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Impact of Compost on Soil Properties and Crop Productivity In the Sahel North Burkina Faso

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Abstract: Lack of adequate nutrient supply and poor soil structure are the principal constraints to crop production under low input agriculture systems of West Africa. Experiments at two sites (Mediga and Yimtenga) were conducted in Burkina Faso to assess the impact of compost to improving crop production and soil properties. In the first experiment, compost was applied at the rate of 0 and 10 ton ha^{-1} in Mediga on a Ferric Lixisol and 5 and 0 ton ha^{-1} on a ferric-gleyic Lixisol in Yimtenga. A second experiment was conducted in Yemtenga to assess the role of compost in mitigating the effect of delay in sowing on crop performance. 0 and 5 ton ha^{-1} compost plots were sown within the normal period for sowing sorghum (*Sorghum bicolor* L. Moench) and with a delay of 1 month. A randomized block design was used with four replications for the two experiments. Semi-structured interviews were used to study socio-economic issues of compost technology. No significant difference in soil organic matter content was found between treatments receiving compost and no-compost. However, compost application increased soil cation exchange capacity (CEC) from 4 to 6 cmol kg^{-1}. Soil pH was also increased by the compost application. Sorghum yield tripled on the 10 Ton ha^{-1} compost plots and increased by 45% at a rate of 5 ton ha^{-1}compost plots, compared to no-compost plots. Compost application mitigated the negative effects of a delay in sowing. The study showed that farmers were aware of the role of compost in sustaining yield and improving soil quality. However, lack of equipment and adequate organic material for making compost, land tenure and the intensive labour required for making compost are major constraints for the adoption of compost technology. It was concluded that compost application could contribute to increase food availability in the Sahel and therefore, efforts should be made to alleviate the socio-economic constraints to the adoption of compost technology.

Key words: Soil properties · Compost · Crop performance · On-farm experiments · Burkina Faso

INTRODUCTION

Frequent dry spells and soil degradation leading to subsequent yield decline are key agriculture problems in the Sahel [1] and they are responsible for frequent food shortage in the region. Pieri [2] analysed the evolution of soil fertility status in continuous cultivation system of the Sahel and suggested that soil organic matter management could be a key element for alleviating soil degradation. Soil organic matter plays a key role in the soil system and is an important regulator of numerous environmental constraints to crop productivity. Soil organic matter is a major source of plant nutrients [3] and improves physical properties of soil, such as soil porosity, structure and water-holding capacity [4]. Soil organic matter management is therefore very important for the development of sustainable low-input agriculture system and for the improvement of soil quality [1]. The extent to which organic matter contributes to soil quality depends on factors such as organic material quality, soil fauna activity and environmental conditions [4, 6, 7]. In the soils of the Sahelian zone, the inherent low content of active clay makes soil organic matter a key element, which can alleviate soil degradation and improve crop production in low-input agriculture systems [8].

In many cropping systems of Sahelian zone, little or no crop residue is returned to the soil. This leads to a decline in soil organic matter content and subsequently a decline in crop yields, biomass production and therefore results in environmental degradation [9, 10]. Other studies, has been conducted in this zone to ascertain the role of soil organic matter in improving soil quality and in sustaining crop production [11, 12]. Due to the lowest decomposition rate of organic material and low fertility

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status of the soils, especially low phosphorous content, it is recommended that organic resources be first composted to increase nutrient availability and decrease the C:N ratio before application in the field[13].

In semi-arid regions, there is still a need to search for means to optimizing the impact of compost on crop production as little on-farm research has been done in the Sahel to study its effect on crop performance under farmers conditions. Furthermore, indigenous knowledge on soil organic matter management in the region is not well known. For these reasons, participatory on-farm research was conducted to study the influence of compost on soil properties and on crop performance. Socio-economic constraints to the large-scale adoption of compost technology in the region were also examined.

MATERIALS AND METHODS

Site Description: Burkina Faso is a tropical country located in the Sahelian zone. The climate ranges from sub-arid to sub-humid [14]. The study was conducted from 2007 to 2008 in the southern part of Burkina Faso between 11° - 12° N, 0°30' -0°50'w.

A survey on socio-economic aspects of compost was done in the two villages where the experiment was conducted, Yimtenga and Mediga and in three other nearby villages. The climate is a south Soudanian type according to Guinko [15]. Rainfall is monomodal and typically occurs for 4 months from June to September. It is irregularly distributed in time and space. The mean annual rainfall is 924 mm [16, 17].

The dominant soil types are Lixisols and Cambisols [18]. The first experiment was conducted on a ferric Lixisol in Mediga (M) site. The topsoil (0-20 cm) has a pH of 6-8 and cation exchange capacity (CEC) ranging from 4 to 5 cmol kg^{-1}. The textural class is loamy-sand (6% clay, 22% silt and 72% sand) for the 0-20 cm horizon and sandy-clay-loam (16% clay, 22% silt and 62% sand) at 40 cm. The second experiment in Yimtenga (Y) was conducted on Ferri-gleyic Lixisol with a pH of 6.8-7.6 and a CEC of 4.4 to 4.8 cmol kg^{-1} in the topsoil. The textural class was loamy-sand (8% clay, 18% silt and 74% sand) for the 0-38 cm horizon and sandy-clay-loam (16% clay, 18% silt and 66% sand) after 38 cm. The main land degradation types in the two villages are nutrient depletion and water erosion.

The Natural Vegetation Consists Of:

- Open woody savannah. The woody vegetation is mainly dominated by *Parkia biglobosa*, *Vitellaria paradoxa* and *Tamarindus indica*.
- Dense woody savannah along the rivers and dominated by *Terminalia sp*., *Anogeisus leiocarpus* and *Borassus aethiopium.*
- Dense herbaceous savannah dominated by *Loudetia togoensis*, *Pennisetum pedicellatum andropon sp*., *Vetiveria nigritana*.

Experimental Design: Participatory on-farm experiments were conducted using a randomized block design with four replications at two sites. Plot size was 5m x 5m with guard rows of 2m. Data was collected in 2008. Rainfall during this year was 890 mm which is close to the mean rainfall of the last decade. The treatments were application of compost at rates of 0 and 10 ton ha^{-1} at the Mediga site and application of compost at rates of 0 and 5 ton ha^{-1} at the Yimtenga site. A second experiment was conducted in Yimtenga site to assess the potential role of compost in mitigating the effect of a delay in sowing. The treatments were no-compost (0 ton ha^{-1}) sown at the normal period for sowing sorghum and compost plots (5 ton ha^{-1}) and no-compost plots sown with a delay of 1 month. A randomized block design with four replications was also used for this experiment.

Compost Production: The preparation of compost was done in two steps using selected household refuses, animal manure, crop residues and ashes as composting material. The first step, which takes place during the rainy season, consists of putting the organic materials in pits for aerobic decomposition. The organic materials were progressively added depending on their availability in the household. The pit size was 3m x 3m x 1.20 m. During this first step, water from rainfall was enough to maintain required moisture in the decomposing material. In the second step, which takes place during dry season, the decomposing material in the pits is placed into heaps for further decomposing. The heaps were built with successive stratums of decomposing material derived from the pits. In addition, grasses were added to increase the availability of carbon as an energy source for decomposer microbes in the decomposing material and also to increase the quantity of the compost. The mean size of the heaps depended on the quantity of available material. Farmers used heaps of 3m x 3m x1m size. The heaps were watered every week. The average C: N ratio of the compost was 12, its average carbon content was 160 g kg^{-1} and its pH was about 7.

Crop and Soil Management: Farmers were in charge (under the supervision of the program) of the compost production, of plot selection and for all farming operations. Compost from one heap was used for all experiments. Compost was spread in the field and ploughed in before sowing. Local variety of sorghum (*Sorghum bicolor* L. Moench) Zuguilsi was sown at the rate of 32,000 seeds $ha^{-1}$for all experiments. The choice of this sorghum variety was made by the farmers in order to measure compost impact on local resources. During the growing season, the field was weeded three times using hoes. Crops were harvested 16 weeks after sowing. For the first experiment, sorghum was sown after the first rain (16 May) and 1 month later for the second experiment, which was concerned with the effect of delay in the date of sowing on sorghum performance.

Data Collection: Morphological description of soil profiles was done after harvest in all the plots using FAO-UNESCO [19] methodology. Four soil samples were taken from each sub-plot and pooled as a composite soil sample during the growing period (at flowering) and after harvest for chemical analysis. Soil properties were measured using methods proposed by Anderson and Ingram [20]: carbon content of soil with Walkley Black method and by incineration for estimation of carbon in the compost; nitrogen content after Kjeldahl method; phosphorus by atomic absorption spectrophotometry; and potassium content using flame photometry. Soil pH was measured in water and KCl using an electronic pH meter. CEC was measured using a displacement method and exchangeable ions measured using flame photometry and absorption spectrophotometry. Yield components were also measured (e.g., grains, straws, 1000 grains weight, number of grains per panicle). Sorghum dry matter and grain yield data were obtained by sun drying and weighing. The 1000 grains weight was obtained using electronic grain counter and an electronic balance. Rainfall amount was recorded using a rain gauge placed at Mediga. All the data was subjected to ANOVA to show the significance of the differences using the student Newman Keuls test [21].

Socio-economic Issues: The first objective of the survey was to obtain information on the state of the art of compost management at household level. Semi-structured interviews involving 150 farmers were conducted in six villages having the same cropping system (Gomboussougou, Kourouga, Taya, Tiéré, Yimtenga and Mediga). The survey focused on the reasons why farmers adopt compost technology, on the constraints of compost production, on which crop farmers use compost and the impact of compost on soil and crops yields. Land tenure and gender issues were also examined.

RESULTS

Morphological and Biological Characteristics of the Soil: In the horizon (0-20 cm), color of the soil was light brownish grey (10YR6/2) in the 0 ton ha^{-1} plots, but brown (10YR5/3) in the plots receiving compost at both 5 and 10 Ton ha^{-1} (data not shown). The soil consistence was hard in the no-compost plots and crumbly in plots receiving compost. There were many voids made by soil fauna down the soil profile in the plots receiving compost, but few in the top 30 cm in the profile of no-compost plots. Earthworms galleries were observed in the topsoil of the plots receiving compost. Many thin and medium size roots were found in the soil profile receiving compost, but few were found in the no-compost plots.

Soil Chemical Properties: At flowering and 3 months after harvest, no significant difference in soil organic carbon content (ranged from 5 to 9 g kg^{-1}) was noted between compost and no-compost plots (data not shown). In all the compost plots, an increase of soil pH was noted compared to the no-compost plots (Table 1). The pH (H_2O) in the compost plots was neutral to slightly alkaline for the surface horizons and slightly acidic to neutral for deeper horizons. Soil CEC was increased in plots receiving compost. The difference in CEC was significant between 0 and 10 ton ha^{-1} compost rates, but no significant difference was observed between 5 and 0 ton ha^{-1} compost plots. At flowering, there was no difference in nitrogen, phosphorus and potassium content of the soil between the compost and no-compost plots. At harvest, the nutrient content increased (data not shown) in all the plots and this increase was higher in plots receiving 10 ton ha^{-1} of compost.

Grain Yield: At 5 ton ha^{-1} compost plots at Yimtenga, an increase of 45% of grain yield was noted compared to no-compost plots (Table 2),while the grain yield was higher at composted plots (10 ton ha^{-1}) by 19 % than no-compost at the Mediga site (Table 3). At both the sites, grain yield and dry matter production were significantly different among treatments (Tables 3 and 4). Furthermore, crop yield index was lower in the no-compost than in the compost Plots, especially at the 10 ton ha^{-1} rate. This suggests that nutrient availability during crop maturing stage was higher in these receiving compost plots. Significant differences was also noted for the number of grains per panicle, however, there was no significant difference in 1000 grains weight between receiving compost plots and no-compost plots.

Table 1: Effect of compost on topsoil (0-20 cm) chemical properties at flowering[a]

Site/treatment	pH (H_2O)	pH (KCl)	CEC (cmolkg-1)	N (g kg^{-1})	P(g kg^{-1})	K(g kg^{-1})
Yimtenga, compost (5 Ton $ha^{-1)}$	7.5 ± 0.6	6.4 ± 1.0	4.9 ± 2.4b	0.3 ± 0.1	1.0 ± 0.0	5 ± 0.1
Yimtenga, no-compost (0 Ton ha^{-1})	6.7 ± 0.0	5.4 ± 0.3	4.1 ± 0.1b	0.3 ± 0.0	1.0 ± 0.0	5 ± 0.1
Mediga, compost (10 Ton ha^{-1})	7.4 ± 0.6	6.6 ± 1.2	6.1 ± 1.0a	0.3 ± 0.1	1.3 ± 0.0	5 ± 0.1
Mediga, no compost (0 Ton ha^{-1})	6.8 ± 0.2	5.6 ± 0.4	4.7 ± 1.0b	0.5 ± 0.0	1.0 ± 0.2	5 ± 0.1

[a] ±S.D. Treatments having the same letters within a column are not significantly different with the Newman Keuls Test at 5%

Table 2: Effect of compost application on sorghum yield components (5 ton ha^{-1}) at the Yimtenga site [a]

Treatments	Grains yield (kg ha^{-1})	Number of grains/panicle	1000 grains weight (g)	Straw dry matter (kg ha^{-1})	Yield index
Compost (5 ton ha^{-1})	1689a	4213a	25.5a	5145 ± 777	0.3
No compost (0 ton ha^{-1})	1160b	2035b	23.2a	4450 ± 1415	0.3

[a] ±S.D. Treatments having the same letters within a column are not significantly different with the Newman Keuls Test at 5%

Table 3: Effect of compost application on sorghum yield components (10 ton ha^{-1}) at the Mediga site [a]

Treatment	Grains yield (kg ha^{-1})	Number of grains/panicle	1000 grains weight (g)	Straw dry matter (kg ha^{-1})	Yield index
Compost (10 ton ha^{-1})	1380a	4213a	25.5a	5145 ± 777	0.3
No compost (0 ton ha^{-1})	1160b	2035b	23.2a	4450 ± 1415	0.3

[a] ±S.D. Treatments having the same letters within a column are not significantly different with the Newman Keuls Test at 5%

Table 4: Impact of compost on crop yield in second experiment at the Yimtenga site as influenced by the date sowing [a]

Treatments	Sowing date	Grains yield (kg ha^{-1})	1000- grains weight	Straw yield (kg ha^{-1})	Yield index
No compost (0 ton ha^{-1})	1 month delayed	87a	16.4a	1575a	0.06a
No compost (0 ton ha^{-1})	Normal sowing	997b	23.2b	4703b	0.21b
Compost (5 ton ha^{-1})	1 month delayed	1853c	24.0b	7763c	0.24b
Compost (5 ton ha^{-1})	Normal sowing	1689c	25.5b	5660d	0.30c

[a] Treatments having the same letters within a column are not significantly different with the Newman Keuls test at 5%

Compost and the Effect of a Delay in Sowing: One month delay in sowing resulted into a sharp decline in crop yield in no-compost plots, compared to those plots receiving compost. In the latter, yield was not influenced by this delay (Table 4). However, there was no significant difference in yield between plots receiving compost sown with a delay of one month and plots receiving compost plots sown at the normal time period.

Socio-economic Data: Three composting methods were used in the area (in heaps, in pits and heaps with maturing phase in pits). Most vegetable growers used an aerobic composting technique (where the compost is prepared in heaps only). With this technique, mature compost could be obtained after only 2 months. This technique requires a lot of water but as vegetables are grown in irrigation system, water which is a key element in aerobic composting method is not limited. However, farmers in rainfed agriculture system produce their compost in pits or produce it in two steps (first in pit and then heaps). The survey revealed that most of the farmers adopted compost technology because of the lowest fertility status of their soils and because of yields decline in their fields (Table 5). Farmers argued that indeed.

The traditional practice of fallow which allows organic matter and nutrient accumulation becomes inefficient to meet the adequate food supply for the growing population. The highest cost and the inaccessibility of chemical fertilizers were major causes of adoption of compost. Some of the farmers who produce vegetables have access to credit to purchase fertilizers, but they cannot pay back their income. Some farmers (26%) adopted compost technology after they had witnessed the experience of other farmers. Other main constraints for the adoption of compost technology mentioned by the farmers are the following.

- Land tenure is an important factor, which influences the adoption of compost technology (mainly for women and young people). The production of compost requires investment in time, organic resources and labour, therefore, people are not always prepared to invest in a soil they are not sure to keep for a time long enough for them to get the maximum benefit of their investment.

Table 5: Reasons for compost technology adoption by farmers

Reasons	Farmers opinions (%)
Low fertility of soil and decrease in soil yield	58
Inaccessibility of chemical fertilisers	16
Motivated by the results of the others	26

Table 6: Crop type and the use of compost by the farmers

Crop type	Farmers opinions (%)
Vegetables	10[a]
Red sorghum	38
Millet	7
Maize	41
Rice	3
Others	1

[a]Ten percent of the surveyed farmers applied compost on the vegetable gardens, but 98% of the farmers who grow vegetables applied compost on their garden

- Some farmers cannot afford to buy equipment such as pickaxes, wheelbarrows and carts, which are of tremendous importance in compost production and management.
- The production of compost requires intensive work and this jeopardizes the adoption of the technology especially by small households.

The question of where farmers allocate the compost is a complex one. In general, farmers prefer to put the compost on the fields where they grow high nutrients demanding crops such as maize (*Zea mays* L.) or red sorghum (Table 6). Socio-economic considerations also determine where the farmers put their compost. Crops such as red sorghum also have priority because farmers need them for their religious or cultural events. When the farmer supplements cereal production with vegetables, the latter always have priority in the allocation of the compost compared to cereal because of their higher market value.

DISCUSSION

Soil Morphology and Structure: The morphological observations of soil pits revealed a better soil structure with many voids and well developed aggregates having various sizes in receiving compost plots than in no-compost plots. Some voids were related to the activities of soil fauna (termites and earthworms).

Soil Organic Matter and CEC: The lack of change in soil organic matter content between plots receiving compost and no-compost plots confirms the lowest rate of carbon sequestration in the tropics, especially in sandy soils [10]. However, CEC, which is linked to soil organic matter, was higher in 10 ton ha^{-1} compost plots than no-compost plots. This suggests that soil organic matter had increased to some degree, although not measurable with the methodology used in this study. Rider and Van Keulen [22] established that an increase of 1 g kg^{-1} of organic carbon in Sahelian soils leads to an increase of 4.3 mol kg^{-1} of CEC.

Nutrients and Crop Yield: Sorghum dry matter production, grain yield and sorghum yield index were higher in composted plots. This is consistent with the results of on-stations research [23]. Moreover, the type of soil is important in determining the response of crop to compost. In Ferric Lixisol (shallower soils the application of 10 ton ha^{-1} produced a lower yield than 5 ton ha^{-1} in Ferri-gleyic Lixisol (deeper soil). The application of compost not only increased yields but also mitigated the negative effect of a delay in sowing, which would be beneficial in the Sahel [24]. The increase of moisture and nutrient availability might be the key elements in mitigating the negative effect of a delay in sowing.

Farmers Response: Farmers were well aware of the role of compost in sustaining yield and improving soil quality. Nevertheless, 26% of the farmers in the study area adopted the practices after they had witnessed the experience of other farmers illustrating the key role in extension of on-farm research, furthermore, many constraint were reported to impede the spread of the technique. It was noticed that lack of tools was a constraint to compost production and therefore, a facilitation policy (credits system and/or subsidization) is needed to allow farmers to increase the production of compost. The fund should be directed towards the acquisition of equipment for transport and also towards the acquisition of rock phosphate (available in Burkina Faso) to improve the quality of the compost. However, the main constraint of compost production is the lowest availability of organic material. In some regions of the Sahel, crop residues are totally removed from the fields and used as building materiel and fodder for livestock [24]. However, in the Soudanian zone, every year more than 6 ton ha^{-1} of organic material is lost through fire [25]. In order to solve the problem of non-availability of organic resources for making compost in the Sahelian zone, the integration of animal husbandry and crop farming should be achieved to ensure judicious management of organic resources for both animal production and soil management[26]. Such integration has an additional benefit, which is the strengthening of the social relation between farmers and livestock keepers. In the Soudanian zone, solving this problem requires proper fire management to alleviate the effect of fire on the loss of organic material. Another constraint mentioned by farmers is that the production of compost requires intensive labour, which jeopardizes the adoption of the technology by small households. To alleviate the labour constraint, farmers have created village level groups for mutual support for the heavier tasks like opening pits. Such groups need to be strengthened and structured.

CONCLUSIONS

Compost amendment improves soil morphological and chemical properties. Soil organic matter was not significantly influenced by the compost application in this short-term on-farm experiment. Long-term experiment is necessary to show such an effect. However, the application of compost results in a significant increase in crop production and mitigates the negative effect of a delay in sowing. The use of compost, therefore, is a sound technology for combating soil poverty in the Sahel. However, socio-ecological constraints need to be mitigated in order to increase the adoption of compost technology at a large scale. These constraints include land tenure security and lack of credit for investment in soil management.

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