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Effect of Tillage Practices and Irrigation Schedule on Soil Quality and Yield of Some Rice (*Oryza sativa* L.) in Sokoto Rima Flood Plain

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Authors' contributions

This work was carried out in collaboration among all authors. Author EAM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MS and OEF managed the analyses of the study while author MIA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Sokoto Rima Flood Plain (SRFP) is located in Sudan Savanna agro-ecology of Nigeria, and is faced with the common challenge of flooding towards the end of the rainy season and widespread drought with high potential for irrigated rice production during dry season. Two year experiment was conducted in the dry season of 2018 and 2019 in a farmer`s field, near the Usmanu Danfodiyo University Teaching and Research Farm, Kwalkwalawa in SRFP, Sokoto State. The treatments consisted of factorial combination of two tillage practices; conventional and reduced tillage, three irrigation schedules; one, two and three days schedule of irrigation and three rice varieties (FARO 44, 60 and 61). Treatments were laid in a split plot design replicated three times, where tillage

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practices and irrigation schedules were allocated to the main plots while rice varieties to the sub-plots. Data on particle size distribution, bulk density and water retention were simulated by RETC model for Mualem-van Genuchten parameters and for estimating the soil physical quality index (S) and the grain yield (kgh^{-1}) of rice varieties were extrapolated from the net plots. Statistical analysis software was used to analyze all data generated, where significant means were compared using Duncan Multiple Range Test. The results revealed that RETC output for van Genutchen parameters demonstrated significant difference between the two tillage practices, irrigation schedule and depth on the value of curve fitting parameters (n). Soil physical quality index (S) increased with increase in soil depth, although not statistically different. From the finding, the S-index in the study area was in the range of 0.023-0.025, which by grouping was considered moderately suitable for optimal root growth. Also, FARO 44 performed better than other varieties in both 2018 (540.05 kgh^{-1}) and 2019 (5835.85 kgh^{-1}), respectively with one day irrigation schedule and convectional tillage practice. Forage legume incorporation during rainy season should be encouraged to improve the soil physical quality over time.

Keywords: Tillage practices; irrigation schedule; soil quality and rice yield.

1. INTRODUCTION

Soil quality is a complex property that play a major roles in terrestrial ecosystems and to a large extend is influenced by management systems. Larson and Pierce [1] defined soil quality as the capacity of soil to function within the ecosystem. Arshad and Coen [2] defined soil quality as the sustaining capability of a soil to accept, store and recycle water, mineral and energy for production of crops at optimum levels while preserving a healthy environment. Gregorich et al. [3] defined soil quality as a composite measure of both soil's ability to function and how well it functions relative to a specific use or degree of fitness of soil for a specific use.

The concept of soil quality emerged in literature in the early 1990s [4], but concerns on soil quality are new because early scientific activities acknowledged the importance of categorizing soil type and soil properties in relation to land or soil use, especially for agricultural purpose [5]. Soil quality measurement is considered important for the assessment of extent of land degradation, amelioration and for identifying management practices which promotes sustainable land use [6]. In general, soil quality consists of three main aspects i.e. physical, chemical and biological qualities. This paper has been focused on the soil physical quality which refers primarily to the soil-strength, fluid transmission and storage characteristics in the crop root zone [7,8]. Soil physical quality affects both chemical and biological processes in the soil and, therefore plays a central role in the studies on soil quality [9]. An agricultural soil with good physical quality maintains a good structure, holds crop upright, resists erosion and compaction; allow unrestricted root growth and proliferation of soil flora and fauna, while permitting the correct proportions of water, dissolved nutrients and air for both maximum crop performance and minimum environmental degradation [7,8].

For efficient utilization of Sokoto Rima Flood Plain (SRFP) for irrigated rice production, farmers are facing the problem of knowing the exact quantity (or optimum amount) of water to apply in areas of abundance and areas of scarcity. Rice needs more irrigation water than other grain crops, therefore, water-saving irrigation technologies for rice are seen as a key component in any strategy to deal with water scarcity [10]. 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 [11]. One of the water conserving irrigation techniques is scheduling of irrigation which provides a means of reducing water consumption at intervals while minimizing adverse effects on yield and the environment [12,13].

This research was aimed at determining the effects of tillage practices and irrigation schedule on soil physical quality and its influence on yield of dry season rice production in SRFP.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted for 2 consecutive dry seasons (2018 and 2019) in a farmer`s field, near the Usmanu Danfodiyo University Teaching and Research Farm, Kwalkwalawa, Sokoto State. The coordinates of the area were taken using global positioning system (GPS) model Garmin etrex 20.0 as (N13°05.963"E005°12.650" and 252 m asl). The soils of the study area are classified as Aeric Endoaquepts at subgroup level in the USDA Soil Taxonomy System [14] which correlated with Gleyic Cambisols in the World Reference Base [15] and Rima series [16]. The area experiences a long dry season from October to May and a short rainy season from June to September. The dry season consists of a cold dry spell (Harmattan) roughly from November to February, followed by a hot dry spell from March to May. The rainfall is erratic, small in quantity and uneven distribution with peak in August and temperature fluctuates roughly between 40°C maximum and 15°C minimum [16].

2.2 Treatments and Experimental Design

The treatments consisted of factorial combination of two tillage practices (Conventional tillage (CT); which involved cutting, inverting, puddling and leveling the field plots and reduced tillage (RT); which involves puddling and leveling of the plots all with local hoes, shovels and a rake), three irrigation schedules (one day, two days and three days irrigation scheduling, which were carried out from one week after transplanting to hard dough stage) with the three rice varieties (FARO 44, 60 and 61). The treatments were laid in a split plot design replicated three times. Tillage practice and irrigation schedule was 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 Agronomic Practices

A nursery bed was established for the three rice varieties (FARO 44, 60 and 61) around the edge of the experimental field. Each seed was treated with seed dressing chemical (Apron star ® 50 DS), which contains metalaxyl-M 20% w/w, difenoconazole 2% w/w and thiamethoxam 20% w/w. It was used at the rate of 3.0 kg of seed per 10 g sachet of chemical to protect the seeds from soil borne fungi and insect pests. The entire field was cleared of shrubs, pre-wetted and sprayed with 3.0 Lha^{-1} of a systemic herbicide before onset of the experiment. Soil samples were collected for the determination of some soil physical properties from both disturbed and undisturbed soils before imposing the treatments. The tillage was incorporated as per the treatment, followed by the construction of basins and water channels. The main plot size for each tillage was 4 m × 10.2 m (40.8 m^2), the sub-plot sizes within the main plots was 4 m × 3 m (12 m^2) and net plot was 3 m × 2.5 m (7.5 m^2).

The entire plot was flooded with water and the rice seedlings after being watered over night from the nursery were transplanted after 28 days of its establishment, using transplanting lines at inter and intra row spacing of 20 cm × 20 cm apart, using two seedling per stand. Immediately after transplanting, the field was sprayed with pendimethalin at the rate of 1.2 Kgai/ha and irrigation water was maintained for one week all through the field before imposing of the irrigation scheduling according to the treatment. Weeding was done at 3 and 6 WAT using local hoe followed by hand pulling of weeds in the plots as the need arises which assisted to maintain weed free plots. Fertilizer was applied through broadcasting at the recommended rate of 100, 40 and 40 kg N, P_2O_5 and K_2O per ha^{-1} respectively. 40 kg of nitrogen and full dose of phosphorous and potassium were applied at 2 WAT using NPK 15:15:15: while a split dose of 30 kg N ha^{-1} was applied at 6 WAT and the balance of 30 kg N ha^{-1} was applied during panicle initiation using Urea (46%) as a source of N.

2.4 Harvesting, Threshing, Winnowing and Grain Yield

The crop was harvested at physiological maturity when the entire plants had turned yellow and the grain fully filled and at hard dough stage. The plants within the net plot were cut at ground level and bundled into sheaves. Each net plot harvested was threshed by putting into polythene sack and beaten with sticks. The paddy collected for each net plot was cleaned by winnowing, sun-dried and weighed using a sensitive electronic weighing balance and the yield expressed in kg per hectare.

2.5 Measurement of Soil Parameters

After harvest, both disturbed and undisturbed soil samples were collected at 0-10 cm and 10-20 cm depths at the experimental site. The samples collected were used to determine some soil physical properties and water retention at the end of each season`s experiment using standard procedures. Particle size distribution of the less than 2 mm fine earth fraction was determined using Boyoucous hydrometer method as described by [17], bulk density was determined by gravimetric method [18] and the soil moisture retention characteristics for the undisturbed core samples were measured using pressure plate extractors [19].

2.6 Soil Physical Quality Index (S)

The S as proposed by Dexter [9] was computed using the constants values 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^3m^{-3}), θ_{res} is residual moisture content (m^3m^{-3}) or moisture content at permanent wilting point (PWP), and n is Mualem-van Genuchten equation parameters [20,21].

The retention curve (RETC) model is a widely used computer program developed at the US Salinity Laboratory for estimating parameters of the retention curve and hydraulic conductivity functions of unsaturated soils [22]. While the retention curve (often also called the soil water 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 [20] to represent the soil water retention curve and the theoretical pore-size distribution model of Mualem [23] 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 [20] has been very popular in the field of soil physics and water conservation management.

2.7 Data Analysis

Data generated were all subjected to analysis of variance (ANOVA) using SAS 9.3 software, [24]. Significant means were compared using Duncan multiple range test (DMRT) at $P<0.05$ [25].

3. RESULTS AND DISCUSSION

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

Table 1 shows the effect of tillage practices and irrigation schedule of the study using the RETC Output model for Van Genutchen parameters and the values of S-index.

The data showed that there was no significant difference ($P>0.05$) in residual moisture content (θr) between the two tillage systems. Significant difference was observed in irrigation schedule, with three days irrigation schedule having the least value of θr, while one and two days irrigation schedule 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 schedule, where both one and two days irrigation schedule were at par (0.44) while three days irrigation schedule was the least.

The curve fitting parameters (n), showed significant difference between tillage, irrigation schedule and depths. Conventional tillage had significantly higher n than RT, both one and two days irrigation schedule had similar (1.01) values of curve fitting parameters while three days irrigation irrigation schedule 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.

Absence of variation in values of the θr, θs and α obtained in the study area may be a result of the short duration of the trial period (two years), while the significant differences between the treatments and depth on the value of n may be 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 [26] in two years studies of tillage and Van Genutchen parameters of soils in Samaru. But contrary to the findings, [27] and [28] 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 practices (Table 1). The S-index value was greater in RT compared to CT. S-index increased with increase in soil depth, though it was not statistically different. From these findings, the value of S-index in the study area was in the range of 0.023

to 0.025, which by grouping of Dexter [29] is considered to be a moderately suitable for optimal root growth.

3.2 Effect of Tillage Practices, Irrigation Schedule and Variety on Grain Yield in 2018 and 2019 Dry Season at Kwalkalawa

Table 2 presents results on the statistical analysis of the effect of tillage practices, irrigation schedule and varieties on the grain yield/ha of rice in 2018 and 2019 dry season in Kwalkwalawa. A significant difference was observed between tillage practices, irrigation schedule and varieties with respect to grain yield in 2018. Conventional tillage had significantly higher grain yield/ha compared to RT, there was an increase in grain yield with corresponding increase in water application, where alternate one day irrigation schedule had significantly higher grain yield compared to the other two irrigations. The varieties also demonstrated significant variation in grain yield/ha, with FARO 44 having a significantly higher grain yield/ha, followed by FARO 60 and then FARO 61. However, significant difference was also observed between tillage practices, irrigation schedule and varieties with respect to grain yield/ha in 2019 dry season (Table 2). Conventional tillage had significantly higher grain yield/ha compare to RT, there was an increase in grain yield with corresponding increase in water application, a trend similar to that in 2018. This observed difference in yield between tillage practices, irrigation schedule and variety may be as a result of good soil preparation, less weed competition, available water for the production of assimilates as well as the variation in the genetic make-up of each variety.

Abu and Malgwi, [30] reported a higher value of grain yield/ha in an experiment conducted at Talata Mafara, and observed that higher water application and shortened irrigation frequencies favors this yield attribute and assisted in higher paddy yields. This also agrees with the findings of [31] and [32] in a yield evaluation trial of rice in Jega, Kebbi state. Alhassan [33] also reported a significant increase in yield of FARO 44 in a multi-location trial conducted at Talata Mafara and Kadawa in Kano State on the effect of weed management practices, seeding method and seed rate.

Table 1. Effect of tillage practices, irrigation schedule and depths on RETC ouput of van-genutchen parameters and S-index values

Treatment	Θr	Θs	A	N	S-Index
Tillage practice (T)					
CT	0.083	0.44	0.012	1.03a	0.023b
RT	0.083	0.44	0.011	1.01b	0.025a
LOS	NS	NS	NS	*	*
SE(±)	0.0025	0.025	0.002	0.125	0.0003
Irrigation schedule (W)					
One day schedule (W1)	0.084a	0.44a	0.011	1.01b	0.025
Two days schedule (W2)	0.084a	0.44a	0.011	1.01b	0.024
Three days schedule (W3)	0.082b	0.43b	0.011	1.04a	0.024
LOS	*	*	NS	*	NS
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
LOS	NS	NS	NS	*	NS
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, NS= Not significant, SE±=Standard error, θr= Residual moisture content, θs=Saturated moisture content, α=Inverse of air entry point, n= Curve fitting parameters and S=Soil physical quality index and LOS=Level of significant

Table 2. Effect of tillage practices, irrigation schedule and varieties on grain yield/ha (kg/Ha) of rice during 2018 and 2019 dry season production at Kwalkalawa

Treatment	Grain yield (kg/ha) in 2018	Grain yield (kg/ha) in 2019
Tillage practice (T)		
CT	3843.92a	4139.50a
RT	3663.71b	3943.99b
LOS	*	*
SE(±)	26.284	29.331
Irrigation schedule (W)		
One day schedule (W1)	5021.36a	5470.17a
Two days schedule (W2)	4092.18b	4358.12b
Three days schedule (W3)	2147.91c	2296.93c
LOS	*	*
SE(±)	32.191	35.924
Variety (V)		
FARO 44	3905.12a	4185.33a
FARO 60	3756.76b	4036.84b
FARO 61	3599.57c	3903.04c
LOS	*	*
SE(±)	32.191	35.924
Interaction		
T × W	NS	NS
T × V	NS	NS
W × V	**	**
T × W × V	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, NS= Not significant, **= Highly significant and LOS=Level of significant*

Table 3. Interaction between irrigation schedule and variety on grain yield/ha (kg/ha) during 2018 dry season

Irrigation schedule (W)	Rice variety		
	FARO 44	**FARO 60**	**FARO 61**
W1	5410.05a	4942.35b	4711.67c
W2	4055.20d	4148.63d	4072.72d
W3	2250.10e	21.79.30e	2014.33e
SE(±)		55.756	

Means followed by the same letter(s) are not significantly difference at 5% level of probability using DMRT, SE±=Standard error, W1= One day irrigation schedule, W2= Two days irrigation schedule and W3= Three days irrigation schedule

Table 4. Interaction between irrigation schedule and variety on grain yield/ha (kg/ha) during 2019 dry season

Irrigation schedule	Rice varieties		
	FARO 44	**FARO 60**	**FARO 61**
W1	5835.85a	5367.83b	5206.83c
W2	4321.12de	4414.55d	4338.70d
W3	2399.03f	2328.15f	2163.60g
SE±		62.221	

Means followed by the same letter(s) are not significantly difference at 5% level of probability using DMRT, SE±=Standard error, W1= One day irrigation schedule, W2= Two days irrigation schedule and W3= Three days irrigation schedule

There was also a highly significant interaction between irrigation schedule and varieties on grain yield/ha in 2018 (Table 3). FARO 44 and alternate one day irrigation schedule had the highest yield/ha (5410.05 Kg/ha) while FARO44, 60 and 61 with alternate three days irrigation schedule were statistically the same. There is also a highly significant interaction effect between irrigation schedule and variety on grain yield/ha in 2019 (Table 4). FARO 44 and one day irrigation schedule had the highest yield/Ha (5835.85 Kg/ha) while FARO 61 with three days irrigation schedule was the least (2163.60 kg/ha).

4. CONCLUSION

RETC output for Van-Genutchen parameters demonstrated significant difference between the two tillage practice, irrigation schedule and depth on the value of n while θs and θr were significant only at irrigation schedules, where both one and two days irrigation schedule were similar in value for both θs and θr while the S-index value was greater in RT compared to CT. S-index increased with increase in soil depth, though it was not statistically different. From these findings, the value of S-index in the study area was in the range of 0.023 to 0.025, which by grouping was considered to be a moderately suitable condition for optimal root growth. While for the rice yield, there was increase in grain yield with a corresponding increase in water application, where one day irrigation schedule and convectional tillage practice had significantly higher grain yield and FARO 44 out yielded both FARO 60 and 61 in both 2018 and 2019, respectively. Forage legume incorporation during the rainy season should be encouraged with a combination of convectional tillage to improve the soil physical quality over time.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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