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Original Research Article

Performance of Sorghum (*Sorghum bicolor* L. Moench) in sub-saharan africa using organic and inorganic sources of materials

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The decline in soil fertility is a fundamental impediment to agricultural growth and a major reason for food insecurity in Sub-Saharan Africa. This study aimed to identify the best management practice applicable to organic manures (OM) and inorganic fertilizers (IF) for sustainable production. It was conducted in 2018-2019 in Burkina Faso using a Randomized Complete Block Design with six treatments in three replications. The applied treatments were: T1 (control); T2 (simple compost), T3 (*Piliostigma reticulatum* leaves compost), T4 (T2 + ½ IF), T5 (T3 + ½ IF) and T6 (IF). The effects of these treatments were evaluated on soil properties (C, N, P, K) and sorghum grain yield using XLSTAT version 2014.5.03 software. The results showed that the incorporation of O Min soil increased significantly soil pH and its properties. The combined application of OM with IF decreased soil properties but it contributed to increase significantly sorghum yield specifically under the combined application of simple compost with IF. Under an exclusive use of IF and the control plot, soil C decreased with consequent decline in soil pH and nutrients content. Also, under the combined incorporation of *P. reticulatum* compost with IF, sorghum yield decreased. Therefore, appropriate application of inorganic and organic fertilizers is needed to increase soil organic matter and maintain its productivity

Keywords: NPK + urea fertilizer, *piliostigma reticulatum*, Simple compost, sustainable production, sorghum yield.

INTRODUCTION

The soils, world over, have become vulnerable due to the onset of climate change, degradation and loss of biodiversity. Therefore, millions of farmers mainly in developing countries are struggling to feed their families (Winterbottom et al., 2013). Many smallholder farmers and food producers have to deal with a climate that is becoming more unpredictable by the day, with low and unpredictable crop yields and incomes, as well as chronic food insecurity (FAO, 2020). These challenges are particularly acute in Sub-Saharan Africa where about 65% of the agricultural land is degraded (Zingore et al., 2015). From the about 350 million ha (representing 20 to 25%) of the total land area, not less than 100 million ha is estimated to be severely degraded mainly due to agricultural activities (Zingore et al., 2015). This situation affects about 80-90% of the population actively engaged in agriculture (Doso, 2014). In 2007, these degraded soils were estimated to affect 485 million Africans and cost the continent nearly 9.3 billionUS dollars annually (Thiombiano and Tourino-Soto, 2007), reducing the regional annual agricultural GDP by 3% (Zingore et al., 2015)

For the specific case of Burkina Faso, land degradation is the consequence of population growth. The increasing population, resulting in a growing demand for the area to be cultivated, raises concern about the agricultural lands in the country (Nyamekye et al., 2018). Increasing the area of cultivation would result in the destruction of natural vegetation cover (Zoungrana et al., 2018) leading to the environmental stress (Lenhardt et al., 2014) such as the loss of fertile topsoil (Pimentel and Satkiewicz, 2013). This decline in soil fertility is a fundamental impediment to agricultural growth and a major reason for food insecurity in the country. Attempts to address this problem began in the early 1960s with the development of Soil and Water Conservation Measures purposely for runoff control, soil moisture improvement, land rehabilitation, and nutrient management (Reij et al., 2009). These management practices were found to improve crop production in the country but the accompanying incentive measures were needed to empower rural farmers to adopt them (Zougmoré et al., 2014). Moreover, a part of the solution suggested lies on agroforestry system which is a form of agricultural production practice with low external input technologies but comes with enhanced productivity, profitability, diversity and ecosystem sustainability (Bayala et al., 2018). Many other approaches are developed to improve soil fertility in the country (Stewart et al., 2020). Among them, there is the use of organic manuresin combination with inorganic fertilizers (NPK and urea).

Indeed, the use of organic resources has achieved significant strides in improving soil fertility in many agroecological zones in Burkina Faso. These organic resources have been identified as reliable alternatives to reduce continuous large scale use of inorganic fertilizers and are important for maintaining a healthy environment for plants and soil micro-organisms (Lanigan and Hackett, 2017). They play crucial roles in many soil functions and ecosystem services such as buffering against climate change, supporting food production, regulating water availability, improving the physical, chemical and biological composition of the soil (FAO, 2017a). Then, the management of organic matter and its maintenance into the soil are central to sustaining soil fertility on smallholder farms in Burkina Faso. Therefore, this study aimed to assess the best management practice in the use of organic manures alone or in combination with NPK and urea for a sustainable production.

MATERIALS AND METHODS

Study Site

The study was conducted in 2018-2019 in Song-Naba (Figure 1), a village in the Northern part of Burkina Faso. It is located at 12° 57' N and 2° 16' W in the agroecological zone with rainfall between 600 and 900 mm (Sahel zone). According to the Department of Agriculture, over the past five years, a decline in soil fertilility and crop yields have been noted in this site because of severe land degradation. The difficulty in accessing to inorganic fertilizers and organicmanures (animal manure + crop residues) led to the adoption of *Piliostigma reticulatum* (DC.) Hochst as a potential vegetation cover which improves soil fertility.*P. reticulatum* is widely found in this area. It has massive and quality leaf biomass(Yélémou et al., 2007).

Fertilizer used for the study

The simple compost, one of the organic manures used in this study, is derived from the decomposition of crop residues and animal manure by soil microorganisms (Pansus et al., 2009). Several other research findings indicated that it contributes to improve the physico-chemical and biological quality of the soil.

The second compost used in this study was derived from the leaves of *P. reticulatum* in combination with crop residues and animal manure. *P. reticulatum* is used in this area to cover the degraded land.

The mineral fertilizers NPK and urea (46% N) were applied at the recommended dose of 100 kg ha^{-1} of NPK and 50 kg ha^{-1} of urea.

Experiment design and applied treatments

The experiment was carried out in rainy season using a completely randomized block design with six treatments in three replications (Figure 2). The applied treatments were: T1: control; T2: application of simple compost (SC); T3: application of compost from *P. reticulatum*; T4: application of simple compost + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea; T5: application of compost from *P. reticulatum* + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea; T6: recommended dose: 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea.

Management of plots

The experimental area was ploughed at about 20 cm depth with a donkey-coupled ploughand harrowed manually before planting. Basal applications of organic resources were done at a dose of 30 t ha^{-1}. The doses of inorganic fertilizers to be applied were done in two fractions to each of the three treatments T4, T5 and T6. The half dose of NPK was applied at sowing and the other half NPK and the total amount of urea were applied 45 days after sowing. The plot size was 16 m^2 (4 m x 4 m) with 1 m spacing between the plots and the plot borders. The area of the experiment was 496 m^2 (31 m x 16 m). Seeds weres own by hand with a sowing density of 0.8 m between lines and 0.4 m between seed hills. There was a total of sowing lines and 8 seed hills per plot. The measurements were done in yield squares of 8,96 m^2 (2,8 m x 3,2 m).

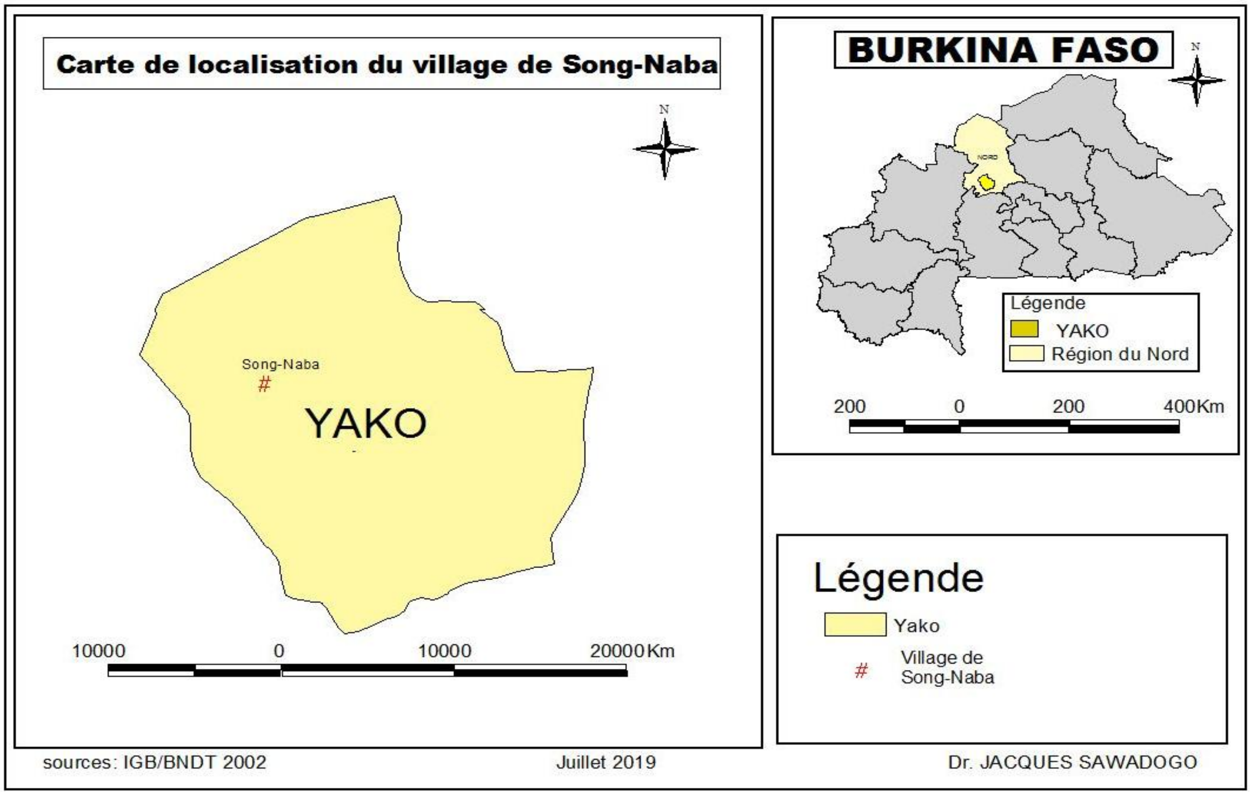

Figure 1 : Location of the study site (Song-Naba)

Sources : IGB/BNDT (2002)

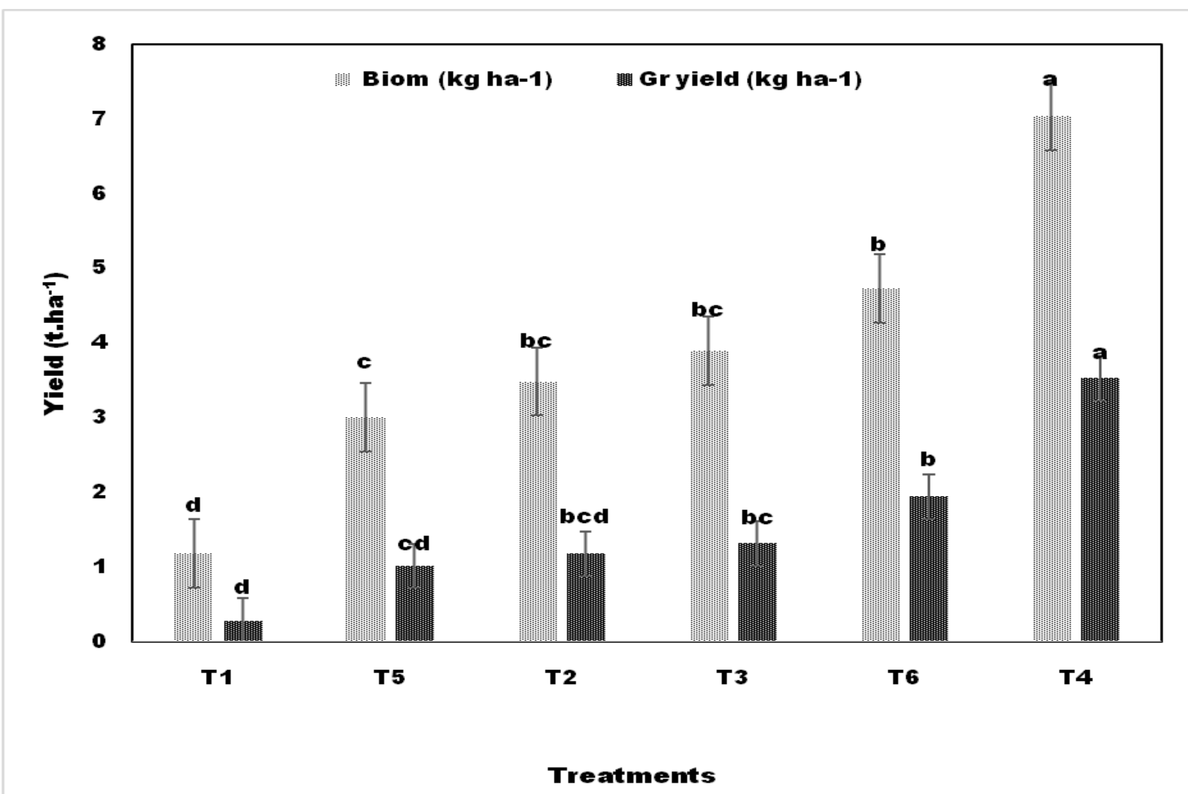

Figure 2: Sorghum biomass and grain yield as affected by the treatments

Table 1. Analysis of variance on the effect of treatments on sorghum yield and yield components

	Begin flow	Mi-flow	Maturity	Pcleswg (g)	Biom (kg/ha)	Gr Yield (kg/ha)	Har Index	TGW (g)
R^2	0.564	0.614	0.875	0.597	0.884	0.853	0.790	0.588
F	6.783	25.004	120.672	20.634	87.842	38.396	160.592	534.319
Pr > F	0.003	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Treatments	12.987	130.292	923.816	94.021	459.250	114.190	2737.903	59062.781
	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

Begin flow: beginning of flowering; Mi-flow: mi-flowering; Pcleswg: panicles weight; Biom: biomass; Gr yield: grain yield; Har Index: harvest index; TGW: thousand grain weight

Soil sampling and laboratory analyses

Two composite soil samples were taken before sowing at horizon 0-20 cm. After harvest, soil samples were again taken from all treatments and also at horizon 0-20 cm. The samples were air-dried and ground to pass 2 mm and 0.5 mm sieve. The samples were analyzed at the INERA Farako-Ba soil and plant analysis laboratory for pH, soil organic carbon (SOC), total nitrogen (N), total and available phosphorus (P), total and available potassium (K).

These analyses were done using standard analytical procedures. SOC was determined using the Walkley and Black method. The pH was measured with a pH-meter (WTW InoLab, Weilheim, Germany). After mineralization of soil samples, P and N were determined in the digest with a SKALAR automatic colorimeter (SkalarSANplus Segmented flow analyser, Model 4000-02, Breda, Holland), K was determined using a flame photometer, available phosphorus and potassium were determined by the Bray-1 method.

Measurements and data collection

The data collected for the experiment were the phenology of sorghum crop, panicle weight, total biomass, grain yield, harvest index and thousand grain weight (1000 seed). For sorghum phenelogy, daily field observations were made from booting period until maturity to estimate sorghum reproductive cycle. The observations consisted of noting the number of booting plants per day, and the number of panicles per day. The period of 50% flowering and the number of panicles was noted at the maturity. Total biomass, grain yield and harvest index were determined using the following formulas :

$$\text{Biomass (kg ha}^{-1}) = \frac{\text{Straw weight (kg)}}{\text{Area (ha)}} \times 10$$

$$\text{Grain yield(kg ha}^{-1}) = \frac{\text{Grain weight (kg)}}{\text{Area (ha)}} \times 10$$

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Straw yield}}$$

Data analysis

The data were analyzed using XLSTAT version 2014.5.03 software. A Multi-way analysis of variance (ANOVA) was performed to analyze the effects of the treatments on soil pH, organic carbon, total nitrogen, phosphorus, potassium, available phosphorus and potassium contents. The descriptive statistics method was used for means comparison at the probability level of 5% and Fischer Least Significant Difference (L.S.D) was subsequently used to compare the means at$p \leq 0.05$. The best management practice to improve and maintain soil organic matter into the soil was identified by a correlation analysis using the same software XLSTAT version 2014.5.03.

RESULTS AND DISCUSSION

The results showed that the applied treatments had high significant (p<0.05) effects on sorghum yield and yield components and on soil pH, organic carbon, nitrogen phosphorus and soil potassium (Tables 1 and 2)

Effect of treatments (practices) on sorghum biomass and grain yield

There were significant effects ($p<0.001$) of treatments on sorghum biomass and grain yield (Table 1). Compared with the control treatment (T1), the single application of organic fertilizers (T2 and T3) contributed to improve 3 times sorghum biomass and 4 to 5 times its grain yield (Figure 2).

Comparing the effect of the single use of the two organic fertilizers, the high yields (biomass and grain) were noted with the incorporation of *P. reticulatum* leaves compost (T3). However, the combined incorporation of these organic fertilizers with NPK and urea (T5) decreased significantly sorghum biomass and its grain yield. Contrary, the effect of the single use of the simple compost (T2) on biomass and grain yield was less compared to the combination (T2 + NPK + urea) effect. The combined incorporation of simple compost and inorganic fertilizers (T4) contributed to improve more sorghum biomass and grain yield (Figure 2). The improvement due to this combination was twice for biomass and 3 times for grain yield.

The study highlighted the important role that soil organic matter played in the soil and to crop production. The differences in yield were due to the nature of the organic material that was used. The result obtained from the single incorporation of the two organic materials indicated the

Table 2: Analysis of variance on the effect of treatments on soil physico-chemical properties

	pH	SOC	N-total	C/N	P-total	P_Bray1	K-total	K-available
		%				mg kg^{-1}		
R²	0.340	0.560	0.543	0.303	0.640	0.328	0.349	0.421
F	808.126	75.586	89.981	1051.970	19.692	7.010	249.325	22.115
Pr > F	< 0.0001**	< 0.0001**	< 0.0001**	< 0.0001**	< 0.0001**	0.002*	< 0.0001**	< 0.0001**
Traitements	215978.737	1290.430	1889.936	386190.856	76.902	21.212	20391.400	154.505
	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

SOC: soil organic carbon; SOM: soil organic matter; *: Significant at the *p<0.05*; **: highly significant at the *p<0.05*

high quality of organic matter from *P. Reticulatum* leaves compost. Indeed, this organic manure incorporated in the soil might have contributed to increasing the soil chemical properties and therefore improved sorghum yield. However, when combined with inorganic fertilizers (NPK + urea), the nutrients especially nitrogen (N) was immobilized to allow the mineralization of this organic material. This immobilization created N deficit and then decreased sorghum yields in this treatment. Similar results were found by Ba et al. (2014a). For these authors, this immobilization of N was due to the polyphenols contained in *P. reticulatum* leaves compost.

The study moreover revealed that the application of inorganic fertilizers (T6) contributed to improve but not significantly sorghum biomass and grain yield as compared to the combined incorporation of simple compost and NPK+urea fertilizers (T4). The improvement of yields in this treatment (T4) was facilitated by the availability of its nutrients and soil moisture during grain filling period. Also, the combination of NPK + urea fertilizers with this simple compost led to the mineralization process and therefore soil properties were improved and were profitable to sorghum crop. This result confirmed that of CILSS (2012) who reported the benefits of combining organic manure and inorganic fertilizers. This combination was found to improve the efficiency of mineral fertilizers and improve soil physical, chemical and biological properties.

T1 : control ; T2 : Simple Compost (SC) ; T3 : compost from *P. reticulatum* (CP) ; T4 : T2 + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T5 : T3 + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T6 : 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea ; the bars represent the standards errors; the bars with same letters indicate that there is no significant difference among them.

Effect of managementpractices on soil pH

The analysis of variance (Table 1) showed that the six treatments or practices affected significantly soil pH (p<0,05). The application of simple compost (T2) and *P. reticulatum* leaves compost (T3) contributed more to improve soil pH compared to T6 (application of exclusive inorganic fertilizer) (Figure 3). This is due to the presence of the high amount of nitrogen introduced to the environment by the inorganic fertilizer (NPK + urea). This result confirmed the importance of organic materials in improving soil pH and it highlighted the negative effect of using excessive inorganic fertilizers on soil pH. A study conducted by Opala et al. (2012) on two organic materials, farmyard manure and *Tithonia diversifolia,* indicated similar results where they reported that the two organic materials increased soil pH more than when they were combined with inorganic fertilizers. According to these authors (Opala et al., 2012), the combination of these organic materials with inorganic fertilizers may, however, have other benefits associated with integrated soil fertility management.

T1 : control ; T2 : Simple Compost (SC) ; T3 : compost from *P. reticulatum* (CP) ; T4 : T2 + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T5 : T3 + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T6 : 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea ; the bars represent the standards errors; the bars with same letters indicate that there is no significant difference among them.

Effect of management practices on soil organic carbon

Similarly, to soil pH, soil organic carbon was significantly influenced by organic resources (p<0,05) (Table 1). Compared to other treatments, the application of T3 (*P. reticulatum* leaves compost) was noted to increase more soil organic carbon (Figure 4). It was followed by the application of simple compost and the combination of simple compost with NPK + urea. The increase in soil organic carbon due to T2 and T3 was 22.5% and 20.4% respectively and this improvement was due to the surplus of nutrients brought into the soil by the two organic materials. Indeed, because of the importance of its leaf biomass, *P. reticulatum* is commonly grown at the study site to somehow restore degraded fields (Yélémou et al., 2018). Some chemical analysis showed that it contains 46, 23% of C, 1.31% of N, 0.09% of P, 0.08% of K with C/N = 35% (Truong et al., 1978). Agronomically, *P. reticulatum* is an indicator species of soil fertility (Zounon et al., 2019). Its capacity to grow in the dry season and the persistence of its leaves after harvest in the fields (Bationo et al., 2012) is a source of organic matter for improving soil fertility (Diakathé, 2014). The conventional practice (T6) was found to have no significant influence in improving soil organic matter, but it contributed instead, to decrease soil organic carbon in the fields where it was combined with the two organic resources (Figure 4). This decrease could be

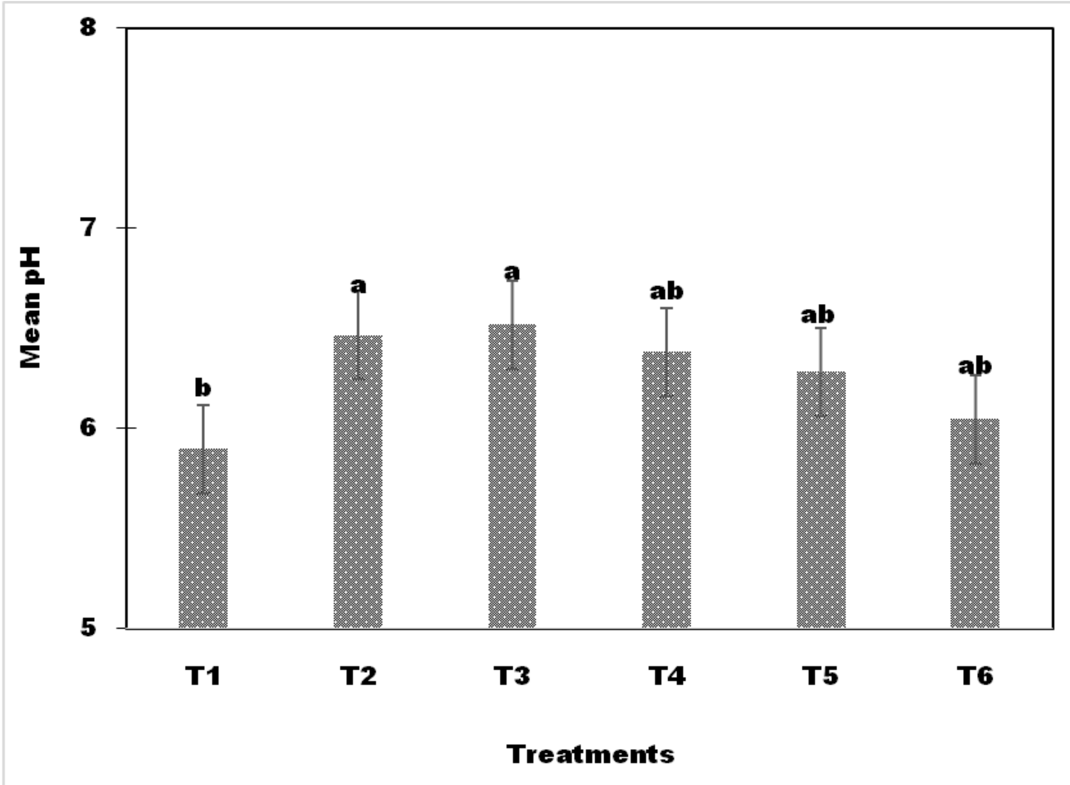

Figure 3: Soil pH as affected by the treatments

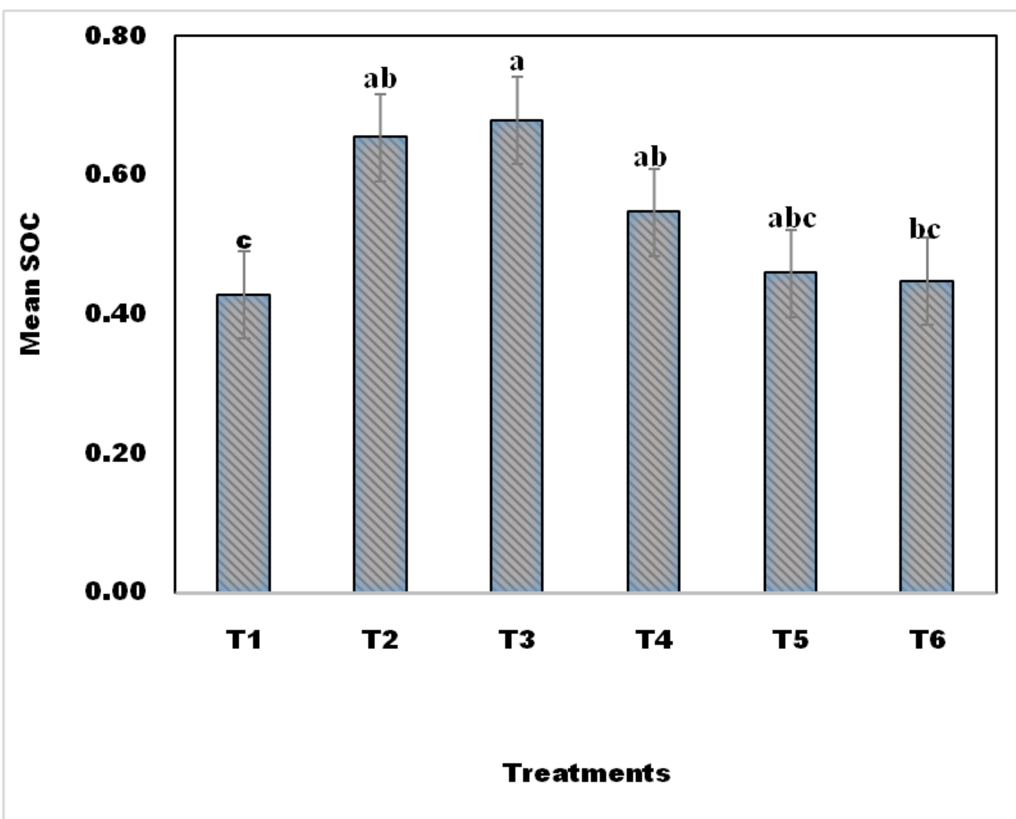

Figure 4 : Soil organic carbon as affected by the treatments

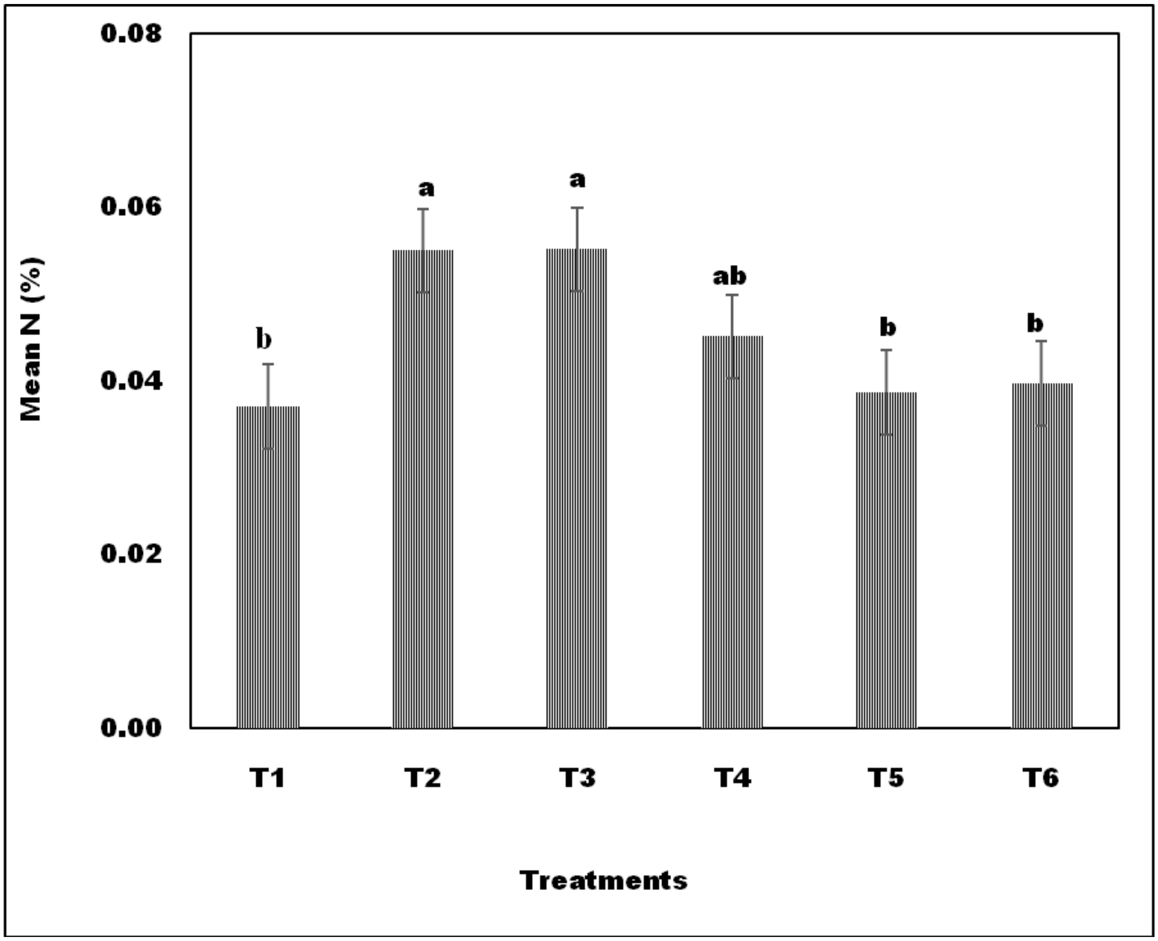

Figure 5 : Soil nitrogen as affected by the treatments

explained by the process of mineralization of soil organic C that was converted to soil nutrients for plants. Based on the literature review, the practices which increase soil organic carbon contribute also to improve soil quality and fertility (Saljnikov, 2013). Improving soil quality implies the improvement in soil structural stability by promoting aggregate formation which, together with porosity, ensure sufficient aeration and water infiltration to support plant growth (FAO, 2017b). From the practices used in this study, the application of the two organic materials in treatments T2 and T3 would therefore provide nutrients to enhance soil fertility and improve crop production.

T1 : control ; T2 : Simple Compost (SC) ; T3 : compost from *P. reticulatum* (CP) ; T4 : CS + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T5 : CP + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T6 : 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea ; the graphs with the same letters indicate that there is no significant difference among them.

Effect of managementpractices on soil nitrogen

From the management practices, the analysis of variance showed a significant influence (p<0.05) of the application of simple compost and *P. reticulatum* leaves compost on soil nitrogen (Figure 5). These two organic materials contributed to increasing more soil N by 29% compared to the control treatment. The improvement in soil total N was due to the mineralization of soil organic matter which was found by Ros et al. (2011) to play a dominant role in N mineralization as it serves as an easily accessible energy source for microorganisms.

Figure (5) also indicated that the conventional practices (T6) as well as the control (T1) did not contribute to increasing soil nitrogen. N, that was available in these two practices, was used for sorghum crop nutrition to produce grain yield (Figure 3). The result is in accordance with that of Ning et al. (2017) and Wei et al. (2016) where the single application of inorganic fertilizer was reported to reduce soil available N, P, K but increase crop yield.

This study also showed that by combining two composts with inorganic fertilizers (T4 and T5), there was a decrease in soil nitrogen (Figure 5). This decrease was linked to the mineralization process in the case of T4 where N was used for sorghum crop nutrition, and to N immobilization process in the case of T5 where N was immobilized to mineralize the organic matter from *P. reticulatum* leaves

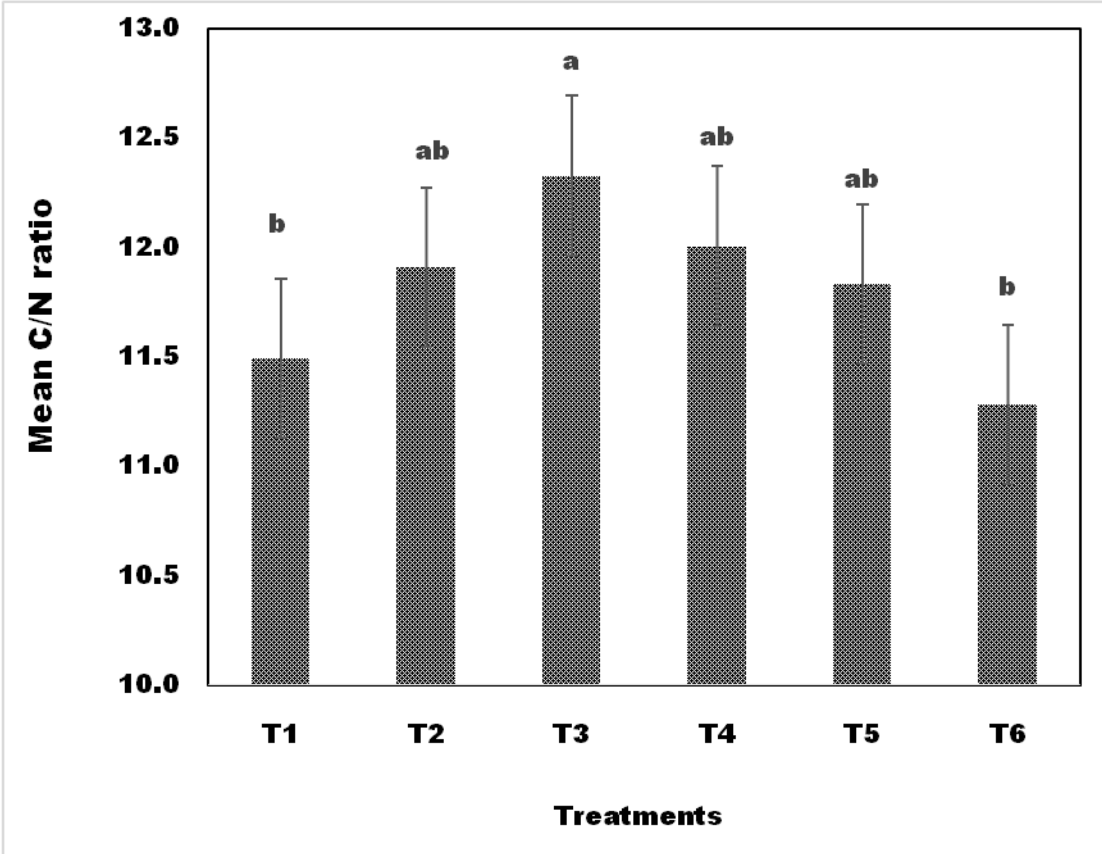

Figure 6 : Soil C/N ratio as affected by the treatments

compost. This result was confirmed by those of CILSS (2012) and Ba e al. (2014a) who highlighted these processes of minelization and immobilization of nitrogen.

T1 : control ; T2 : Simple Compost (SC) ; T3 : compost from *P. reticulatum* (CP) ; T4 : CS + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T5 : CP + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T6 : 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea ; the graphs with the same letters indicate that there is no significant difference among them.

Effect of management practices on soil C/N ratio

At this level of C/N ratio, the results revealed that C/N ratio was most significantly influenced (p<0,05) by the application of *P. reticulatum* leaves compost (Figure 6). Conventional practices (T6) and the control treatment showed the lowest values of C/N ratio. This is in accordance with the results found above with soil organic carbon and nitrogen. This result indicated the capability of soil under compost from *P. reticulatum* leaves compost to stock carbon and to regulate soil organic matter mineralization. According to Saljnikov (2013), the active fraction of organic matter has a C/N ratio between 15 and 30, indicating good reserves of partially decomposed organic matter, which are a substrate for micro-organisms and a source of mineralisable plant nutrients, particularly nitrogen. In the current study, apart from T3, which C/N ratio was above 12, all the other treatments had their values of C/N ratio below 12, highlighting the importance of N content in this treatment (Figure 6).

T1 : control ; T2 : Simple Compost (SC) ; T3 : compost from *P. reticulatum* (CP) ; T4 : CS + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T5 : CP + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T6 : 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea ; the bars represent the standards errors .

Effect of management practices on soil phosphorus

The effects of treatments on soil total P and available P are shown in Figure 7.

Concerning soil total P, a highly significant influence (p<0.05) was noted between the two composts in T2 and T3 with the other treatments. The most dominant influence was due to the application of *P. reticulatum* leaves compost and the lowest effect was due to the exclusive application of chemical fertilizers in T6 and the control T1. Soil P mineralization was increased when *P. reticulatum* leaves compost was applied to the soil. This mineralization was 3 times more induced by *P. reticulatum* leaves compost than by conventional practice and the control treatment. Also,

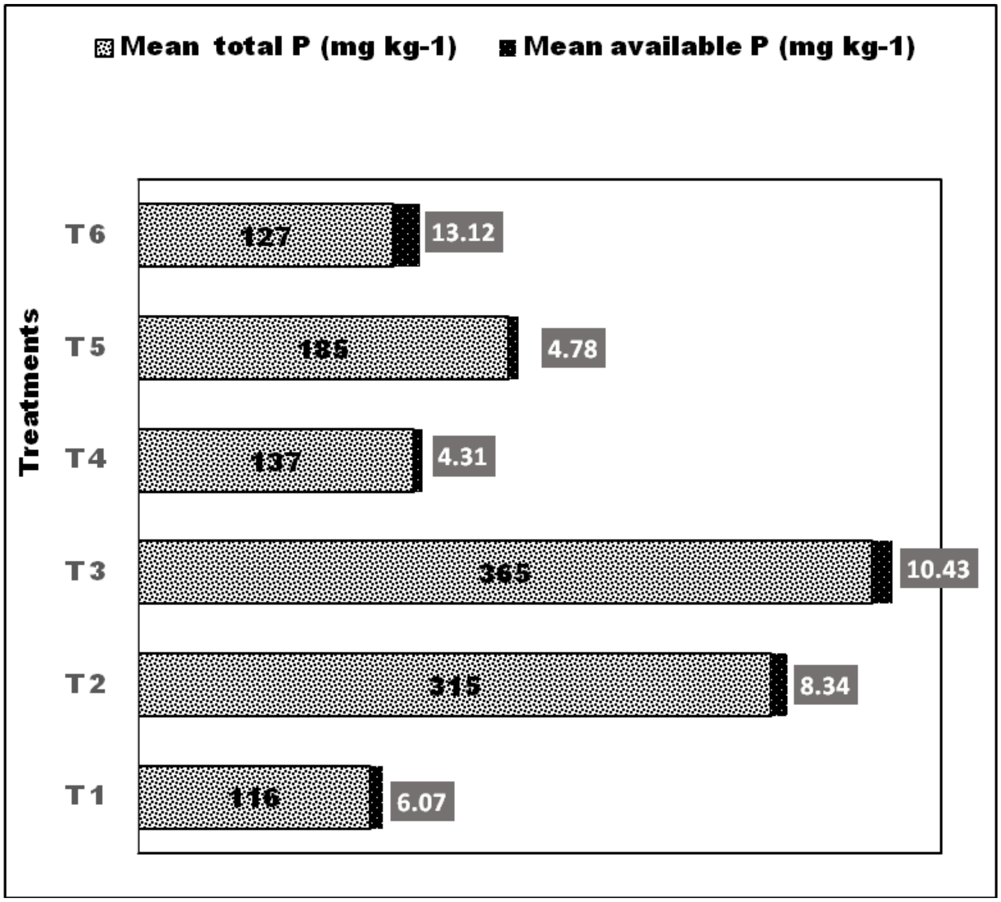

Figure 7: Soil P and P available as affected by the treatments

the reduction in P content induced by the combination effect is less important when *P. reticulatum* leaves compost is combined with NPK + urea than in the case where simple compost is combined with NPK + urea. The mineralization of P is therefore due to the nature of organic material. This result agrees with that of Wandruszka (2006) where it was reported that the short-term availability of P into the soil is strongly influenced by biochemical processes that affect organic matter, while its long-term status is generally determined by geochemical transformations.

Regarding availableP, the highest content was noted in conventional practice (exclusive use of inorganic fertilizer) and the lowest available P content were obtained in the practices combining organic and inorganic fertilizers (T4 and T5) (Figure 7). This decrease in available P content in the practices combining organic manures and inorganic fertilizers indicated its utilization by sorghum crop and therefore grain yield was most increased in these two treatments especially in T4 compared with the conventional practice (Figure 2). Some study especially that of Hafiz et al. (2016) found that it was a waste of P whenmore manure amendment is used to increase soil P. In such situation, less fertilizer would be needed to maintain P concentrations in soil solution.

T1 : control ; T2 : Simple Compost (SC) ; T3 : compost from *P. reticulatum* (CP) ; T4 : CS + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T5 : CP + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T6 : 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea.

Effect of management practices on soil Potassium

The effect of the management practices on soil total K and its availability are presented in Table 1 and Figure 8. The results showed that organic amendments incorporated in the soil affected soil total K and availability K in the single and combined applications. The highest increases in soil total K and available K contents were found with the application of *P. reticulatum* leaves compost (T3) and the application of simple compost combining with chemical fertilizers (T4). This result denoted the importance of using organic matter in agricultural soils as it improves their physical and chemical properties and was found by Usman et al. (2008) to play an important role in the redistribution of K among its various forms.

The treatment using exclusively NPK + urea (T6) is the one presenting the lowest values of total K and availableK. This is due to the degradation of soil organic matter known as a reservoir for soil nutrients in the soil where T6 was applied.

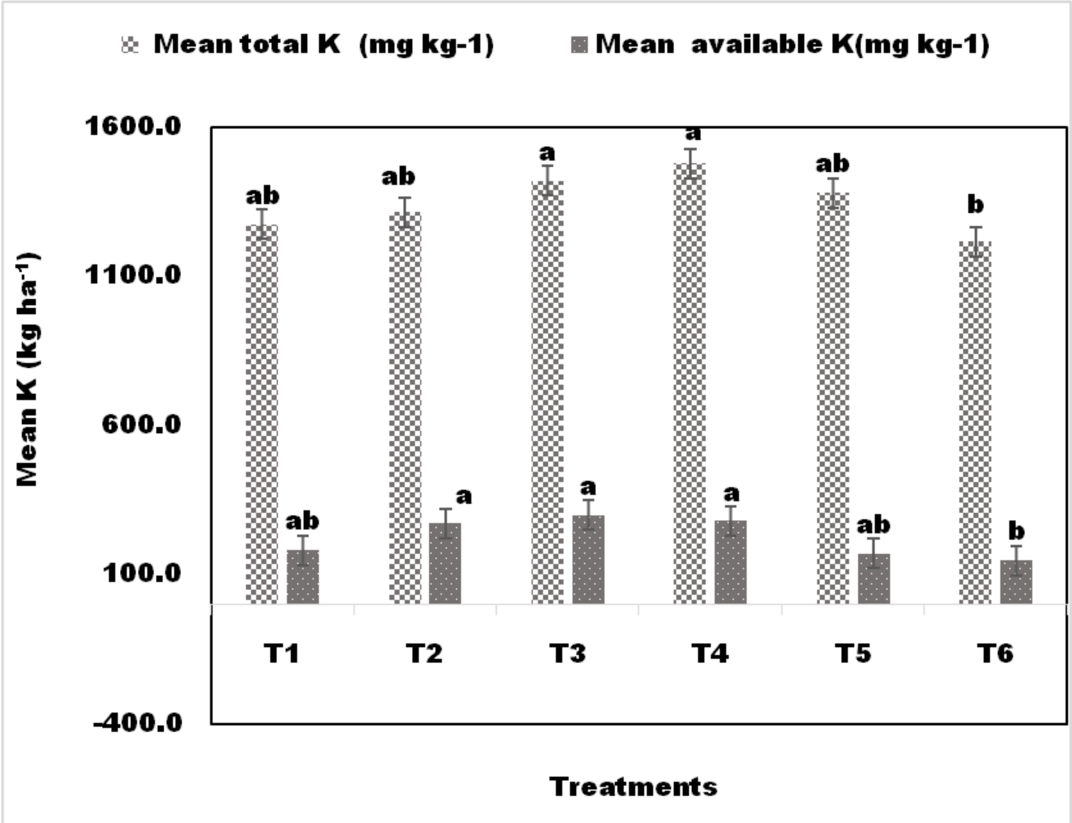

Figure 8 : Soil total K and available K as affected by the treatments

In addition to this degradation of soil organic matter, Bhatt et al. (2019) reported that continuous use of inorganic fertilizers alone causes soil acidity and environmental pollution.

T1 : control ; T2 : Simple Compost (SC) ; T3 : compost from *P. reticulatum* (CP) ; T4 : CS + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T5 : CP + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T6 : 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea ; the graphs with the same letters indicate that there is no significant difference among them.

Sustainable practice to improve and maintain soil organic matter into the soil

The effect of the six management practices on soil pH and nutrients content was statistically significant (p<0,05) (Table 2). According to the correlation analysis (Table 3), an exclusive use of NPK + urea in T6 has contributed to reduce soil organic carbon content, with a consequent decline in the agricultural soil quality (decline in the whole soil nutrients contents) and even an increase in soil acidification (reduction in pH value) (Table 3). The same result was obtained with the control treatment (T1) and the opposite effect was observed when the organic materials (T2 and T3) were incorporated in the soil. Soil pH and the whole nutrients contents increased significantly when *P. reticulatum* leaves compost has been incorporated compared to simple compost whose incorporation decreased slightly soil total K. In addition, under this incorporation of simple compost, the increase in available P content and the capability of soil to stock carbon and regulate soil organic matter mineralization (C/N ratio) were not significant (Table 3). The correlation analysis also showed that the combined application of organic and inorganic fertilizers (T4 and T5) decreased all major nutrients (total N, P and available P) of soil. Moreover, soil organic matter and carbon decreased significantly under the combined application of *P. reticulatum* leaves compost with NPK + urea (T5), whereas these soil organic carbon improvement were not significant under the combined application of simple compost with NPK + urea (T4). This study therefore showed the positive effect of the single application of organic materials in the soil compared to the combined application of organic and inorganic materials. The combination of *P. reticulatum* leaves compost with NPK+urea led to an immobilization process where soil N was immobilized to decompose soil organic matter. This decomposition would bring nutrients to the soil for future crop nutrition. But on the other hand, the combination of simple compost with NPK + urea led to a mineralization process where soil N mineralized was used directly by sorghum crop for high grain yield. The decrease in soil

Table 3. Correlation among treatments and soil properties

Variables	T1	T2	T3	T4	T5	T6	pH	pHKCl	SOC	SOM	N-total	C/N	P-total	P avail	K-total	K avail
T1	**1**															
T2	-0.20	**1**														
T3	-0.20	-0.20	**1**													
T4	-0.20	-0.20	-0.20	**1**												
T5	-0.20	-0.20	-0.20	-0.20	**1**											
T6	-0.20	-0.20	-0.20	-0.20	-0.20	**1**										
pH	**-0.43**	**0.23**	**0.29**	0.13	0.02	**-0.25**	**1**									
pHKCl	**-0.38**	**0.21**	**0.34**	**0.27**	-0.12	**-0.32**	**0.91**	**1**								
SOC	**-0.36**	**0.40**	**0.48**	0.04	**-0.26**	**-0.29**	**0.54**	**0.71**	**1**							
SOM	**-0.36**	**0.40**	**0.48**	0.04	**-0.26**	**-0.29**	**0.54**	**0.71**	1.00	**1**						
N-total	**-0.36**	**0.44**	**0.44**	0.00	**-0.28**	**-0.24**	**0.47**	**0.64**	**0.98**	**0.98**	**1**					
C/N	**-0.23**	0.07	**0.38**	0.14	0.02	**-0.38**	**0.55**	**0.64**	**0.59**	**0.59**	**0.44**	**1**				
P-total	**-0.34**	**0.40**	**0.58**	**-0.26**	-0.08	**-0.30**	**0.52**	**0.62**	**0.66**	**0.66**	**0.62**	**0.48**	**1**			
P avail	**-0.14**	**0.04**	**0.21**	**-0.29**	**-0.25**	**0.43**	**-0.19**	**-0.09**	**0.13**	**0.13**	**0.12**	**0.10**	**0.37**	**1**		
K-total	**-0.22**	-0.10	**0.22**	**0.39**	0.10	**-0.39**	**0.63**	**0.72**	**0.29**	**0.29**	**0.20**	**0.44**	**0.37**	-0.18	**1**	
K avail	**-0.21**	**0.23**	**0.36**	**0.26**	**-0.26**	**-0.38**	**0.66**	**0.86**	**0.60**	**0.60**	**0.55**	**0.45**	**0.63**	-0.02	**0.78**	**1**

The bold values indicate that the correlation is significant at the 0.05 level of probability
T1 : control ; T2 : Simple Compost (SC) ; T3 : compost from *P. reticulatum*(CP) ; T4 : CS + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T5 : CP + 50 kg ha^{-1} of NPK + 25 kg ha^{-1} of urea ; T6 : 100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea.

organic C and nutrients content under NPK + urea and the control treatments was due to the degradation of soil organic matter known as a reservoir for soil nutrients and an element to increase soil pH. Numerous studies have also shown that balanced application of inorganic and organic fertilizers can increase soil organic matter and maintain soil productivity. According to Han et al. (2016), most studies in agricultural fields have reported that the combined application of chemical and organic fertilizers decreases the damage that can be induced by chemical fertilizers and improves crop productivity. Furthermore, Ning et al. (2017) added that taking into account the advantages and disadvantages of organic and inorganic fertilizer, their combined application has become an effective approach to nutrient management. They also noted that incorporation of organic fertilizers can improve inorganic fertilizer use efficiency. The combined use of inorganic fertilizers and organic manure is therefore necessary for increasing crop yield, as well as maintaining adequate soil fertility and soil buffering capacity.

CONCLUSION AND RECOMMENDATIONS

The main objective of this study was to identify the best management practice applicable to organic manures and inorganic fertilizers for a sustainable production. From the results, we found that the incorporation of organic manures into the soil increased significantly soil pH and the whole nutrients contents. The combined application of organic manure and inorganic fertilizers decreased soil organic C and all major nutrients (total N, P and available P) but it contributed to increase significantly sorghum yield mainly under the combined application of simple compost with NPK + urea. Numerous studies have shown that appropriate application of inorganic and organic fertilizers can increase soil organic matter and maintain soil productivity. Therefore, this study ought to be taken further to identify the suitable practices which will allow the organic matter from *Piliostigma reticulatum* leaves compost to be immediately usable by crops, particularly sorghum, for high yield production. For this reason, researches are needed and funding should be available to support researchers. For taking into account the sustainability of production systems in agricultural policy, it is the responsibility of policy decision-makers to take their responsibilities.

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Conflict of interests

The authors declare that they have no conflicting interests.

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