of the soil except in 2020 season at 0-15 cm depth, were FARO 44 had significantly ($p\leq0.05$) higher AC (0.10 m^3 m^{-3}) than the TOFA variety which had the least AC (0.08 m^3 m^{-3}) Table 4. In general, higher BD and lower TP implied compaction in soils while greater AC signifies better aeration and structural stability in soils. Therefore, despite non-significant effects of irrigation regimes and rice varieties on the BD TP and AC of the soil in most seasons and depths of measurement, the results suggests lower BD, higher TP and AC in AWD treatments and FARO 44 variety than CF and TOFA variety implying AWD treatments and FARO 44 have potentials for improving the soil physical quality than CF and TOFA combinations. Abdulkadir *et al.* (2022) also found decreased BD and improved TP with adoption of AWD water management than the CF treatment in paddy soil of Northwestern Nigeria. Additionally, the BD and TP range observed in this study are within the range reported in irrigated soils of Katsina State, Northwestern Nigeria (Sani *et al.*, 2019).

Moreover, the comparable bulk density (BD), total porosity (TP) and air capacity (AC) observed in all irrigation regimes and rice varieties across most of the seasons and depths of measurement in this study, could be ascribed to the puddling done to all treatments to reduce percolation of water down the profile and ponding to maintain saturated soil conditions which might have compacted the soil at the same magnitude across all irrigation regimes and rice varieties, leading to comparable BD, TP and AC across irrigation regimes and the two rice varieties. Haque *et al.* (2021) reported similar BD across AWD and CF water management practices in a clay paddy soil of Malaysia, which corroborates the findings of this study.

Cowdung rates (0, 5, 10 and 15 t ha^{-1}) however, significantly ($p\leq0.05$) affected bulk density (BD) at 0-15 cm (2021 season) and 15-30 cm (2020 season) likewise air capacity (AC\) at 15-30 cm in 2021 rice growing season. Total porosity of the soil was affected same way as the BD of the soil by cow dung rates but, in the opposite direction (Tables 4 and 5). Fertilized treatments (5, 10 and 15 t ha^{-1}) had lower BD and higher TP than no fertilization (control) as AC remained unaffected by cow dung fertilization (Tables 4 and 5). The 5, 10 and 15 t ha^{-1} cow dung rates decreased soil BD by 4 %, 4.70 % and 7.59 % and increased TP by 5.70 %, 6.47 % and 10.16 % compared to the control (0 t ha^{-1}) at 0-15 cm soil depth for the 2021 season with similar decreases at 15-30 cm depth in 2020 season (Tables 4 and 5). This suggests that cow dung fertilization decreases soil

BD, increases total porosity and thus soil physical quality (Doran and Parkin 1994; Eswaran *et al.* 1998;) with similar improvements across 5, 10 and 15 t ha^{-1} rates. Moreover, the decreased BD in fertilized treatments (5, 10 and 15 t ha^{-1} rates) than the control treatments could be ascribed to the addition of organic matter through the decomposition of the cow dung manure added, resulting in lower soil BD and higher TP. Rasoulzadeh and Yaghoubi (2010) made similar observations in a sandy clay loam of north east Iran. Haque *et al.* (2021) also reported decreased BD and increased TP due to organic amendments application in a paddy clay soil of Malaysia further strengthening findings of this study.

Furthermore, the interactions of irrigation regimes and cow dung rates on bulk density (BD), total porosity (TP) and air capacity (AC) of the soil were significant as well as variety and cow dung rates interactions on AC of the soil (Tables 6, 7, 8 and 9). In summary, the interactions demonstrated that all irrigation regimes (AWD1, AWD2, AWD3 and CF) combined with FARO 44 and 5-15 t ha^{-1} cow dung (plus 60-100 kg N) are better soil, crop and water management options for improving soil BD, TP and AC in the study area.

Influence of irrigation regimes, varieties and cow dung rates on plant available water (PAW)

Results obtained in this study showed that irrigation regimes affected plant available water (PAW) significantly only in 2021 season at surface 0-15 cm soil depth in which AWD3 gave the highest PAW (8.15 %) while AWD1 had the least PAW (5.25 %) Tables 4 and 5. The greater PAW in AWD3 and AWD2 than in AWD1 and CF could be due to higher microporosity (Pmic) values (data not shown). Pmic had been reported to enhance water retention in soils (Farahani *et al.*, 2020) which supports the findings of this research. Also, the AWD treatments had relatively higher organic carbon content than the CF treatment, this could have also enhances water retention in AWD treatments (Golchin and Asgari, 2008) thereby increasing PAW of AWD3 and AWD2 than the CF treatment.

Similarly, the two rice varieties (FARO 44 and TOFA) had no significant ($p>0.05$) effects on plant available water (PAW) content of the soil in this study across all seasons and depths of measurement (Tables 4 and 5). However, cow dung rates (0, 5, 10 and 15 t ha^{-1}) affected PAW significantly in 2021 season at both 0-15 cm and 15-30 cm soil depths (Tables 4 and 5). At 0-15 cm soil depth, 5 and 15 t ha^{-1} had higher PAW (7.01 and 7.79 %) compared to the control (4.68 %) while at 15-30 cm depth, 15 t ha^{-1} rate outperformed all other rates in improving PAW contents of the soil (Tables 4 and 5).

Additionally, 5, 10 and 15 t ha^{-1} rates improved plant available water (PAW) by 49.79 %,41.45 % and 70.30 % over no fertilization at 0-15 cm soil depth. This suggests that cow dung fertilization improves PAW than no fertilization implying improvement in soil physical quality (Doran and Parkin 1994; Eswaran *et al.* 1998) due to cow dung fertilization with best improvements (49.79 % and 70.30 %) observed in 5 and 15 t ha^{-1} rates. Moreover, the greater PAW in fertilized treatments than the control (0 t ha^{-1}) could be attributed to improvement in organic carbon and organic matter contents due to cow dung application leading to increased water retention and PAW. Golchin and Asgari (2008) also attributed greater water contents in soils to greater OC and OM contents which tallies with findings of this study. Furthermore, PAW values in this study ranged between 4.68 %-8.19 % across all treatments (Tables 4 and 5) which is similar to the PAW range (4.34 %-7.83 %) reported by Igwe and Ejiofor (2005) in similar soils of southeastern Nigeria.

Table 2. Influence of irrigation regimes, variety and Cow dung rates on textural composition of the soil at 0-15 cm depth

Treatments	Textural composition of the soil at 0-15 cm soil depth							
	2020	2021	2020	2021	2020	2021	2020	2021
	Sand (g kg^{-1})		Silt (g kg^{-1})		Clay (g kg^{-1})		Textural class	
Irrigation regimes (I)								
AWD 1	625.50	477.70	172.00	260.00	202.50	262.30	Sandy clay loam	Sandy clay loam
AWD 2	626.30	525.50	156.80	236.80	216.90	237.70	Sandy clay loam	Sandy clay loam
SAWD 3	609.20	564.50	176.20	218.50	215.00	217.00	Sandy clay loam	Sandy clay loam
CF	604.50	549.00	173.20	215.50	222.30	239.70	Sandy clay loam	Sandy clay loam
SE ((±)	27.220	30.220	31.860	15.230	16.560	25.040		
Variety (V)								
FARO 44	608.40	528.00	169.90	227.30	221.60^{a}	246.70	Sandy clay loam	Sandy clay loam
TOFA	624.30	530.30	169.10	239.40	206.80^{b}	232.30	Sandy clay loam	Sandy clay loam
SE ((±)	7.670	26.690	7.400	19.350	6.140	11.460		
Cow dung rates (C) t ha^{-1}								
0	611.70	542.50	172.80	229.40^{ab}	215.50	232.30	Sandy clay loam	Sandy clay loam
5	603.90	543.80	171.80	216.40^{b}	224.30	239.80	Sandy clay loam	Sandy clay loam
10	618.60	517.20	165.80	239.00^{ab}	215.60	243.80	Sandy clay loam	Sandy clay loam
15	631.30	513.20	167.80	248.70^{a}	201.30	242.20	Sandy clay loam	Sandy clay loam
SE ((±)	14.300	13.180	11.060	10.920	10.500	13.090		
Interactions								
I x V	NS	NS	NS	NS	NS	NS		
I x C	NS	NS	NS	NS	NS	NS		
Vx C	NS	NS	NS	NS	NS	NS		
Ix Vx C	NS	NS	NS	NS	NS	NS		

Means followed by the same letter(s) in the same column are not significant at p≤0.05 using Tukey HSD, NS- not significant, AWD- alternate wetting and drying, CF- continuous flooding, SE- standard error

Table 3. Influence of irrigation regimes, variety and cow dung rates on textural composition of the soil at 15-30 cm depth

	Textural composition of the soil at 15-30 cm soil depth							
	2020	2021	2020	2021	2020	2021	2020	2021
Treatments	**Sand (g kg^{-1})**		**Silt (g kg^{-1})**		**Clay (g kg^{-1})**		**Textural class**	
Irrigation regimes (I)								
AWD 1	608.90	516.10	163.20	239.90	227.80	244.00	Sandy clay loam	Sandy clay loam
AWD 2	617.20	555.70	150.80	201.60	231.90	220.50	Sandy clay loam	Sandy clay loam
AWD 3	626.90	597.60	167.10	223.70	218.40	182.10	Sandy clay loam	Sandy loam
CF	619.70	613.30	161.20	187.30	219.00	193.40	Sandy clay loam	Sandy loam
SE ((±)	28.600	33.570	35.280	20.200	21.980	24.170		
Variety (V)								
FARO 44	608.30^{b}	569.00	164.90	214.10	228.10	216.90	Sandy clay loam	Sandy clay loam
TOFA	628.10^{a}	572.30	156.30	224.50	215.50	203.10	Sandy clay loam	Sandy clay loam
SE ((±)	7.250	20.720	8.740	17.120	10.810	8.360		
Cow dung rates (C) t ha^{-1}								
0	624.40	580.40	158.80	212.70	185.80	216.70	Sandy loam	Sandy clay loam
5	626.50	582.90	147.20	208.40	177.80	226.30	Sandy loam	Sandy clay loam
10	600.70	558.80	169.50	224.20	196.80	232.30	Sandy loam	Sandy clay loam
15	621.20	560.70	166.90	231.90	199.40	211.90	Sandy loam	Sandy clay loam
SE ((±)	14.020	11.560	10.360	12.910	9.220	11.070		
Interactions								
I x V	NS	NS	NS	NS	NS	NS		
I x C	NS	NS	NS	NS	NS	NS		
V x C	NS	NS	NS	NS	NS	NS		
I x V x C	NS	NS	NS	NS	NS	NS		

Means followed by no/same letter(s) in the same column are not significant at $p \leq 0.05$ level of probability using Tukey HSD, NS- not significant, AWD-alternate wetting and drying, CF- continuous flooding, SE- standard

Table 4. Influence of irrigation regimes, variety and cow dung rates on selected physical quality indicators of the soil at 0-15 cm soil depth

	Selected physical quality indicators							
Treatments	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Irrigation regimes (I)	BD (g cm^{-3})		TP (%)		AC (m^3 m^{-3})		PAW (%)	
AWD 1	1.39	1.45	47.44	45.44	0.08	0.12	5.78	5.25^{b}
AWD 2	1.40	1.52	47.10	42.47	0.11	0.07	4.93	6.60^{ab}
AWD 3	1.44	1.47	45.79	44.52	0.09	0.10	6.01	8.15^{a}
CF	1.45	1.54	45.26	41.74	0.08	0.13	6.84	6.29^{ab}
SE ((±)	0.084	0.049	3.188	1.837	0.021	0.019	0.735	0.518
Variety (V)								
FARO 44	1.42	1.49	46.36	43.75	0.10^{a}	0.10	5.47	5.91
TOFA	1.41	1.50	46.44	43.34	0.08^{b}	0.11	6.32	7.24
SE ((±)	0.037	0.011	1.411	0.426	0.008	0.008	0.425	0.657
Cow dung rates (C) t ha^{-1}								
0	1.45	1.56^{a}	45.26	41.24^{b}	0.08	0.09	5.99	4.68^{b}
5	1.44	1.50^{ab}	45.57	43.59^{ab}	0.10	0.11	6.16	7.01^{a}
10	1.42	1.49^{ab}	46.36	43.91^{ab}	0.09	0.11	5.68	6.62^{ab}
15	1.37	1.45^{b}	48.40	45.43^{a}	0.09	0.11	5.73	7.97^{a}
SE ((±)	0.034	0.035	1.276	1.346	0.008	0.012	0.570	0.818
Interactions								
I x V	NS	NS	NS	NS	NS	NS	NS	NS
I x C	NS	NS	NS	NS	NS	***	NS	*
V x C	NS	NS	NS	NS	NS	NS	NS	NS
Ix V x C	NS	NS	NS	NS	NS	NS	NS	**

Means followed by the same letter(s) in the same column are not significant at p≤0.05 using Tukey HSD, *- significant at p≤0.05, **- significant at p≤0.01, ***- significant at p≤0.001, NS- not significant, AWD- alternate wetting and drying, CF- continuous flooding, SE- standard error

`Table 5. Influence of irrigation regimes, variety and cow dung rates on selected physical quality indicators of the soil at 15-30 cm depth

	Selected physical quality indicators							
Treatments	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Irrigation regimes (I)	BD (g cm^{-3})		TP (%)		AC (m^3 m^{-3})		PAW (%)	
AWD 1	1.52	1.48	42.66	44.00	0.11	0.16[a]	6.27	5.28
AWD 2	1.49	1.47	43.83	44.72	0.11	0.11[ab]	6.68	8.28
AWD 3	1.53	1.51	42.35	42.82	0.10	0.08[b]	7.02	5.52
CF	1.57	1.51	40.78	43.01	0.09	0.08[b]	8.19	6.92
SE ((±)	0.052	0.024	1.957	0.877	0.018	0.021	1.518	1.039
Variety (V)								
FARO 44	1.54	1.49	41.80	43.64	0.11	0.12	6.50	6.39
TOFA	1.51	1.49	43.01	43.63	0.10	0.10	7.57	6.62
SE ((±)	0.041	0.021	1.547	0.786	0.011	0.018	0.606	0.709
Cow dung rates (C) t ha^{-1}								
0	1.58[a]	1.49	40.51[b]	43.79	0.09	0.11[a]	6.48	6.48[b]
5	1.52[ab]	1.51	42.70[ab]	42.86	0.10	0.12[a]	7.67	5.40[b]
10	1.54[ab]	1.49	41.78[ab]	43.78	0.11	0.11[a]	7.17	6.08[b]
15	1.47[b]	1.48	44.63[a]	44.13	0.10	0.09[b]	6.84	8.04[a]
SE ((±)	0.035	0.030	1.327	1.131	0.009	0.010	0.642	0.487
Interactions								
I x V	NS	NS	NS	NS	NS	NS	NS	NS
I x C	NS	***	NS	***	NS	**	NS	***
V x C	NS	NS	NS	NS	NS	***	NS	NS
Ix V x C	NS	NS	NS	NS	NS	NS	NS	*

Means followed by the same letter(s) in the same column are not significant at p≤0.05 using Tukey HSD, *- significant at p≤0.05, , **- significant at p≤0.01, ***- significant at p≤0.001, NS- not significant, AWD- alternate wetting and drying, CF- continuous flooding, SE- standard error

Table 6. Interactions of irrigation regimes and cow dung rates on bulk density (BD)

Treatments	BD (g cm^{-3})			
	Cow dung rates (t ha^{-1})			
	0	5	10	15
	15-30 cm			
Irrigation regimes	2021			
AWD 1	1.43^{abc}	1.64^{a}	1.58^{ab}	1.28^{c}
AWD2	1.43^{abc}	1.46^{abc}	1.38^{bc}	1.58^{ab}
AWD3	1.53^{ab}	1.43^{abc}	1.58^{ab}	1.52^{ab}
CF	1.57^{ab}	1.52^{ab}	1.42^{abc}	1.53^{ab}
SE (±)	0.057			

Means followed by the same letter (s) are not significant at p≤0.05 using Tukey HSD, AWD- alternate wetting and drying, CF- continuous flooding, SE- standard error

Table 7. Interactions of irrigation regimes and cow dung rates on total porosity (TP)

	TP (%) of the soil at 15-30 cm depth			
	Cow dung rates (t ha^{-1})			
Irrigation regimes	0	5	10	15
	2021			
AWD 1	45.93^{abc}	38.27^{c}	40.32^{bc}	51.48^{a}
AWD2	46.19^{abc}	44.77^{abc}	47.71^{ab}	40.21^{bc}
AWD3	42.20^{bc}	45.94^{abc}	40.53^{bc}	42.62^{bc}
CF	40.82^{bc}	42.46^{bc}	46.55^{abc}	42.22^{bc}
SE (±)	2.145			

Means followed by the same letter (s) are not significant at p≤0.05 level of probability using Tukey HSD AWD- alternate wetting and drying, CF- continuous flooding,, SE- standard error

Table 8. Interactions of irrigation regimes and cow dung rates on air capacity (AC)

Treatments	AC (m^3 m^{-3})			
	Cow dung rates (t ha^{-1})			
Irrigation regimes	0	5	10	15
	15-30 cm			
	2021			
AWD 1	0.13^{ab}	0.17^{ab}	0.22^{a}	0.07^{b}
AWD2	0.12^{ab}	0.14^{ab}	0.09^{b}	0.07^{b}
AWD3	0.09^{b}	0.08^{b}	0.08^{b}	0.07^{b}
CF	0.11^{ab}	0.08^{b}	0.07^{b}	0.13^{ab}
SE (±)	0.028			

Means followed by the same letter (s) are not significant at p≤0.05 using Tukey HSD, AWD- alternate wetting and drying, CF- continuous flooding, SE- standard error

Table 9. Interactions of variety and cow dung rates on air capacity (AC)

	Cow dung rates (t ha^{-1})			
Variety	**0**	**5**	**10**	**15**
		2021		
		15-30 cm		
FARO 44	0.07^{b}	0.11^{ab}	0.15^{a}	0.13^{a}
TOFA	0.10^{ab}	0.12^{ab}	0.08^{ab}	0.10^{ab}
SE (±)		0.021		

Means followed by the same letter (s) are not significant at p≤0.05 using Tukey HSD, AWD- alternate wetting and drying, CF- continuous flooding, SE- standard error

Additionally, the interactions of irrigation regimes and cow dung rates likewise irrigation regimes, rice varieties and cow dung rates were significant. The interactions showed that, AWD1 and AWD2 in combination with TOFA variety and 15 t ha^{-1} cow dung are better soil and water management practices for improving PAW in the soil (Tables 10 and 11).

CONCLUSION

From the results obtained and discussions made, it can be concluded that AWD1, AWD2, AWD3 and CF combined with FARO 44 or TOFA and 5, 10 or 15 t ha^{-1} cow dung (plus 100, 80 or 60 kg N) are better soil, crop and water management practices for improving the physical quality of the soil. It is however, recommended that same research should be extended to 3-4 years to assess medium term effects of the management practice tested on the physical quality of the soil.

Table 10. Interactions of irrigation regimes and cowdung rates on plant available water (PAW)

	PAW (%)			
	Cowdung rates (t ha^{-1})			
Irrigation regimes	**0**	**5**	**10**	**15**
		2021		
		0-15 cm		
AWD1	4.27^{b}	7.17^{ab}	5.41^{b}	4.17^{b}
AWD2	6.01^{ab}	4.91^{b}	8.02^{ab}	7.46^{ab}
AWD3	5.06^{b}	8.88^{ab}	7.30^{ab}	11.35^{a}
CF	3.38^{b}	7.10^{ab}	5.77^{ab}	8.90^{ab}
SE (±)		1.508		
		2021		
		15-30 cm		
AWD1	5.81^{abc}	5.81^{abc}	4.79^{bc}	4.71^{bc}
AWD2	8.62^{abc}	6.96^{abc}	6.52^{abc}	11.04^{a}
AWD3	5.63^{abc}	3.75^{c}	6.26^{abc}	6.44^{abc}
CF	5.87^{abc}	5.07^{abc}	6.77^{abc}	9.99^{ab}
SE (±)		1.337		

Means followed by the same letter (s) at the same depth are not significant at p≤0.05 level of probability using Tukey HSD, AWD- alternate wetting and drying, CF- continuous flooding, SE- standard error

Table 11. Interactions of irrigation regimes, varieties and cow dung rates on plant available water (PAW %)

Means followed by the same letter (s) at the same depth are not significant at p≤0.05 level of probability using Tukey HSD, AWD- alternate wetting and drying, CF- continuous flooding, SE- standard error

	FARO 44				Cowdung rates ($t\ ha^{-1}$)	TOFA			
Irrigation regimes	0	5	10	15		0	5	10	15
					0-15 cm				
AWD1	4.91^{b}	6.89^{b}	4.32^{b}	3.73^{b}		3.62^{b}	7.45^{b}	6.49^{b}	4.60^{b}
AWD2	6.05^{b}	5.06^{b}	7.10^{b}	5.47^{b}		5.97^{b}	4.76^{b}	8.94^{ab}	9.46^{ab}
AWD3	5.73^{b}	6.76^{b}	6.25^{b}	5.04^{b}		4.39^{b}	10.99^{ab}	8.35^{ab}	17.67^{a}
CF	3.07^{b}	8.07^{ab}	4.47^{b}	11.57^{ab}		3.70^{b}	6.12^{b}	7.07^{b}	6.24^{b}
SE (±)					2.268				
					15-30 cm				
AWD1	5.71^{ab}	5.38^{ab}	4.74^{b}	5.13^{ab}		5.92^{ab}	6.24^{ab}	4.84^{b}	4.28^{b}
AWD2	7.75^{ab}	7.47^{ab}	6.14^{ab}	7.81^{ab}		9.48^{ab}	6.44^{ab}	6.90^{ab}	14.28^{a}
AWD3	4.93^{b}	3.88^{b}	6.19^{ab}	6.65^{ab}		6.33^{ab}	3.62^{b}	6.32^{ab}	6.25^{ab}
CF	6.66^{ab}	4.99^{b}	7.44^{ab}	11.32^{ab}		5.08^{ab}	5.14^{ab}	6.10^{ab}	8.65^{ab}
SE (±)					1.872				

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Appendix 1. Description of the treatments tested

Treatments	**Water management**	**Fertilization regimes (CD = cow dung)**	**Weeding**	**Seedling age**
AWD1	Irrigate to 8 cm water depth above soil surface (ASS) when water level is 10 cm below the soil surface	0t/ha,5t/ha CD + 100 kg N/ha,10 t/ha CD + 80 kg N/ha, 15 t/ha CD + 60 kg N/ha,	2 hand hoe weeding (at 3 and 6 WAT), 1 weeding by hand uprooting (9 WAT)	14 days
AWD2	Irrigate to 8 cm water depth ASS when water level is 15 cm below the soil surface	Same as AWD 1	Same as AWD 1	14 days
AWD 3	Irrigate to 8 cm water depth ASS when water level is 20 cm below the soil surface	Same as AWD 1	Same as AWD 1	14 days
CF	Irrigate to 8 cm water depth ASS when water level is 1 cm ASS throughout the growing season except at weeding: 3 and 6 WAT	Same as AWD 1	Same as AWD 1	14 days

Appendix 2. Chemical properties of the cow dung used for the experiment

	Values	
Parameters	**2020**	**2021**
pH (water) 1:2.5	8.65	8.70
EC (dS m^{-1})	4.25	4.27
OC (%)	21.47	21.50
OM (%)	37.12	37.17
N (%)	0.40	0.40
P (%)	0.73	0.75
Ca (cmol kg^{-1})	0.87	0.89
Mg (cmol kg^{-1})	1.65	1.67
Na (cmol kg^{-1})	9.45	9.59
K (%)	1.92	1.90
CEC (cmol kg^{-1})	26.15	27.00
Moisture content (%)	10.10	9.90

EC- electrical conductivity, OC- organic carbon, OM- organic matter, N- nitrogen, P- phosphorus, Ca- calcium, Mg- magnesium, Na- sodium, K- potassium, CEC- cation exchange capacity

Appendix 3. Climatic characteristics of Sokoto across 2020 and 2021 seasons

	Min.Temperature (^oC)		**Max. Temperature (^oC)**		**Rainfall (mm)**	
Month	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
January	16.7	17.9	31.6	35.2	0	0
February	18.7	18.4	33.6	35.0	0	0
March	23.3	23.1	39.8	39.0	0	0
April	27.6	25	41.8	41.2	2.2	0
May	27.5	18.6	39.4	35.0	65.3	44.3
June	25.9	19.2	36.2	33.8	112.1	102.1
	Sunshine Hours		**Evapotranspiration (mm)**		**Relative Humidity (%)**	
January	8.6	8.1	3.8	4.6	23.0	28.0
February	8.3	7.6	4.7	4.7	20.0	25.0
March	9.0	6.9	5.3	5.0	27.0	39.0
April	8.7	8.1	5.8	5.6	37.0	50.0
May	9.0	7.2	5.3	5.9	51.0	54.0
June	6.3	6.5	4.7	4.9	62.0	63.0

Min. - minimum, Max. –maximum