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SOIL NUTRIENT STATUS OF SUDAN SAVANNA INCEPTISOL (NIGERIA) AMENDED WITH JATROPHA (Jatropha curcas L.) FOLIAGE

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Abstract

Evaluation of soil nutrient status is fundamental in sustainable soil nutrient management of an area. In order to assess the soil nutrient status of the low fertility inceptisols of Nigerian Sudan Savanna amended with foliage of jatropha, field trials were conducted during the 2018 and 2019 wet seasons at Kadawa, Nigeria (11.650^{0}N and 8.450^{0}E). The treatments included 3 rates of jatropha foliage (0, 5 and 10 t/ha), 3 rates of N-P-K mineral fertilizer (0, half and full recommended rate) and 2 application methods (incorporation and surface placement). These were all combined to have 18 treatments replicated 3 times and assigned to plots in a randomized complete block design (RCBD). Test crop was pearl millet (super sosat variety). Soil and plant samples were analyzed using standard procedures. Results showed that the soil of the area was loamy sand and of low fertility status. Incorporation of 10 t/ha jatropha foliage plus half rate of mineral fertilizer increased exchangeable potassium from 0.16-0.22 Cmol/kg (37.5%). However, Surface application of 10 t/ha of jatropha foliage plus half rate of mineral fertilizer increased soil organic carbon from 0.34- 0.67% (103%), CEC from 4.7-8.2 Cmol/kg (74.5%), exchangeable calcium from 2.7-5.3 Cmol/kg (96.3%), exchangeable magnesium from 0.71-1.44 Cmol/kg (102.8%), total nitrogen from 0.026-0.042% (61.6%), available phosphorus from 3.7-9.8 mg/kg (164.9%), Soil fertility index (SFI) from 12.97-19.71 (52%), soil evaluation factor (SEF) from 7.2-13.9 (93.1), grain yield from 1275-2991.8kg/ha and 966.7-3842.3kg/ha (134.6-297.7%) while stover yield was increased from 4791.3-7216kg/ha and 4698-10642kg/ha (50.6-126.7%). Hence, the surface placement of jatropha pruning at higher rates (≥ 10 t/ha) plus modest amounts of mineral fertilizer may lead to sustainable management of soils of the Nigerian Sudan Savanna

Keywords: Nutrient management, soil fertility, Jatropha foliage, surface placement, incorporation

Introduction

Inceptisols are relatively recent soils with minimal profile development. Inceptisols are among the most abundant types of soils in the Sudan Savanna that can support arable crop production with adaptation of good agriculture management practices (Encyclopedia Britannica, 2018; Brady and Weil, 2008). The effect of soil management on soil quality of Inceptisols in semi-arid areas indicated that management practices such as low tillage and application of 100% optimum rate of organic sources of nutrients gave the highest soil quality index (Sharma et al., 2014).

Soil nutrient depletion is a major constraint to crop production in the Sudan Savanna of Nigeria where Inceptisols are predominantly immature, sandy, and shallow with low water holding capacity and low nutrient retention (Adamty, 2016; Chude et al., 2012). In Sudan Savanna, these soils are derived from aeolian materials frequently low in organic matter, cation exchange capacity and available phosphorus. Besides that, crop productivity is highly variable and depends on organic matter and clay content (Plant and Soil, 2018). Therefore, the addition of large quantities of organic matter can greatly improve the fertility status of these soils in the Sudan Savanna of Nigeria. A study by Bai et al. (2017) stated that the use of green leaf biomass as soil input facilitates mineralization and enhances soil fertility.

In order to estimate soil productivity and properly manage these soils, it is pertinent to have a better understanding of their fertility problems (Yusuf et al., 2004). Consequently, several soil variables are integrated to measure soil quality rather than using a single variable, since each soil property responds differently to a particular soil degradation process. Integrating multiple soil properties in soil quality assessment provides avenue to identify variations among soils (Perumal et al., 2017). Moreover, Panwar et al. (2011) explained that soil fertility or quality can be determined by measuring soil attributes referred to as *indicators*. The assessment involves transforming these indicators into a single value called soil fertility/quality index, which can be used to compare changes in soil properties.

In Nigeria, many small scale farmers fence their fields with jatropha **(***Jatropha curcas* L**.**) as a common agriculture practice. This plant generates large amount of foliage (biomass) that is cheap and easily accessible to the low-income and low-resource farmers. Mainly because, the foliage of jatropha have been regarded as a suitable source for use as organic amendment, due to C:N ratio (12.9-35), total nitrogen content (1.2-3.4%) and low lignin and polyphenols (Dieye et al., 2016; Chaudhary et al, 2014; Victor et al., 2010). Furthermore, the use of jatropha seed cake in relation to soil and plant development have been noted to improve soil fertility as it adds organic matter as well as macro and micro nutrients to the soil (Azza et al., 2017; Traore et al., 2012). However, past studies on jatropha are focused on their potential as biofuel plant for sourcing energy and usage as seed cake to improve soil properties, instead of the unprocessed plant parts (such as foliage). Jatropha foliage are low-cost and easily available to local farmers. Hence this study objective was to determine the nutrients and fertility status of Sudan Savanna soil (Inceptisol) amended with foliage of jatropha, that will support the farmers' initiative towards sustainable farming system.

MATERIALS AND METHODS

The experiment was conducted at the kadawa research station (11.650^{0}N and 8.450^{0}E) within the Sudan Savanna of Nigeria. The climate is described as '*Aw'* Koppen classification (Shehu et al., 2015). Average rainfall is approximately 700mm (annually). Soil of the area has been reported as typic ustropept (Okai et al., 2000). Table 1 shows some properties of the soil. The experiment was carried out during the 2018 and 2019 wet seasons. Test crop was pearl millet (super sosat variety). Treatments included 3 levels of jatropha foliage (0, 5 and 10 t/ha), 3 levels of mineral fertilizer (0, half and full recommended rate of 60kgN/ha, 30kgP_2O_5/ha and 30kgK_2O/ha) and 2 application methods (surface placement and incorporation) to have 18 treatments as follows:

Treatment no.	Label
T1	J1F1S
T2	J1F2S
T3	J1F3S
T4	J2F1S
T5	J2F2S
T6	J2F3S
T7	J3F1S
T8	J3F2S
T9	J3F3S
T10	J1F1I
T11	J1F2I
T12	J1F3I
T13	J2F1I
T14	J2F2I
T15	J2F3I

T16	J3F1I
T17	J3F2I
T18	J3F3I

Where;

J1 = O rate of jatropha pruning (soil amendment).

J2 = 5t/ha rate of jatropha pruning (soil amendment).

J3 = 10t/ha rate of jatropha pruning (soil amendment).

F1 = O rate of mineral fertilizer.

F2 = Half recommended rate of mineral fertilizer, applied 2 weeks after sowing (2WAS).

F3 = Full recommended rate of mineral fertilizer, applied 2 weeks after sowing (2WAS).

S = Surface applied soil amendment.

I = Incorporated soil amendment.

All these were combined and assigned to field plots using the randomized complete block design (RCBD) with 3 replications. Gross plot size was 4.5m x 6m = 27m^2. Inter row and intra row spacing were 75cm and 25cm respectively. Weeding was done manually with hoe at 2 days before sowing as well as 2 and 6 weeks after sowing. 10 seeds were sown and later thinned to 2 plants per stand at 2 weeks after sowing. Incorporated jatropha foliage was applied in furrows and then buried at 3 weeks before sowing while surface application was done by placing the foliage on the furrows. Half of N and all P & K mineral fertilizers were applied at 2 weeks after sowing while the remaining N was applied at 6 weeks after sowing using urea. Experimental parameters taken were grain yield per hectare, soil pH, cation exchange capacity (CEC), organic carbon, total nitrogen, available phosphorus, exchangeable potassium, exchangeable calcium, exchangeable magnesium, soil fertility index (SFI) and soil evaluation factor (SEF).

Grain yield was taken after harvest by sun drying matured millet plants from net plot for 3 weeks followed by threshing and winnowing to obtain clean grains. Grain yield was then converted to kg/ha basis. Soil and foliage analyses were conducted using standard procedures as detailed by Anderson and Ingram (1993) and Okelabo et al. (2002) as follows:

Soil was sampled from each plot at a depth of 0-20cm (zig-zag pattern). Thereafter, equal amounts of soil samples were mixed to form one composite sample per plot. Composite samples were air-dried, crushed and passed through a 2mm sieve. 3 sub-samples from each composite sample were then analyzed for some physical and chemical properties. Particle size distribution was by hydrometer method using calgon (5%) as dispersant and textural class determined with USDA textural triangle. Soil pH was determined by using pH meter in 1:2.5 soil/solution ratio. Organic carbon was by the wet oxidation method of walkley and black (Nelson and Sommers, 1982). Total nitrogen was by the microkjeldahl method after wet oxidation of organic matter. Free NH_3 was liberated from the digest by steam distillation in the presence of excess alkali. The distillate was collected in a receiver with excess boric acid (indicator pH of 4.5). Total nitrogen was then determined by titration. Available phosphorus was by the Bray no. 1 method (0.025N HCl +0.03N NH_4F) as detailed by Bray and Kurtz (1945). Exchangeable cations and CEC by 1N NH_4OAC at pH 7. Exchangeable K was determined by flame emission spectroscopy.

For plant samples, the jatropha foliage was randomly taken from 10 plants at 4 weeks after the on-set of rains. Foliage was cut into pieces for homogenization, mixed, air-dried for 3 weeks, ground and passed through 2mm sieve. The samples were ground and screened through 2mm sieve. Three sub-samples were taken for determination of nutrients concentration. Total nitrogen was determined by microkjeldahl procedure (Bremner, 1965). Total phosphorus using wet digestion was determined by the vanadomolybdate phosphoric yellow color method (Kalra and Maynard, 1994), while potassium was determined using flame photometry after wet digestion (Anderson and Ingram, 1993). Organic carbon was by ash method as described by Okelabo et al. (2002). Lignin in foliage was determined based on the acid detergent fibre (ADF) method by boiling with sulfuric acid and the lignin removed by oxidation with buffered permanganate solution, while polyphenols determination was done with 50% methanol (at 80^0C) by using tannic acid as standard (Anderson and Ingram, 1993). SFI and SEF were determined as detailed by Moran *et al*. (2000) and Lu *et al*. (2002) using the following expressions respectively:

Soil Fertility Index (SFI) = pH + organic matter (%, dry soil basis) + available P (mg/kg dry soil) + exch K (cmol+/kg) + exch Ca (cmol+/kg) + exch Mg (cmol+/kg) - exch Al (cmol+/kg)

Soil Evaluation Factor (SEF) = [exch K (cmol+/kg) + exch Ca (cmol+/kg) + exch Mg (cmol+/kg) – log (1 + exch Al (cmol+/kg)] × organic matter (%, dry soil) + 5

Both indices (SFI and SEF) were developed to assess the soil biomass and fertility status. Lu *et al*., 2002 explained that SEF values of less than 5 indicate extremely poor soil, while higher soil fertility can be expected from values > 5. In 2019, all procedures were performed as done in 2018.

All data were subjected to analysis of variance and means separation was by Tukey's honestly studentized test (HSD) at 5% level of significance (LOS) using statistical analysis system (SAS, 2013) version 9.4.

RESULT AND DISCUSSION

Properties of soil and jatropha foliage

Selected properties of the soil in the study area can be seen in table 1. The soil texture was loamy sand. The soil reaction was slightly acidic (pH_{water}=6.3-6.4), organic carbon was low 0.6-0.61%(), total nitrogen was low (0.04-0.09%), available phosphorus was also low (5.8-6.1 mg/kg) and cation exchange capacity was as well low (3.7-5.9 Cmol/kg). This implies that soil fertility is low. According to Bary et al. (2016) and Horneck et al. (2011), application of fertilizer or manure to such soil is very likely to increase crop yield.

Table 2 shows the chemical content of some attributes of the jatropha foliage. Total nitrogen content was 3.04-3.08%, C:N ratio (14.4), lignin (12.5-13.1%) and polyphenols (0.47-1.21%). Based on the guide provided by Giller (2001) and Palm et al. (2001) regarding the suitability of an organic material to be used as soil amendment, the jatropha foliage can be directly incorporated in to soil for annual crop production.

Table 1: Initial Physico-chemical properties of the soil at experimental site

Property	**2018**	**2019**
Sand (%)	84	84
Silt (%)	14	10
Clay (%)	2	4
Textural class	Loamy sand	Loamy sand
pH (water)	6.4	6.3
pH (0.01M $CaCl_2$)	5.4	5.1
Organic carbon (%)	0.61	0.60
Total nitrogen (%)	0.09	0.04
Available P (mg/kg)	6.1	5.8
Exch. Ca (Cmol/kg)	2.1	4.0
Exch. Mg (Cmol/kg)	0.25	1.08
Exch. K (Cmol/kg)	0.15	0.08
Exch. Na (Cmol/kg)	0.17	0.06

CEC (Cmol/kg)	3.7	5.9
Exch. H+Al (Cmol/kg)	0.6	0.6

Table 2: Chemical content of jatropha foliage used

Attribute	**2018**	**2019**
Organic carbon (%)	43.6	44.5
Total nitrogen (%)	3.04	3.08
Phosphorus (%)	0.25	0.27
Potassium (%)	1.8	1.7
C:N ratio	14.4	14.4
Lignin (%)	12.5	13.1
Polyphenol (%)	0.47	1.21

Effect of treatment on soil pH, CEC and exchangeable acidity

From table 3 (2018 to 2019), soil pH decreased from 6.6-6.2 (6.1%). This implies more acidity. Cation exchange capacity (CEC) increased from 4.2-4.8Cmol/kg (14.3%) while exchangeable acidity also increased from 0.56-0.85Cmol/kg (51.8%). However, rates of jatropha foliage or mineral fertilizer have not been consistent in influencing pH, CEC and exchangeable acidity, but the surface application of jatropha foliage was significantly superior than incorporation method in decreasing exchangeable acidity and in increasing both soil pH and CEC.

The interaction result (table 4) showed that application of mineral fertilizer (with or without jatropha pruning) significantly decreased soil pH. Gardiner and Miller (2008) stated that most fertilizers and organic resources that supply nitrogen are acid forming substances and it is the major cause of rapid acidification in agricultural fields. The pH range of 6-7.5 is regarded suitable for the production of most crops (Manitoba, 2013). Table 5 indicated that surface placement of 10t/ha jatropha foliage (with or without mineral fertilizer) significantly enhanced soil CEC by up to 74.5% (4.7-8.2Cmol/kg). From table 6 also, 10t/ha jatropha foliage (surface applied) was significantly superior than all other treatments in increasing CEC of soil by 54.1% (3.7-5.7Cmol/kg). Soares and Alleoni (2008) submitted that organic matter can contribute >80% of total CEC in tropical soils, while Gardiner and Miller (2008) mentioned that organic matter contributes 30-70% of total CEC in soil. According to Arit (2016), CEC confers soil the ability to hold cations that help in preventing loss of negative ions such as nitrates, sulfates and chlorides. Essentially, CEC is key to soil fertility as higher CEC makes soils to have more Ca, Mg and K. CEC values of <10Cmol/kg are low and typically found in sandy soils. Low CEC makes soils to be very acidic and require frequent liming.

Table 7 indicated that the application of mineral fertilizer significantly increased exchangeable acidity. Also, incorporation of 5t/ha jatropha foliage (with or without mineral fertilizer) significantly increased exchangeable acidity while the application of full rate of mineral fertilizer plus 10t/ha jatropha foliage did not increase exchangeable acidity. Brady and Weil (2008) explained that the causes of soil acidity are complex, but hydrogen (H^+) and aluminum (Al^{3+}) ions generally control acidity in soil. Tisdale et al. (2003) stated that organic residues in soil help to reduce aluminum toxicity by complexation reactions with soil organic matter, while liming the soil leads to neutralization of H^+ and Al^{3+}

Table 3: Influence of jatropha pruning, mineral fertilizer and method of application on soil pH, CEC and exchangeable acidity at Kadawa.

	pH ($CaCl_2$)		CEC (cmol/kg)		H+Al (cmol/kg)	
Jrate	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
0t/ha	6.7a	6.3a	4.3a	4.2c	0.58a	0.96a
5t/ha	6.6ab	6.1b	4.3a	4.7b	0.60a	0.91b
10t/ha	6.5b	6.3a	3.9b	5.7a	0.52b	0.68c
Frate						
0	6.5ns	6.5a	4.3a	4.9b	0.58b	0.75c
Half	6.6ns	6.1b	4.1b	5.1a	0.64a	0.83b
Full	6.6ns	6.1b	4.2b	4.5c	0.47c	0.96a
Method						
Incorporation	6.5b	6.2b	4.0b	4.2b	0.58ns	0.93a
surface	6.7a	6.3b	4.4a	5.4a	0.55ns	0.77b
Mean	6.6	6.3	4.2	4.8	0.57	0.85
SE±	0.12	0.09	0.22	0.13	0.08	0.06
Interaction						
MxJ	ns	*	*	*	ns	*
MxF	ns	*	*	*	ns	*
JxF	ns	*	*	*	ns	*
MxJxF	ns	*	*	*	ns	*

Means followed by the same letter(s) within same column and treatment group are not statistically different at 5% LOS using HSD

Table Error! No text of specified style in document.:**Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil pH at Kadawa (2019)**

	Incorporation			Surface application		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	6.8a	6.1fg	6.0g	6.8a	6.1fg	6.0g
5t/ha	6.1efg	6.1fg	5.6h	6.1efg	6.2cdef	6.2cdef
10t/ha	6.3c	5.6h	6.6b	6.6b	6.3cd	6.2cdef
SE±	0.09					

Means followed by the same letter(s) within and between columns in same treatment group are not statistically different at 5% LOS using HSD

Table 5: Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil CEC at Kadawa (2019)

	Incorporation			Surface application		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	4.7e	3.9hi	4.2fg	4.7e	3.9hi	4.2fg
5t/ha	4.2fg	5.8c	3.3j	4.7e	4.8e	5.2d
10t/ha	3.8i	4.1gh	4.3f	7.3b	8.2a	5.8c
SE±	0.13					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 6: **Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil CEC at Kadawa (2018)**

	Incorporation			Surface application		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	3.7efgh	4.4d	4.8bc	3.7efgh	4.4d	4.8bc
5t/ha	4.5cd	3.9ef	3.9ef	5.1d	4.6cd	4.0e
10t/ha	3.4h	3.6fgh	3.7fgh	5.7a	3.5gh	3.8efg
SE±	0.22					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 7: **Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil exchangeable acidity at Kadawa (2019)**

	Incorporation			Surface application		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	0.6f	1.0c	1.2b	0.6f	1.0c	1.2b
5t/ha	1.3a	0.8d	1.3a	0.6f	0.6f	0.6f
10t/ha	0.6f	0.8d	0.6f	0.6f	0.7f	0.6f
SE±	0.06					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Effect of treatment on soil organic carbon, total nitrogen and available phosphorus

Between 2018 and 2019 (table 8) soil organic carbon content increased from 0.34-0.48% (41.2% rise). This can be due to the accumulation of the added jatropha foliage. Cooperland (2002) noted that to build and maintain soil organic matter there is need for sustained incremental addition of organic resources. Majority of productive soils have organic matter of 3-6% (1.8-3.5% organic carbon) and the benefits from good amounts of organic matter include improvement in soil water holding capacity, aggregate stability, CEC and enhancing soil microbial biodiversity and activity (Fenton et al., 2008). Mean total nitrogen declined from 0.1-0.025% (75% decrease). This may be due to dynamics of mineralization and immobilization of nitrogen by soil microbes with respect to C:N ratio, because as the organic carbon increases, the total nitrogen in soil declines (Manitoba, 2013). Low C:N ratio of <20-30 may favor mineralization while values >30 lead to immobilization of nitrogen (Thygesen, 2016). Soil total nitrogen of <0.15% is regarded as low (Hazelton and Murphy, 2007). Within the same period, mean available phosphorus increased from 7.4-14.2mg/kg (91.4% increase). Maximum P efficiency is achieved by keeping soil pH at 6-7 as well as application of fresh organic matter and/or addition of P bearing mineral fertilizer. Both N and P are major essential macro nutrients that are constituents of many organic compounds in plants and therefore play key roles in the growth and development of plants (Ketterings et al., 2016). Values of available P below 20mg/kg are classified as low (Horneck et al., 2011).

Applied jatropha foliage was consistent in significantly increasing soil organic carbon in the order: 10t/ha>5t/ha>0t/ha, but it was not consistent with respect to total nitrogen and available phosphorus. Mineral fertilizer was also inconsistent in influencing organic carbon and total nitrogen while its application to soil significantly increased the amount of available P in both 2018 and 2019 seasons. Surface placement method was significantly superior to incorporation method in improving organic carbon, total nitrogen and available P (except in 2019 for available P).

Interaction results (table 9 and 10) revealed that surface application of 10t/ha jatropha foliage (with or without mineral fertilizer) mostly increased soil organic matter ($P<0.05$). Moreover, surface placement of 5t/ha jatropha foliage plus mineral fertilizer (table 11) significantly increased the total N in soil. FAO (2020) indicated that surface placement of organic materials is important in terms of preventing loss of nutrients through the adverse effects of sun, wind and water. From tables 13 and 14, application of mineral fertilizer (with or without 10t/ha jatropha foliage) significantly increased available P in soil. The result is in agreement with the suggestion by Gardiner and Miller (2008) to use fresh organic materials and mineral sources of phosphorus (at pH of 6-7) in the efficient management of soil available phosphorus.

Table 8: **Influence of jatropha pruning, mineral fertilizer and method of application on soil organic carbon, total nitrogen and available phosphorus at Kadawa.**

	Organic carbon (%)		**Total nitrogen (%)**		**Available P (mg/kg)**	
Jrate	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
0t/ha	0.30c	0.41c	0.10b	0.021c	8.9a	13.41b
5t/ha	0.32b	0.48b	0.11a	0.025b	5.4c	10.88c
10t/ha	0.41a	0.55a	0.09b	0.028a	7.9b	18.19a
Frate						
0	0.36a	0.45b	0.09b	0.027a	4.9c	9.73c
Half	0.30b	0.54a	0.11a	0.028a	10.7a	15.20b
Full	0.36a	0.46b	0.10b	0.019b	6.5b	17.54a
Method						
Incorporation	0.33b	0.46b	0.10b	0.021b	7.2b	14.43a
surface	0.35a	0.50a	0.11a	0.029a	7.6a	13.89b
Mean	0.34	0.48	0.11	0.025	7.4	14.16
SE±	0.02	0.01	0.008	0.002	0.18	0.09
Interaction						
MxJ	*	*	*	*	*	*
MxF	*	ns	ns	ns	*	*
JxF	*	*	*	*	*	*

MxJxF	*	*	*	*	*	*

Means followed by the same letter(s) within same column and treatment group are not statistically different at 5% LOS using HSD

Table 9: **Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil organic carbon (%) at Kadawa (2019)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	0.33g	0.47de	0.44f	0.33g	0.47de	0.44f
5t/ha	0.47de	0.46e	0.44f	0.47de	0.53c	0.52c
10t/ha	0.47de	0.63b	0.43f	0.62b	0.67a	0.49d
SE±	0.013					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 10: **Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil organic carbon (%) at Kadawa (2018)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	0.29e	0.24f	0.37d	0.29e	0.24f	0.37d
5t/ha	0.37d	0.24f	0.35d	0.28e	0.30e	0.36d
10t/ha	0.42c	0.52ab	0.16a	0.51b	0.29e	0.54a
SE±	0.02					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 11: **Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil total nitrogen (%) at Kadawa (2019)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	0.026d	0.022e	0.014f	0.026d	0.022e	0.014f
5t/ha	0.015f	0.021e	0.008g	0.028cd	0.029c	0.047a
10t/ha	0.028cd	0.029cd	0.022e	0.040b	0.042b	0.009g
SE±	0.002					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 12: **Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil total nitrogen (%) at Kadawa (2018)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	0.077f	0.123ab	0.090def	0.077f	0.123ab	0.090def
5t/ha	0.113bc	0.087ef	0.097de	0.117bc	0.140a	0.120b
10t/ha	0.083ef	0.103cd	0.090def	0.093de	0.087ef	0.097de
SE±	0.10					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 13: Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil available phosphorus (mg/kg) at Kadawa (2019)

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	6.85k	16.74c	16.64c	6.85k	16.74c	16.64c
5t/ha	16.65c	8.60j	11.34h	6.83k	6.89k	14.94d
10t/ha	11.50g	28.15b	13.39f	9.71i	14.07e	32.31a
SE±	0.09					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 1 Error! No text of specified style in document.**: Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on soil available phosphorus (mg/kg) at Kadawa (2018)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	3.68j	17.17a	5.89g	3.68j	17.17a	5.89g
5t/ha	3.02k	5.60gh	5.78g	6.85f	5.29i	5.79g
10t/ha	6.80f	9.28c	7.86e	5.41hi	9.79b	8.22d
SE±	0.18					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Effect of treatment on exchangeable potassium, calcium and magnesium

Potassium is a primary macro nutrient while calcium and magnesium are secondary nutrient elements and they all function in the regulation of plant metabolism (Manitoba, 2013). Low levels of K, Ca and Mg are respectively <3Cmol/kg, <5Cmol/kg and 1Cmol/kg (Hazelton and Murphy, 2007). From 2018 to 2019 (table 15), mean exchangeable K, Ca and Mg increased from 0.12-0.14Cmol/kg (16.7%), 2.2-2.72Cmol/kg (23.6%) and 0.4-0.72Cmol/kg (80%) respectively. These increases may be due to application of both organic resource (jatropha foliage) and mineral fertilizer (NPK). Brady and Weil (2008) outlined the practices that enhance exchangeable K, Ca and Mg in soil to include conservation tillage as well as application of fertilizesr and organic materials, while erosion, leaching and plant removal lead to losses of these nutrients. However, the availability of each of these nutrient elements is related to the concentration of each other (Tisdale et al., 2003). For example, the concentration of Ca^{2+} is reduced when $Mg^{2+}>Ca^{2+}$. High Ca:Mg ratio of 10:1-15:1 causes deficiency of Mg. also, high level of K interferes with Mg availability and uptake, whereby K:Mg ratios of <5:1, 3:1 and 2:1 are recommended for field crops, vegetables and fruit crops respectively. A Ca:Mg ratio of 1:1 is recommended for better crop performance. The availability of K is highly dependent on its relative concentration to Ca^{2+} and Mg^{2+} rather than total K present. Laekmariam et al. (2018) reported Mg-induced K deficiency in soils of southern Ethiopia. Also, Sui et al. (2017) found that the effect of mineral fertilizer K was similar to residue incorporation after a 3-year field trial using cotton and wheat system. Levels of treatments were mostly inconsistent in influencing Ca and Mg but application of jatropha foliage significantly improved exchangeable K and also, surface placement of jatropha foliage significantly enhanced exchangeable Ca and Mg.

Result of interaction (table 16) indicated that incorporation of 10t/ha jatropha foliage plus half rate of mineral fertilizer was significantly superior to all other treatments in improving exchangeable K. From tables 17 and 18, surface application of 10t/ha jatropha foliage (with or without mineral fertilizer) significantly increased exchangeable Ca, while surface placement of 10t/ha jatropha foliage plus half rate of mineral fertilizer was significantly superior than all other treatments in increasing exchangeable Mg (tables 19 and 20). The result suggests a synergistic effect when 10t/ha jatropha foliage (especially surface applied) is combined with half rate of mineral fertilizer in terms of improving the amount of exchangeable Ca and Mg probably due to protection of soil surface from adverse effects of sun, wind and rainfall (FAO, 2020). Furthermore, factors that influence the availability of Mg in soil have been detailed by Spectrum (2020) to include: total amount, soil pH (decreases as Mg declines), CEC which potentially increases Mg as it rises as well as the presence of other cations such as K and Ca that leads to lower exchangeable Mg if present in high quantities.

Table 15: **Influence of jatropha pruning, mineral fertilizer and method of application on soil exchangeable K, Ca and Mg at Kadawa**

	Organic carbon (%)		**Total nitrogen (%)**		**Available P (mg/kg)**	
Jrate	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
0t/ha	0.11b	0.12c	2.1b	2.17c	0.52a	0.56c
5t/ha	0.13a	0.13b	2.3a	2.59b	0.36c	0.69b
10t/ha	0.12a	0.17a	2.2b	3.41a	0.39b	0.91a
Frate						
0	0.12ns	0.15a	2.3a	2.85b	0.37b	0.76b
Half	0.12ns	0.14a	2.2b	2.99a	0.46a	0.79a
Full	0.12ns	0.12b	2.1c	2.33c	0.44a	0.61c
Method						
Incorporation	0.12ns	0.14ns	2.0b	2.22b	0.42ns	0.57b
surface	0.12ns	0.14ns	2.3a	3.22a	0.42ns	0.86a
Mean	0.12	0.14	2.20	2.72	0.40	0.72

SE±	0.008	0.01	0.11	0.12	0.02	0.02
Interaction						
MxJ	ns	*	*	*	*	*
MxF	ns	*	*	*	*	*
JxF	ns	*	*	*	*	*
MxJxF	ns	*	*	*	*	*

Means followed by the same letter(s) within same column and treatment group are not statistically different at 5% LOS using HSD

Table 16: Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on exchangeable K (cmol/kg) at Kadawa (2019)

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	0.16c	0.09f	0.10ef	0.16c	0.09f	0.10ef
5t/ha	0.12d	0.16c	0.12d	0.12d	0.13d	0.09f
10t/ha	0.16c	0.22a	0.12d	0.16c	0.17c	0.20b
SE±	0.01					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 17: Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on exchangeable Ca (cmol/kg) at Kadawa (2019)

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	2.70ef	2.03h	1.77i	2.70ef	2.03h	1.77i
5t/ha	1.93hi	3.63c	1.33j	2.67f	2.09de	3.07d
10t/ha	2.27g	2.03h	2.30g	4.83b	5.30a	3.73c
SE±	0.12					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 18: **Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on exchangeable Ca (cmol/kg) at Kadawa (2018)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	2.00ef	2.17de	2.10cde	2.00ef	2.17de	2.10cde
5t/ha	2.20cd	2.00ef	2.03def	2.80a	2.57b	2.20cd

10t/ha	1.90fg	1.73g	2.03def	2.77a	2.23c	2.27c
SE±	0.11					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 19: Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on exchangeable Mg (cmol/kg) at Kadawa (2019)

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	0.71g	0.53j	0.42l	0.71g	0.53j	0.42l
5t/ha	0.47k	0.91d	0.33m	0.76f	0.79f	0.85e
10t/ha	0.59i	0.52j	0.66h	1.30b	1.44a	0.96c
SE±	0.02					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 20: **Interaction among method vs Jrate (jatropha pruning) vs Frate (mineral fertilizer) on exchangeable Mg (cmol/kg) at Kadawa (2018)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	0.53c	0.44d	0.57b	0.53c	0.44d	0.57b
5t/ha	0.56bc	0.31f	0.35e	0.12i	0.38e	0.47d
10t/ha	021h	0.35c	0.31f	0.25g	0.64a	0.38e
SE±	0.02					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Effect of treatment on soil quality

Soil quality was estimated using two assessment tools: soil fertility index (SFI) and soil evaluation factor (SEF). Result is presented in table 21. In 2018, the SFI was highest (26.4) in plots that received half rate of mineral fertilizer while the control treatment recorded the lowest SFI of 12.97. Next was treatment with 10t/ha jatropha foliage (surface applied) plus half rate of mineral fertilizer (19.71) and it increased soil fertility by 52%. However, in 2019, highest SFI was recorded in plots that received full rate of mineral fertilizer plus incorporated 10t/ha jatropha foliage (36.85) and the lowest was also the control (17.03). here the treatment with half rate of mineral fertilizer plus 10t/ha jatropha foliage (incorporated) increased soil fertility by 16.4%. SEF was also used to assess soil quality and in 2018, the plots that received 10t/ha jatropha foliage (surface applied) recorded the highest value of 8.0 representing an increase of 25% over control (6.4). in 2019, highest SEF (13.9) was observed in plots that received 10t/ha jatropha foliage (surface applied) plus half mineral fertilizer which recorded an increase of 93.1% over the control (7.2). Lu et al. (2002) stated that a SEF of <5 is an indication of low soil fertility whereas values ≥ 5 suggests higher soil fertility status. Perumal et al. (2017) reported SFI and SEF of approximately 30 and 20 respectively for Sampadi forest reserve of Malaysia and attributed it to leaf litter accumulation on the surface of the forest floor. Panwar et al. (2011) recorded SFI of more than 18.4 and SEF of greater than 6.5 on the forest floor of an acidic soil in subtropical humid zone of India and also concluded that the result was due to high accumulation of plant organic matter through litter fall.

On the whole, the results showed that surface application of 10t/ha jatropha foliage (with or without mineral fertilizer) improved soil quality by up to 156.1% (SFI) and 93.1% (SEF). This also suggests that surface application of jatropha foliage can be of great benefit in terms of sustainable soil fertility management in the Sudan Savanna of Nigeria.

Table 21: Effect of treatment on soil fertility index (SFI) and soil evaluation factor (SEF)

	SFI		**SEF**	
Treatment	**2018**	**2019**	**2018**	**2019**
J1F1S	12.97	17.03	6.4	7.2
J1F2S	26.40	25.29	6.0	7.2
J1F3S	15.46	24.11	7.0	6.5
J2F1S	16.13	16.94	6.7	8.3
J2F2S	14.78	17.45	6.6	8.7
J2F3S	15.79	25.33	6.8	8.7
J3F1S	15.79	22.93	8.0	12.7
J3F2S	19.71	28.11	6.6	13.9
J3F3S	18.05	43.62	7.8	9.4
J1F1I	12.97	17.03	6.4	7.2
J1F2I	26.40	25.29	6.0	7.2
J1F3I	15.46	24.11	7.0	6.5
J2F1I	12.64	24.72	7.0	6.8
J2F2I	14.00	19.28	5.8	9.1
J2F3I	14.77	18.11	6.5	6.1
J3F1I	15.69	21.16	6.7	7.5
J3F2I	18.79	36.85	7.4	8.0
J3F3I	16.63	23.30	5.7	7.5
Mean	16.80	23.90	6.7	8.3

Effect of treatment on the yield of pearl millet

The highest and significantly superior grain and stover yields were mostly obtained in plots that received full rate of mineral fertilizer plus 10t/ha jatropha pruning (incorporated). In 2018, this combination produced a grain yield of 4493.7kg/ha against the lowest (control) that yielded 966.7kg/ha of grains. This represents an increase of 364.8%, while its corresponding stover yield was also significantly highest with a yield of 9128.7kg/ha against that of control (4791.3kg/ha) which is an increase of 90.5%. However, next in yield performance was mostly the treatment with half rate of mineral fertilizer plus 10t/ha jatropha pruning which significantly increased grain and stover yields by 297.5% and 50.6% respectively. In 2019, similar treatment after the highest but with 5t/ha jatropha pruning recorded grain and stover yield increases of 158.7% and 154.1% respectively.

The benefit of combining both organic and inorganic materials in pearl millet production was highlighted by Brady and Weil (2008) and ICRISAT (1997) whereby yield increases of more than 250% were observed when mineral fertilizer plus crop residues were used together compared to when each was used separately. Maman and Mason (2013) found that a combination of poultry manure plus mineral fertilizer increased pearl millet grain and stover yield by 117% and 94% respectively as against poultry manure alone (56% and 53% respectively). In the Sudan and sahel zones of West Africa, Toure *et al*. (2018) found that a combination of manure plus mineral fertilizer (NPK) produced the highest pearl millet grain yield (1948kg/ha) against that of full mineral fertilizer alone (1281kg/ha) or manure alone (1130kg/ha) or control (813kg/ha). Increase in pearl millet due to combined application of both organic and inorganic resources has been attributed to synergistic interaction which was described by Troeh and Thompson (2005) and Tisdale *et al*. (2003) as an interaction in which the influence of two factors applied together is much more than the influence of either of the factors when applied alone. According to Rovensa (2016), synergy that comes from a combination of organic resources and mineral fertilizers leads to efficient nutrition, better plant growth and development as well as greater yield and quality of crops

Table 22: **Effect of treatment combinations on grain yield (kg/ha) at Kadawa (2018)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	966.7e	3456.3abc	3923.7abc	966.7e	3456.3abc	3923.7abc
5t/ha	1629.7de	2637.3bcd	2555.3bcde	1833.0de	2353.7cde	3979.7ab
10t/ha	1792.3de	3842.3abc	4493.7a	2402.0bcde	3836.7abc	3785.0abc
Mean	2880.8					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 23: **Effect of treatment combinations on stover yield (kg/ha) at Kadawa (2018)**

	Incorporation			**Surface application**		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	4791.3gh	6682.0def	8807.1ab	4791.3gh	6682.0def	8807.1ab
5t/ha	4545.7h	6250.1efg	6723.7cdef	4621.3gh	7481.1abcd	8163.2abcd
10t/ha	5303.3fgh	6723.7cdef	9128.7a	5397.7fgh	7216.2bcde	8390.1abc
Mean	6711.2					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Table 24: Effect of treatment combinations on grain yield (kg/ha) at Kadawa (2019)

	Incorporation	**Surface application**

Jrate	Control	Half	Full	Control	Half	Full
0t/ha	1275g	1744.1fg	3606.9ab	1275g	1744.1fg	3606.9ab
5t/ha	1898.2efg	3298.5abc	2825.5bcd	1627.4fg	2612.2cde	2269.5def
10t/ha	2192.9def	2991.8bcd	3892.9a	1247.4g	3112.2abc	3394.9abc
Mean	2478.6					

Means followed *by the same letter within and between columns are not statistically different at 5% LOS using HSD.*

Table 25: Effect of treatment combinations on stover yield (kg/ha) at Kadawa (2019)

	Incorporation			Surface application		
Jrate	**Control**	**Half**	**Full**	**Control**	**Half**	**Full**
0t/ha	4698.2fg	9254.1de	10570.0cd	4698.2fg	9254.1de	10570.0cd
5t/ha	3540.1g	11819.2bc	13928.4ab	4745.2fg	11936.4bc	9311.2d
10t/ha	8939.3de	10642.1cd	16003.2a	6942.5ef	9728.2cd	11993.4bc
Mean	9364.9					

Means followed by the same letter within and between columns are not statistically different at 5% LOS using HSD.

Conclusion

From the study, it can be seen that:

1. Surface placement of higher amounts (≥10t/ha) of jatropha foliage improved soil organic carbon, CEC and exchangeable calcium
2. Application of mineral fertilizer increased available phosphorus and exchangeable acidity in the soil
3. Surface placement of jatropha foliage was superior to incorporation in improving soil organic carbon, total nitrogen and available phosphorus
4. Incorporation of 10t/ha jatropha foliage plus half mineral fertilizer increased exchangeable K, while the same combination but surface applied enhanced exchangeable Mg
5. Application of 10t/ha jatropha foliage plus half rate of mineral fertilizer increased grain yield from 1275-2991.8kg/ha and 966.7-3842.3kg/ha (134.6-297.7%) while stover yield was increased from 4791.3-7216kg/ha and 4698-10642kg/ha (50.6-126.7%). This highlights the benefit of such combination in pearl millet production
6. For SFI, control treatments recorded the lowest values in both 2018 and 2019 (12.97 and 17.30 respectively) while highest values were recorded in plots that received half rate of mineral fertilizer or incorporated 10t/ha jatropha foliage plus full rate of mineral fertilizer. However, surface application of 10t/ha jatropha foliage plus half mineral fertilizer increased SFI by 52% (12.97-19.71)
7. In 2018, SEF recorded highest values in treatments with surface applied 10t/ha jatropha foliage (8.0) while in 2019, highest SEF (13.9) was recorded in plots with surface applied 10t/ha jatropha foliage plus half mineral fertilizer, which is an increase of 93.1% over control (7.2)

Therefore, surface application of jatropha foliage in combination with modest amounts of mineral fertilizer can help in the sustainable management of Sudan Savanna soils for crop production

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