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Soil Physical Quality and Water Retention Evaluation under Tillage and Irrigation Schedule, using RETC Model at Kwalkwalawa, Sokoto, Nigeria.

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Abstract

A two-year study was conducted on tillage and irrigation schedule on soil physical quality and water retention evaluation for irrigated rice production at Kwalkwalawa, Sokoto State. The treatments consisted of a factorial combination of two tillage systems; conventional tillage (CT) and reduced tillage (RT); three irrigation water schedules (Alternate one-day irrigation (W1), alternate two days irrigation (W2) and alternate three days irrigation (W3)) and three varieties of rice (FARO 44, FARO 60 and FARO 61 all used as test crops). The treatments were laid in a split-plot design replicated three times, where tillage and irrigation water schedules were allocated to the main plots while varieties were allocated to the sub-plot. Undisturbed soil samples were collected from 0-10 cm and 10-20 cm depth at the end of each cropping season for the determination of soil moisture retention characteristics and soil physical quality index (S) using the RETC model. RETC output shows a significant difference (P<.0.05) between tillage, irrigation schedule and depth on the value of n, while the S-index was greater in RT compared to CT, and it increased with a corresponding increase in depth but not statistically significant and fall within the ranges of 0.023-0.025. The measured and fitted RETC output were not close to 1:1 solid line, though weak and positive, hence cannot predict with accuracy the hydraulic behavior of the soils.

Keywords: Soil Physical Quality, Tillage, Irrigation Schedule and RETC Model.

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1.0 Introduction

Soil quality degradation is defined as the increasing inability of soil to perform its ecosystem functions, which is manifested in persisting problems of erosion, compaction, acidification, organic matter losses, nutrient losses, desertification and chemical contaminations which reduce agricultural production capacity and food security (Larson and Pierce, 1991). Soil quality is considered a key element for evaluating the sustainability of land management practices (Carter, 2002). Numerous physical, chemical and biological properties can be used as indicators for assessing the effect of ecosystem disturbance by human activity on soil quality (Gregorich *et al.,* 1994). Although these properties are interdependent, soil physical quality strongly affects water availability, nutrient adsorption, aeration, rooting ability and thus crop performance; therefore it plays a central role in studies on soil quality (Dexter, 2004a).

Soil and water quality plays a crucial role in the successful production of any crop, most especially rice that is a profligate user of water. It uses 3000-5000 Litres of water to produce 1 Kg of paddy, which is about 2 to 3 times more than the quantity required to produce 1Kg of other cereals such as maize or wheat (Cantrell, 2002). Therefore, evaluation of the degree of deterioration of soil physical quality under different tillage practices and irrigation schedules will assist in the adoption of appropriate management options for sustainable rice production in the study area.

2.0 Materials and methods

2.1 Experimental Location

The experiment was conducted in a farmer`s field, near the

Usmanu Danfodiyo University Teaching and Research Farm, Kwalkwalawa, Sokoto State in the dry season of 2018 and 2019. The coordinates of the area were taken using the global positioning system (GPS) model Garmin etrex 20.0 as (N13^{0}05.963"E005^{0}12.650" and 252m asl). The soils of the study area were classified as Aeric Endoaquepts at the subgroup level in the USDA Soil Taxonomy System (USDA, 2014) which correlated with Gleyic Cambisols in the World Reference Base (FAO, 2015) and Rima series (Noma, 2005).

2.2 Treatments and Experimental Design

The treatments consisted of a factorial combination of two tillage systems (Conventional tillage (CT); which involves cutting, inverting, puddling and levelling the field plots and reduced tillage (RT)**;** which involves puddling and levelling of the plots all with local hoes, shovels and rake), three irrigation schedules (alternate one day, two days and three days irrigation intervals, which were carried out from one week after transplanting to hard dough stage) and rice varieties of Faros (44, 60 and 61) were used as test crop for the study.

The treatments were laid in a split-plot design replicated three times. Tillage system and irrigation schedule were allocated to the main plots while varieties were allocated to the sub-plots. Field observations and measurements were made for two consecutive seasons (dry) using the same experimental design and field layout.

2.3 Soil Samples Collection

After harvest in each cropping season, undisturbed soil samples were collected at 0-10 and 10-20cm soil depths at the experimental site. The samples collected were used for the determination of soil moisture retention characteristics and soil physical quality index (S) as described below:

Soil water retention characteristics

The soil moisture retention characteristics for the undisturbed core samples were measured using pressure plate extractors (Klute, 1986). The moisture content of the soil was evaluated at -2, -5, -10, -33, -100, -500, -1000 and -1500 kPa. The saturated moisture content of the soil was determined by equilibrating the soil on the tension table without suction (i.e. at 0 kPa). The available water holding capacity (AWHC) was calculated as the difference between moisture content at field capacity (FC) at -33 kPa and permanent wilting point (PWP) at -1500 kPa, using the bulk density values obtained at various depths.

Soil physical quality index (S)

The S as proposed by Dexter (2004a) was computed using the values of the constants that were simulated by RETC Model for Mualem-van Genuchten parameters from the equation below as;

$$S = -n(\theta_{sat} - \theta_{res})\left[\frac{2n-1}{n-1}\right]^{\left[\frac{1}{n}-2\right]}$$

Where θ_{sat} is saturated soil moisture content (m^{3}m^{-3}), θ_{res} is residual moisture content (m^{3}m^{-3}) or moisture content at permanent wilting point (PWP), and n is Mualem-van Genuchten equation parameters (Van Genuchten, 1980; Mualem, 1986), using the values of particle size distribution and bulk density obtained from the field as additional inputs to the RETC Model.

The retention curve (RETC) model is a widely used computer program developed for estimating parameters of the retention curve and hydraulic conductivity functions of unsaturated soils (Van Genuchten *et al*, 1991). While the retention curve (often also called the soil moisture characteristic curve) characterizes the energy status of the soil water, the unsaturated hydraulic conductivity function describes the ability of the porous medium to conduct water. The RETC model uses the parametric model of Van Genuchten (1980) to represent the soil water retention curve and the theoretical pore-size distribution model of Mua-lem (1976) to either predict the unsaturated hydraulic conductivity function from observed soil water retention data or to use the obtained data in the fitting procedure. The Van Genuchten retention function (Van Genuchten, 1980) has been very popular in the field of soil physics and water conservation management.

2.4 Data Analysis

All soil water retention data collected and the RETC output was subjected to analysis of variance (ANOVA) using SAS (Statistical Analysis System) software version 9.3 (SAS, 2011). Significant means were compared using Duncan Multiple Range Test (DMRT) at P<0.05 (Gomez and Gomez, 1984).

3.0 Results and Discussion

Influence of Tillage, Irrigation Schedule and Depth on Soil Moisture Retention Characteristics (m^{3}m^{-3}). Table 1 present results of soil water content at various matric potentials at harvest in 2018 which was significant between the two tillage operations only at lower matric potentials between 0 kPa to -5kPa, where RT was significantly higher than CT. There was significant increase in water retention among all the matric potentials with increasing days to irrigation, where alternate one day irrigation retained more water compared to the others, except at -100kPa and -500kPa, where all the water retention values were similar (0.27 m^{3}m^{-3}) and (0.26 m^{3}m^{-3}), and at -1000kPa, where alternate three days irrigation had significantly higher values and alternate one and two days irrigation were at par (0.021 m^{3}m^{-3}). Among the two depths considered, soil moisture retention increased with corresponding increase in depth of soil sampling in the various matric potentials considered, except at -10kPa and -33kPa where both values of moisture retention were the same. This could be linked to high organic matter content and greater dry aggregate stability observed in RT. This was supported by Lal and Shukla (2004) and Alliaume *et al*. (2010) who reported increase in moisture retention as organic matter and structural stability increases. Soil organic matter positively improves soil moisture retention, especially at high tensions. This is because as the soil begins to dry, characteristics of surface soil particles become more important than the pore geometry (Lipsius, 2002). Also, from the result in Table 2, there was a significant difference (P<0.05) in water retention among the various matric potentials between the two tillage systems. Reduced tillage had significantly higher values compared to CT, except at -100kPa matric potential where CT was significantly higher than RT. At matric potentials of -33, -100 and -500 kPa, both RT and CT were similar in water retention values.

A consistent trend of increase in water retention among all the matric potentials with a corresponding increase in water application was observed, where alternate one-day irrigation retained more moisture compared to alternate two days while alternate three days was the least with their corresponding matric potentials. A significant difference in moisture contents among the two depths was significant at low matric potential, where moisture contents increased with depth. But from -5kPa to -1500kpa, there was no significant difference between moisture contents among the various matric potentials for the two depths, except at -100kpa where it increased with an increase in depth.

Lower soil moisture retention capacity under CT relative to RT could be linked to higher saturated hydraulic conductivity based on the effect of tillage operations and the degree of soil disturbance. This finding corroborates that of Arshad *et al*. (1999), who observed that soil water retention and storage capacity was higher under no-tillage compared to conventional tillage.

Table1: Influence of Tillage, Water Management and Depth on Soil Moisture Retention Characteristics (m^3m^{-3}) in 2018 Dry Season.

Treatments	**0kPa**	**2kPa**	**5kPa**	**10kPa**	**33kPa**	**100kPa**	**500kPa**	**1000kPa**	**1500kPa**
Tillage (T)									
CT	0.36b	0.31b	0.31b	0.30	0.30	0.27	0.26	0.021	0.012
RT	0.37a	0.33a	0.33a	0.30	0.30	0.27	0.26	0.022	0.012
SE±	0.001	0.001	0.001	0.003	0.003	0.003	0.002	0.002	0.002
Water management (W)									
Alternate one day (W1)	0.38a	0.35a	0.34a	0.33a	0.31a	0.27	0.26	0.021b	0.014a
Alternate two days (W2)	0.37b	0.34b	0.32b	0.32b	0.30b	0.27	0.26	0.021b	0.011c
Alternate three days (W3)	0.35c	0.33c	0.32b	0.31c	0.29c	0.27	0.26	0.022a	0.013b
SE±	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001
Depth (cm)									
0-10 cm	0.36b	0.33b	0.33a	0.32	0.30	0.27b	0.26b	0.021b	0.012b
10-20 cm	0.37a	0.34a	0.32b	0.32	0.30	0.28a	0.27a	0.022a	0.013a
SE±	0.001	0.001	0.001	0.003	0.003	0.003	0.002	0.002	0.002
Interaction									
T × W	NS	NS	NS	NS	NS	NS	NS	NS	NS
T × D	NS	NS	NS	NS	NS	NS	NS	NS	NS
W × D	NS	NS	NS	NS	NS	NS	NS	NS	NS
T × W × D	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) are not significantly different at 5% level of probability using DMRT, NS=Not significant, CT=Conventional Tillage, RT=Reduced Tillage and kPa=Kilo pascal.

Table 2: Effect of Tillage, Water Management and Depth on Soil Moisture Retention Characteristics (m^3m^{-3}) in 2019 Dry Season.

Treatments	**0kPa**	**2kPa**	**5kPa**	**10kPa**	**33kPa**	**100kPa**	**500kPa**	**1000kPa**	**1500kPa**
Tillage (T)									
CT	0.36b	0.33b	0.32b	0.32b	0.31	0.28	0.27	0.036a	0.018b
RT	0.38a	0.35a	0.34a	0.34a	0.31	0.28	0.27	0.032b	0.022a
SE±	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.003	0.003
Water management (W)									
Alternate one day (W1)	0.38a	0.35a	0.34a	0.34a	0.32a	0.28	0.27	0.043a	0.02a
Alternate two days (W2)	0.38a	0.34b	0.33b	0.32b	0.30c	0.28	0.27	0.028c	0.018c
Alternate three days (W3)	0.35b	0.33c	0.32c	0.32b	0.31b	0.28	0.27	0.029b	0.020b
SE±	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002
Depth (cm)									
0-10 cm	0.37b	0.34b	0.33	0.33	0.31	0.27b	0.27	0.028b	0.020
10-20 cm	0.38a	0.35a	0.33	0.33	0.31	0.29a	0.27	0.039a	0.020
SE±	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.003	0.003
Interaction									
T × W	NS	NS	NS	NS	NS	NS	NS	NS	NS
T × D	NS	NS	NS	NS	NS	NS	NS	NS	NS
W × D	NS	NS	NS	NS	NS	NS	NS	NS	NS
T × W × D	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) are not significantly different at 5% level of probability using DMRT, NS=Not significant, CT=Conventional Tillage, RT=Reduced Tillage and kPa=Kilo pascal.

Van Genutchen Parameters and Soil Physical Quality Index (S-index)

Table 3 shows the influence of tillage systems and irrigation schedules using the RETC Output model for Van Genutchen parameters and the values of the S-index.

The data showed that there was no significant difference (P>0.05) in residual moisture content (θr) between the two tillage systems. A significant difference was observed in the irrigation schedule; with alternate three days irrigation having the least value of θr, while alternate one and two days irrigation values were the same.

Considering saturated water content (θs) and inverse of air entry point (α), there was no significant difference between both tillage, irrigation schedule and depths, except in θs values in irrigation scheduling, where both alternate one and two days irrigation were at par (0.44) while alternate three days irrigation was the least.

The curve fitting parameters (n) shows a significant difference between tillage, irrigation schedule and depths. Conventional tillage had significantly higher n than RT, both alternate one and two days irrigation had similar (1.01) values of curve fitting parameters while alternate three days irrigation had the highest value. The value of n decreased with increasing depths, with 10-20 cm having smaller values compared to 0-10 cm, respectively.

The absence of variation in values of the θr, θs and α obtained in the study area may be as a result of the short duration of the trial period (two years), while the significant differences between the two tillage systems, water management and depths on the value of n may be as a result of variation in cultivation intensities between the two tillage operations were the same field was consistently maintained for the period of the study. These results corroborate the finding of Enjugu (2014) in a two years study of tillage and Van Genutchen parameters of soils in Samaru. However, contrary to these findings, Poreska *et al*. (2006) and Evett *et al.*(1999) reported significant differences in the values of Van Genutchen parameters in different types of soils under different managements and attributed the differences to variation in their physical and chemical properties, with the content of particle size fractions playing the greatest role.

Soil physical quality index (S-index) significantly varied between the two tillage systems (Table 3). The S-index value was greater in RT compared to CT. S-index increased with increase soil depth, though it was not statistically different. From these findings, the value of the S-index in the study area was in the range of 0.023 to 0.025, which by a grouping of Dexter (2004b) is considered to be moderately suitable for optimal root growth.

Table 3: Influence of Tillage, Water Management and Depths on RETC Ouputs of Van-Genutchen Parameters and S-Index values

Treatment	**Θr**	**θs**	**α**	**N**	**S-Index**
Tillage (T)					
CT	0.083	0.44	0.012	1.03a	0.023b
RT	0.083	0.44	0.011	1.01b	0.025a
SE±	0.0025	0.025	0.002	0.125	0.0003
Water management (W)					
Alternate one day (W1)	0.084a	0.44a	0.011	1.01b	0.025
Alternate two days (W2)	0.084a	0.44a	0.011	1.01b	0.024
Alternate three days (W3)	0.082b	0.43b	0.011	1.04a	0.024
SE±	0.0035	0.030	0.004	0.135	0.0003
Depths (D)					
0-10 cm	0.084	0.44	0.011	1.03a	0.024
10-20 cm	0.084	0.44	0.011	1.01b	0.025
SE±	0.0025	0.025	0.002	0.125	0.0003
Interaction					
T × W	NS	NS	NS	NS	NS
T × V	NS	NS	NS	NS	NS
W × V	NS	NS	NS	NS	NS
T × W × V	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column are not significant at 0.05 level of probability, RT=Reduced tillage, CT= Conventional tillage, SE±=Standard Error and NS= Not significant, θr= Residual moisture content, θs=Saturated moisture content, α=Inverse of air entry point, n= Curve fitting parameters and S=Soil physical quality index.

3.1 Relationship between Observed and Fitted Water Content at Various Pressure Heads

Measured water retention data at various pressure heads was inputted into RETC computer programme which predicted other water retention values (fitted values). The measured and fitted water retention values were compared to validate the applicability and suitability of RETC for studies of hydraulic properties of soils in the study area. The results obtained at 0-10 cm and 10-20 cm depths for the three irrigation schedules are presented in Fig. 1 and 2 respectively. As seen from the figures, both the measured and the fitted values at all depths and various irrigation schedules were not close to the 1:1 solid line, except at 10-20 cm depth with one-day alternate irrigation with a coefficient of determination value of 0.733, while all the rest had a value of <0.60, showing weak and positive values. All these points to the fact that RETC with lower precision cannot predict the hydraulic behavior of the soil under both tillage practices at all the studied depths. But contrary to these findings, Abu and Abubakar (2013) measured the coefficient of determination of >0.97 in a Soil in Northern Guinea Savana Alfisols and proved the validity of the application of RETC for predicting the hydraulic properties of the soil in the study area.

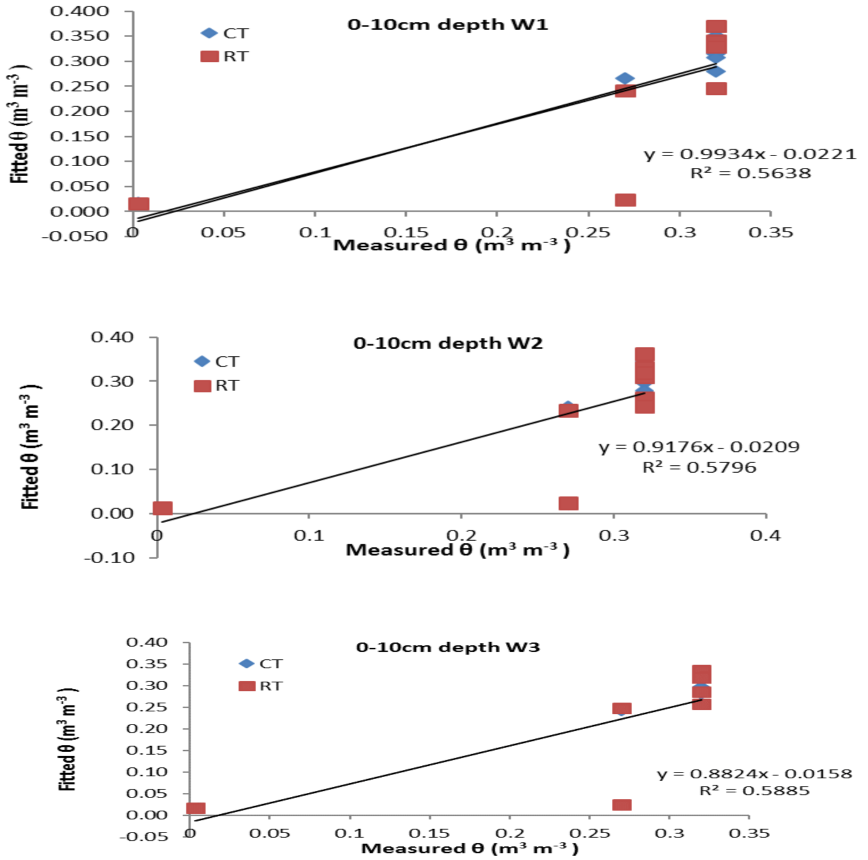

Figure 1: Relationship between measured and fitted volumetric water content at 0-10 cm depth under CT and RT.

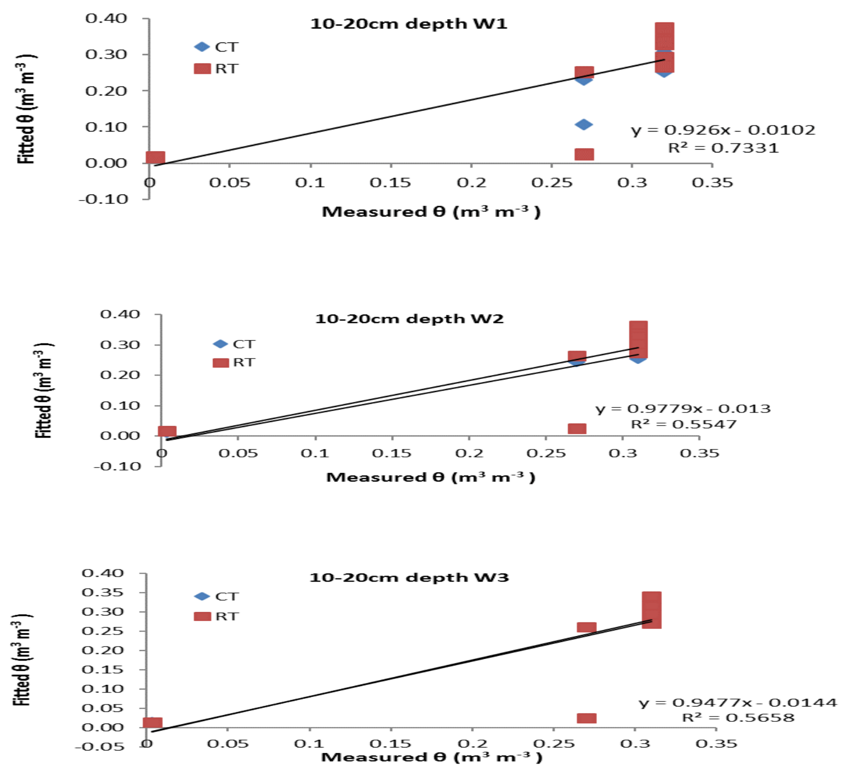

Figure 2: Relationship between measured and fitted volumetric water content at 10-20 cm depth under CT and RT.

4.0 Conclusion

Soil moisture retention increases with increase in one day schedule irrigation and depth, the S-index value was greater in RT compared to CT, though not statistically different with irrigation schedules and depth, it was in the ranges of 0.023 to 0.025, which was considered moderately suitable condition while RETC output model shows weak and positive value of coefficient of determination between the measured and fitted water retention values.

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