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Effect of system of rice intensification (SRI) and conventional farmer's practice on some soil quality indicators in Dutse, Sudan Savannah Zone of Nigeria

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Abstract

Evaluating soil physical properties is very crucial for sustainable soil management options that will enhance optimal crop growth and proper ecosystem functioning. A study was conducted to determine the influence of System of Rice Intensification (SRI) on selected soil properties and compare them with farmers conventional practice in the Sudan savannah zone of Nigeria. Disturbed and undisturbed soil samples were collected at 0-15 cm and 15-30 cm depths from each plot of the study site. The disturbed samples were bulk to form one composite sample per plot, which were used for routine analyses. Soil quality index (SQI) was determined using the Dexter 2004 SQI. The Index was calculated from measured water retention data of the study plots, and van Genuchten parameter (n) was derived from the physically-based equation using a bulk density. The results showed no statistical difference in pH, total dissolve salt, mean weight diameter, and porosity of both practices in the study site. Significance difference was observed in SRI practice with mean value in soil organic carbon (SOC) of 0.6 gkg^{-1}, dry bulk density of 1.6 g cm^{-3} and cation exchange capacity (CEC) value of 16.0 $cmol_{(+)}kg^{-1}$ greater than that of conventional practice with a distinct change. In SRI practice, the soil textural class is silty loam while in conventional practice clay loam was observed. The moisture content at higher kPa(5, 10, and 15 kPa), was found to be statistically dissimilar between SRI and conventional practice. The results of SQI indicated that SRI moderately improves soil physical condition with an SQ value of -0.06 (indicating very good soil physical condition), while conventional practice recorded an SQ value of -0.015 (indicating good soil physical condition). The findings showed that SRI has a significant influence on soil properties of rice growing plots in the study area.

Keywords: Soil properties; System of Rice Intensification; Soil Quality Index; Sudan savannah; rice

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1.0 Introduction

Soil physical property is used as an essential phenomenon in aspects of soil physical process. Such processes are those with a direct and indirect effect on the physical strength of the soil and its ability to retain and conduct air and water conducive for plant growth. However, concern about soil physical quality is growing owing to different soil use with changing land use. This is because savannah soils have been characterized with a weak structure, (Ogunwole and Ogunleye, 2005), poor infiltration capacity (Wudivira, 1998), and subsequently liable to erode quickly with high run-off rates (Odunze, 2003). This, in turn, results in low soil nutrients because of continuous cultivation (Bationo*etal.*, 1997).

Soil physical quality affects chemical and biological processes in the soil and, therefore, plays a central role in studies on soil quality (Dexter, 2004a). The physical quality of agricultural soil refers primarily to soil strength, fluid transmission, and storage characteristics in the crop root zone, (Reynolds *et al.*, 2002). An agricultural soil with an excellent physical quality maintains a good structure, holds crops upright, and resists erosion and compaction. It also allows unrestricted root growth for nutrients and air that allows both maximum crop performance and minimum environmental degradation (Reynolds *et al.*, 2002). The Dexter *S* value is a measure of the micro-porosity of the soil, (Dexter,2004b)has been linked to several soil physical processes and soil quality indicators (SQI), including bulk density. It is also related to root growth in soil(Dexter,2004a). Generally, the higher the value of *S*, the higher the soil physical quality. It is recommended that the *S* value be used in combination with other capacity-based indicators. This is because, in some soils, values may be overestimated, (e.g. sand with uni-modal and narrow pore size distributions). The Dexter *S* value and other capacity-based physical are related to pore volume and pore size distribution (Reynolds et al., 2002). They are derived from soil hydraulic behavior and therefore are likely to be more sensitive to temporal and spatial changes in soil condition and soil quality compared to other less dynamic indicators, which look solely at pore volume, such as bulk density (Dexter, 2004a; Merrington *et al.,* 2006; Naderi-Boldaji and Keller, 2016). Intensive field crop production can cause the physical quality of agricultural soils to decline (Reynolds *et al.*, 2002).

System of rice intensification (SRI), is a Climate- Smart Agro-ecological methodology developed in Madagascar for increasing the productivity of rice and more recently other crops, by changing the management of the plant, soil, water application, and nutrients management practices, (Stoop *et al.,* 2002). Instead of continuous flooding, rice-growing fields should be kept moist to prevent weed growth and allow the plant to receive the ideal amount of water. This minimizes anaerobic condition, improves root growth, support growth, and diversity of anaerobic soil organism, favors their development in soils, and reduces methane emission (Uphoff *et al.,* 2008). The principles of SRI (intermittent irrigation) are; early and healthy plant establishment, reduced plant density, improvements of soil condition through enrichment with the organic matter with reduced and controlled water application (alternate wetting and drying) (Stoop *et al.,* 2002; Zhao *et al.*, 2009; Thakur *et al.*, 2010). These changes cause rice genomes to yield a more productive phenotype, ones with more tillers, a much more extensive root system, and a positive correlation between tillering and grain filling. With fair use of these methods and with improved soil properties, yield can surpass 15 t/ha, pushing beyond what has been considered a yield ceiling for rice (Khush, 1996).

Combinations of these poor physical characteristics of savannah soils warrant the assessment of soil quality under different management practices. Much research has been conducted on SRI practices as one of the most important and among the leading research topics in the world. Most of these researches focused on nutrient imbalances resulting from increasing use of the same piece of land, improved and optimized productivity of rice crop under intensive agricultural land use. Yet, little or none of these studies reported measurements of soil properties on these management practices, especially in the Sudan Savannah zone of Nigeria. The current study aimed at evaluating the effects of SRI practice on selected soil properties and comparing these properties under two different management practices (SRI and conventional management practice).

2.0. Materials and methods

2.1 Study area

The experiment was conducted, at the Faculty of Agriculture Teaching and Research Farm, (Department of Crop Science experimental farm), Federal University Dutse, (latitude 11°46' 39" N and longitude 9°20' 30"E). The climate of the location is characterized by little rainfall throughout the year, with two seasons: the wet season, (May-September) and the dry season (October-April) with an annual rainfall of 800-1000mm per annum. The mean annual temperature is about 19.7°C-26.6°C (Anonymous., 2016).

2.2 Experimental Design

Two treatments were replicated three times using randomized complete block design(RCBD)with a gross plot of 6.5m X 10.5m with a discard of 0.5m between each plot. Besides, each plot was measured and used. A plot size of 3m x 3m was replicated 3times for each treatment, and 12plots were used in the experiment.

The following management practices were applied to different plots as treatments; SRI and convectional practices (farmers field).

2.3 Soil sampling, preparation, and analysis

Composite samples were collected from each plot size of 3m x 3m. Disturbed samples were bulked to form one composite sample per plot, making 9 samples. Undisturbed core samples with core samplers (5 cm in height and 5.3 cm in diameter) were also collected. These samples were prepared for the routine analytical procedure for the determination of the following. The undisturbed soil samples were used to determine the dry bulk density (ρb) using the core method (Blake and Hartge (1986). Total porosity (*f*) was calculated from the relationship between ρb and particle density (ρd).Particle size was determined using the Bouyoucos hydrometer method (Bouyoucos, 1927). Soil aggregate stability was carried out using a dry sieving method (Masri and Ryan, 2006). Soil pH was determined with a glass electrode pH meter 1:2 soil: water ratio (Bates,1954). Soil organic carbon (SOC) was determined by the dichromate oxidation method (Nelson and Sommers, 1982). Cation Exchange Capacity (CEC) was determined by the 1N ammonium acetate (NH_4OAc) saturation method. (Anderson and Ingram, 1993).

2.4 Soil quality index

The soil quality index (S-index) proposes by Dexter (2004a) was calculated for the different treatments by the following equation;

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

Where;

Where Θ_{sat} is saturated water content, i.e. moisture content at 0 kPa pressure potential otherwise total porosity ($m^3\ m^{-3}$), Θ_{res} is the residual water content taken as the water content at 1500 kPa water content at permanent wilting point; PWP ($m^3\ m^{-3}$); *n* is Maulem-van Genuchten equation parameter (van Genuchten, 1980; Maulem, 1986) derived from a physically-based transfer function utilizing ρ_b data given by Tormena *et al.* (1999) as;

$$n = 2.5181 - 2.064^{a}\ \rho_b + 0.7373\ \rho_b^2 \quad \text{.................2}$$

Where *S*-index is a negative value, thus the modulus of *S* is used in this study.

2.5 Data Analysis

Means of measured soil properties and *n* parameters used for the different treatments/plots were determined with statistical analysis software package (SAS. Version 9.4). Mean comparison of soil properties in the different plots was made with Duncan multiple range tests (DMRT).

3.0. Results and Discussion

3.1 Initial soil physical and chemical properties before planting

Table 1shows the results of initial soil properties at the experimental site before planting. Results of particle size analysis indicated that the soil is silty clay loam in nature with a higher sand percentage than clay. This is in agreement with reports by Jones and Wild (1975), Ogunwole and Ogunleye (2005), and Abdulkareem *et al*. (2012) that cultivated soils of the savannah region of West Africa are predominantly loamy sand, sandy loam to loam in nature depending upon the location. Soil Survey Staff (1993) was used to classify as moderate in the study area. The moderate level is a reflection of enhanced soil cohesiveness as reported by Heard *et al*.(1988). The mean total pore space was found below 39.30 %. Mean weight diameter (MWD) representing soil aggregate stability recorded moderately low value. This may be because of the high temperature, low relative humidity, and low water holding capacity of Nigerian savannah soils, which courses rapid drying of soil as observed by Ogunwole and Ogunyele(2004).

Soil pH was found to be neutral (6.70)as classified by Soil Survey Staff (1993).SOC content of the experimental site was in line with the findings of USDA (2004), who documented similar values (0.60 g kg^{-1})in most mineral soils. It is the main component of soil organic matter (SOM) and as such, constitutes the fuel of any soil. SOM supports essential soil functions, as it is critical for the stabilization of soil structure, retention and release of plant nutrients, and allowing water infiltration and storage in soil. CEC of the experimental site was observed to be moderate with a mean value of 6.85 (cmol($_+$)kg). This value is consistent with the findings of Wuddivira (1998) for savannah soils. In addition to low organic matter status of most savannah soils due to rapid decomposition of organic materials as reported by Jones and Wild(1975).

Table 1: Initial soil physical and chemical properties before planting

Soil Properties	**Mean Value**
Sand (%)	40
Silt (%)	32
Clay (%)	28
Texture	Silty clay loam
Bulk Density (g cm^{-3})	1.57
Porosity (%)	39.30
MWD	1.40
pH	6.70
SOC (g kg^{-1})	0.64
CEC (cmol($_+$)kg^{-1})	6.85

3.2 Effect of SRI and conventional practice on soil physical and chemical properties after harvesting

Table 2 shows the results of the effect of SRI and conventional practice on soil physical and chemical properties after harvesting. No Statistical difference was in all the soil fractions between SRI and conventional practice. Before planting, the textural class for both SRI and conventional practice was silty loam. After harvesting SRI still maintains silty loam while the use of conventional practice changed the textural class to clay loam. This change in textural class may

Table 2: Effect of SRI and conventional practice on soil physical and chemical properties after harvesting

Soil property	**Treatment**	
	SRI	**Conventional practice**
%Sand	30a	36a
%Silt	42a	42a
%Clay	48a	32a
Texture	Clay loam	Silty loam
Bulk Density (g cm^{-3})	1.6a	1.5a
f (%)	38.2a	39.7a
MWD	1.5a	1.5a
pH	6.3a	6.3a
SOC g kg^{-1}	0.5a	0.4a
CEC cmol($_+$)kg^{-1}	16.5a	9.26b
TDS g kg^{-1}	25.0a	21.7a

Means that share the same letter are statistically the same while means that they do not share the same letter are statistically different.

be due to alternate wetting and drying in SRI, which makes the soil to break up naturally into aggregates. SRI and conventional practice are statistically similar in terms of bulk density , *f* and MWD. Moderate bulk density and low porosity as classified by Soil Survey Staff (1993)may be due to to a high percentage in silt and clay fractions in both practices. Also, these values may be associated with the incorporation of crop residues and application of farm-yard manure in both SRI and conventional practice (Bhatacharyya *et al*., 2006). However, there is no statistical significance between SRI and conventional practice, MWD increase from 1.4 observed before planting to 1.5 during planting. This may be because of poor quality in the study area, as reported by Ogunwole and Ogunleye (2005).

All the soil chemical properties (pH, OC, and TDS) determine in this study all show a similar pattern of being statistically significant in both SRI and conventional practice. The pH was modified from neutral (6.7)to slightly acidic (6.3) by both practices. This slight decrease in pH and SOC may be due to alternate wetting and drying in SRI and continuous ponding in conventional practice. Unlike other chemical properties which statistically similar, CEC is statistically different between SRI and conventional practice. SRI practice recorded a mean CEC value of 16.5 cmol($_+$)kg^{-1} as compared to 9.26 cmol($_+$)kg^{-1} of conventional practice. Thus, indicating the dominance of SRIover the conventional practice in terms of nutrient retention.

3.3 Effect of SRI and conventional practice on soil moisture retention

The effect of SRI and conventional practice on soil moisture retention is showed in Table 3. At 0, 0.1, 0.5, and 1 kpa, no statistical difference was observed between SRI and conventional practice. However, at higher kpa moisture retention differs between the two practices with SRI showing more promise of water holding capacity at 5, 10, and 15 kPa. Alternate wetting and drying in SRI is the reason behind improve moisture retention as opposed to continuous ponding in conventional practice.

According to Morgan and Connolly (2013) soils with adequate moisture content influence crop growth, not only affecting nutrients availability but also affecting nutrients transformation and biological behavior. In essence, readily

Table 3: Soil moisture retention data of the study plots.

Moisture content (kPa)	**Treatment**	
	SRI	**Conventional**
0.0	0.3a	0.3a
0.1	0.2a	0.1a
0.3	0.2a	0.1ab
0.5	0.2a	0.1a
1	0.1a	0.1a
5	0.1a	0.1b
10	0.1a	0.1b
15	0.1a	0.1ab
SE±	0.96	0.98

Means that share the same letter are statistically the same while means that they do not share the same letter are statistically different.

available moisture in the soil will be easily available for absorption by crops, and thus minimizing surface evaporation and maximizing water use efficiency and productivity.

3.4 Soil quality index

The optimum values for each of the relevant physical SQIs for the provisioning function are presented in Table 4 and are assumed to represent a meaningful change in the physical SQI as changes of this magnitude are expected to affect root (and therefore crop) growth. From the results (Table 5), it was observed that Dexter SQI classified soils under SRI as "Very good physical condition" while soils under conventional practice are classified as "Good physical condition".

4.0 Conclusion

Table 4: Dexter's SQI

Values	**Soil quality class**
SQ>0.020	Very poor soil physical quality
SQ 0.020 ≥ SQ 0.035	Poor soil physical quality
SQ ≥ 0.050	Very good soil physical quality

Table 5:Soil quality values of SRI and conventional practice after harvesting using Dexter's soil quality equation

TREATMENTS	**SOIL QUALITY INDEX**	**SOIL QUALITY CLASS**
SRI	-0.06	VERY GOOD PHYSICAL CONDITION
CONVENTIONAL	-0.015	GOOD PHYSICAL CONDITION

The results of the study showed that there is no statistical difference in pH, total dissolve salt (ppm), mean weight diameter, and percentage porosity of both the practices in the study site. Significance difference was observed in SRI practice with a mean value of soil organic carbon (SOC) 0.6 g/kg, dry bulk density of 1.6 $g/cm^{3,}$ and cation exchange capacity (CEC) value of 16.0 cmol/kg greater than that of conventional practice with a distinct change. In SRI practice, the soil textural class is silty loam while in conventional practice clay loam was observed. At higher kPa (5, 10, and 15 kPa), SRI was found to be statistically dissimilar from conventional practice. The results of the SQ Index indicated that SRI moderately improves soil physical condition with an SQ value of -0.06 which indicates very good soil physical condition, while conventional practice recorded an SQ value of -0.015 which indicates good soil physical condition. From the results, it was observed that SRI has a significant influence on soil properties of rice growing plots in the study area.SQI is useful in accessing and classifying soil physical properties of rice growing soil, according to the degree of alteration, and evaluating the effects of management and best management method of soil management.

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