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Differences in smallholder farmers' compost pits in terms of production and quality across Burkina Faso: The case of Eastern Region

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Sub Saharan African soils have low organic matter contents, hence applying compost is therefore instrumental to improve their fertility. This study investigated the quantity and the quality of compost produced by smallholder farmers in five provinces (Gnagna, Gourma, Komondjari, Kompienga and Tapoa) from Eastern Burkina Faso. Compost quality was determined by the main physical and chemical characteristics including bulk density, pH, organic matter (OM), carbon-to-nitrogen ratio (C/N), total-N and -P contents. The principal component analysis indicated that compost issues were specific to each province. Compost production per pit was higher in Kompienga (4.2 t/pit) as compared to Tapoa (2.9 t/pit) and Komondjari (2.1 t/pit). OM content and C/N were each negatively correlated with total-N, total-P and pH. The lowest OM content, of 16%, was recorded in Kompienga while the highest, nearly the double, was found in Gnagna. The C/N ratio was highest in Gnagna (21.4) as compared to the other provinces (11-18). The total-N content (8.5-9.6 g/kg) and total-P (2525-5068 mg/kg) were similar among provinces. The pH of all composts was alkaline and ranged between 7.7 and 8.9. With regards to the physical and chemical characteristics, these composts could be qualified as good quality, mature and stable composts.

Key words: Bulk density, compost quality, chemical characteristics.

INTRODUCTION

Sub Saharan African soils have low organic matter content, which limits the efficiency of inorganic fertilizer and soil productivity. Under such conditions, applying organic amendments such as compost or manure is seen as instrumental in improving and sustaining soil health and fertility (Adams et al., 2020). For instance, in West Africa, there is a growing interest in organic inputs and research recommends an application rate of 5 tha^{-1} every

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2 years. However, the availability of adequate quantity of organic amendment is a challenge and can be achieved through developing and implementing sound policies for organic amendment production. In Burkina Faso, an endeavor towards this goal is the initiative of compost manufacturing on a large scale, which has been promoted when the national policy “One rural family, one compost pit” was launched in 1986 (Ganry et al., 2001). Subsequently, there was the launch of another programme « manure pits development » in 2001 which aimed to promote the production and use of manure for the sustainable management of soil fertility. The target was to build 2 billion manure pits and produce 20 billion tons of manure (Zongo, 2011).

Furthermore, the use of compost accelerator to reduce the composting time was encouraged to make it possible to produce compost twice a year which supposes that each compost pit will produce 5 tons of manure within the period.

Consequently, many actors including NGO’s, Projects and Government Research Centres that promote their own compost pit types and composting process have led to various compost pit types and different quantity and quality of compost in the same geographic location.

Indeed, smallholder farmers are using diverse raw materials, additives, household refuses, and processing which might induce high variability in the compost quantity and quality. Usually, farmers assessed the maturity and the quality of the compost only by physical characteristics such as color, odor, and temperature. Other robust characteristics not affordable to these smallholder farmers include physical properties such bulk density and chemical properties such as pH, C/N ratios, and primary nutrient contents (Palm and Rowland, 1997). Numerous factors influence the quality of compost, which include the quality of the raw material mostly defined by its C/N ratio, composting processing such as the type of pits (Bissala and Payne, 2006), the size of material, aeration, moisture content, temperature, the turning frequency, the additives (Last, 2006).

In Burkina Faso, numerous works on compost and farmyard manure do exist. However, most studies have dealt with the effect of their application on soil health and crop performance. Hence, compost produced under researchers supervision indicated the following chemical characteristics (mean ± stdev) C/N:15.5±4.7; OM (%): 38.0±18.8; Total-N (g/kg): 14.9±5.6; total-P (mg/kg): 7254±7855; and pH: 7.4±0.5 (Gnankambary 2007; Lompo et al., 2009; Koulibaly et al., 2015; Soma et al., 2017). There is then a paucity of information related to compost quality and quantity from smallholder farmers. Indeed, a few studies have reported an average 3.1 tons dry matter compost production per pit (Zongo, 2011).

In addition, a few on-station research studies indicated the potential compost production of 0.9-1.4 tons dry matter per pit (Zougmoré et al., 2000; Blanchard et al., 2012). However, none of these studies reported the quality of the final matured compost. Also, there is currently no information on physical (bulk density) and chemical characteristics of composts produced on a large-scale basis by smallholder farmers. This has triggered an increasing debate about the quantity of compost that can be produced per compost pit as many actors and farmers stipulated that compost from a single pit is enough to amend one ha of field at the recommended rate of 5 t ha^{-1} every 2 years. The authors therefore undertook this study with the objective to determine compost quantity and quality from smallholders’ compost pits in Burkina Faso. This was done by determining the physical and chemical characteristics of composts produced by smallholder farmers, mainly through analyzing bulk density, pH, organic matter content, total-nitrogen, total-phosphorus contents and carbon-to-nitrogen ratio. We hypothesized that compost characteristics and quantity may differ among smallholder farmers as the quality of the raw material used and compost processing differ.

MATERIALS AND METHODS

Study area

The study was conducted in the Eastern Region of Burkina Faso (10°45’- 13°35’N and 2°20’E-0°30’W) covering five provinces Gnagna, Gourma Komondjari, Kompienga, and Tapoa. The region is characterized by three climatic types: the South sahelian climate with annual rainfall between 400mm and 600 mm covering the provinces of Gnagna and Komondjari; the North soudanian climate with annual rainfall ranging between 600 mm and 900 mm in the province of Gourma, and the South Soudanian zone with an annual rainfall between 900 mm and 1200 mm covering the provinces of Kompienga and Tapoa. The average minimum and maximum temperature are 16°C and 41°C respectively. Soil resources are mainly lixisols, regosols, plinthosols and gleysols, which have low soil organic matter and nutrients, contents (BUNASOLS, 2008). The main crops cultivated in the region are cotton, groundnut, millet and sorghum.

Farmers’ selection and survey

An existing framework of the Research -Action village sites was used to conduct this study at the beginning of the cropping season. In this study period, many farmers involved in the project had already emptied their compost pit and brought their compost to the field. A total of 72 farmers (25 in Gnagna, 9 in Gourma, 7 in Komondjari, 8 in Kompienga, and 23 in Tapoa) still having compost in their pits were selected to conduct the study. We first characterized the compost pit by determining the type of pit (stabilized or traditional), the dimensions of the pit and the filling percentage of the pit. Then, Farmers were questioned on the compost production techniques such as raw materials used (crop residues, livestock dung and farmyard manure, grasses, rock phosphate, urea) and the frequency (number of times) of watering and overturning. Dry raw materials used by farmers composting included crop residues, livestock dung and farmyard manure, household wastes and grasses in various proportions (Table 1).

Table 1. Dry raw ingredients used for composting (expressed as number and percentage of carts per pit) and number of watering and overturning during the compost processing.

Parameter	Gnagna	Gourma	Komondjari	Kompienga	Tapoa
Raw materials as carts per ingredient and (% of each ingredient in compost)					
Crop residues	9 (28.1%)	11 (36.7%)	0 (0%)	17 (40.5%)	14 (37.8%)
Livestock dung and farmyard manure	10 (31.2%)	15 (50%)	29 (96.7%)	17 (40.5%)	14 (37.8%)
Household wastes	5 (15.6)	1 (3.3%)	1 (3.3%)	3 (7.1%)	1 (2.7%)
Grasses	8 (25%)	3 (10%)	0 (0%)	5 (11.9%)	8 (21.6%)
Total	32 (100%)	33 (100%)	30 (100%)	42 (100%)	37 (100%)
Compost processing					
Number of times of watering	4	7	8	8	6
Number of times overturning	0	2	1	2	0

Source: Authors

And finally we collected compost samples from each of the 72 compost pits for chemical and physical analysis.

A number of 30 Komondjari to 42 Kompienga carts of these raw materials were used per pit. Crop residues (28-40%) and, livestock dung and farmyard manure (31-50%) were the main ingredients, except in Komodjari where compost was made almost exclusively (97%) from livestock dung and farmyard manure.

The two options to fill the compost pits were by layer or in a muddle. In the first option, the pits were filled layer by layer. Usually, the first layer is made of crop residues (20-30 cm thick), the second layer is animal dung (5-10 cm thick) as inoculum, the third layer is the enriched ingredients such as rock phosphate or ash (50g/m^2), and then watering with 150-200 l. These successive layers are repeated until the pit is full. A layer of about 4 cm grass is maintained on the surface to create anaerobic conditions, which helps to reduce evaporation and N losses. In the muddle filling option, the materials were added to the pit as they were available.

The two options were practiced in various proportions in the study sites. In three provinces, more than 60% of the farmers filled their pits by layer including Gnagna (76%), Gourma (62%) and Tapoa (72%). The figures were opposite in Komondjari and Kompienga as 61 and 68% of the farmers (respectively) filled their pits in a muddle.

During compost processing period, usually from December to May, the number of times of watering varied between 4 in Gnagna and 8 in Komondjari and in Kompienga depending on the availability of water. Meanwhile, in Gnagna and in Tapoa, the compost heap was never overturned, while in Komondjari, it was done once in Komondjari and twice in Gourma and Kompienga.

Compost sampling and analysis

The focus was on compost from stabilized pits only as compost from non-stabilized pits contain huge amount of soil which might alter the quality of the compost. Stabilized pit had regular forms and their sides, bottom and edge have been cemented to avoid soil in the compost and excess water due to runoff; and non-stabilized are just a hole. In addition, stabilized pits represent 88% of the total number of compost pits. The physical properties consisted of bulk density and moisture content. For bulk density, the upper 30 cm of the compost surface was first removed and then took a core of 50 cm x 50 cm x 50 cm in the central pit. The wet weight of the compost taken from the core was determined *in situ* and then a sub-sample of 500 g was taken to determine the compost moisture content. This sub-sample was air dried before oven drying at 105°C until constant weight was obtained. Then, the dry weight of the compost excavated from the core was estimated as follows (Equation 1):

$$\text{Compost dry weight (kg)} = \text{compost wet weight (kg)} \times \frac{\text{Compost subsample dry weight (kg)}}{\text{Compost subsample wet weight (kg)}} \quad (1)$$

The compost bulk density (kg/m3) was calculated by dividing the estimated dry weight (kg) of compost excavated by the volume of the core (0.125 m^3).

The authors also estimated the real amount of the dry compost produced per pit (Equation 2) and the amount of compost that can be potentially produced per pit (Equation 3).

$$\text{Compost produced (t / pit)} = \frac{\text{Density(kg/m}^3) \times \text{Vol}_{\text{compost}}(\text{m}^3)}{1000} \quad (2)$$

$$\text{Potential compost production } (t / pit) = \frac{\text{Density(kg/m}^3) \times \text{Vol}_{\text{pit}}(\text{m}^3)}{1000} \quad (3)$$

Where Density is the bulk density of the compost, $Vol_{compost}$ is the volume of the compost in the pit and Vol_{pit}, the volume of the compost pit. The production gap per pit was estimated as the difference between the potential compost production and the compost produced.

For chemical analysis, a composite sample was made from each compost pit by mixing nine sub-samples taken as follows: at each corner of the pit, four sub-samples at the surface (after removing the 30 cm layer of the compost surface) and four others sub-sample at the 30 cm from the bottom of the pit, and one sub-sample from the core compost sampled for bulk density determination.

For chemical properties determination, compost was air dried, and then oven dried at 65°C until constant weight. Chemical properties of compost dried included pH, total organic matter (OM), total nitrogen (total-N), total phosphorus (total-P) and available phosphorus (P- Olsen).

The compost pH (in water) was measured using a pH-meter (WTW InoLab, Weilheim, Germany) in slurries formed from a ratio of 1 g compost to 5 ml water. The total organic matter content was determined from mass loss after ignition at 550 °C for 5 h; this provided a measure of the total carbon (Nelson and Sommers, 1982). Total nitrogen (N) and phosphorus (P) were determined based on samples that were first mineralized using H_2SO_4-Se-H_2O_2

Table 2. Proportion (in %) of type of compost pit in the East region of Burkina Faso.

Type of compost pit	Provinces					
	Gnagna	Gourma	Komandjari	Kompienga	Tapoa	Mean
Stabilized	88	78	71	38	96	82
Non-stabilized	12	22	29	62	4	18

Source: Authors

(Houba et al., 1997). The total N and total P contents in the digested solution were assessed using an automatic colorimeter (Skalar SANplus Segmented flow analyzer, Model 4000-02, Breda, Holland). Available phosphorus was extracted according to the Olsen method (Olsen et al., 1954) and determined calorimetrically as for total P.

Data analyses

Compost physical and chemical data were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) univariate implemented in Minitab (V. 14) statistical software for Windows (Minitab Inc.). Data were checked for normality prior to running the ANOVA. Means that showed differences at $p<0.05$ were compared using Tukey's pair-wise tests. Principal Component Analysis (PCA) was performed using CANOCO 5.1 software to study the variability of compost pit dimensions and, compost production and chemical characteristics across the eastern region of Burkina Faso.

RESULTS

Compost pit types

Throughout the provinces, two main types of compost pits were found; stabilized pit whose sides, bottom and edge have been cemented to avoid soil in the compost and excess water due to runoff; and non-stabilized ones which are just a hole. In the eastern region of Burkina Faso, most of the compost pits (82%) were stabilized (Table 2). Within the provinces, only Kompienga had <70% stabilized pit and while at Tapoa, almost all the pits were stabilized.

Compost pit characteristics

Mean values of compost pit length and width were similar in all provinces (Table 3). Length varied from 2.9 m (Kompienga) to 3.4 m (Tapoa). However, at Tapoa, a pit showed an exceptional length of 6 m. The width varied from 2.8 m (Komondjari) and 1.7 m (Gnagna). There was a significant difference for depth which ranged from 0.9 m (Komondjari) to 1.2 m (Gnagna). Pits with 0.5 m depth were found in the Komondjari and Tapoa provinces. Compost pit volume was similar between provinces and ranged from 8.0 m^3 (Komondjari) and 11.8 m^3 (Tapoa). However, pits with huge volumes of 15 m^3 to 22 m^3 were found in Gnagna, Gourma and Tapoa.

Compost physical characteristics and production

The Principal component analysis (PCA) showed that 75% of the variability in compost production and quality was explained by the first two canonical axes (Figure 1). There was a clear indication that compost issues were specific to each of the province of eastern region of Burkina Faso as there was no relationship between the five provinces (Figure 1).

Compost production was positively correlated with the crop residues. The first principal component had large positive association with livestock dung and farmyard manure. The compost manufacturing operation (number of time of watering and overturning) was negatively correlated with the compost pit dimensions.

The compost produced per pit was significantly higher in Kompienga than in Komandjari and Tapoa provinces (Table 3). Both the highest (> 6.5 t/pit) and lowest (0.091 t/pit) production was recorded on farms in Tapoa. With these conditions of compost pit volume and compost density, a projection of potential compost production per pit ranged from 2.6 t/pit (Komondjari) to 5.0t/pit (Kompienga). Two pits with potential production of 10 t were recorded Gnagna; volume of 16 m^3 and 19 m^3 and compost density of 634 kg/m^3 and 542 kg/m3.

There was no difference in the compost production gap although it varied between 12.5% at Kompienga to 23.6% at Tapoa. However, pit production gap at 0%, meaning these pits were at their maximum potential production were found in all of the provinces.

Compost chemical characteristics

Compost chemical characteristics had different correlation pattern with the PCA axes (Figure 1). Only, available P (P-Olsen) was correlated with the first axis. The second axis had large and positive associations with OM content and C/N. These two parameters were negatively correlated with total-N, total-P and pH. The OM content (16%-30.4%) and C/N (11.2-21.4) (Table 4) were positively correlated with household waste (Figure 1). The major nutrients content (Total-N and total -P) were

Table 3. Mean± standard deviation of compost pit characteristics, compost moisture and, compost density and production dry weight basis in the East region of Burkina Faso. Means with the same letter within rows are not statistically different at the 5%.

Characteristics		Province					LSD	Grand mean (n=72)
		Gnagna (n=25)	Gourma (n=9)	Komandjari (n=7)	Kompienga (n=8)	Tapoa (n=23)		
Length of the pit (m)	Mean	3.2±0.3^{a}	3.3±0.3^{a}	3.1±0.4 ^{a}	2.9±0.4^{a}	3.4±0.7^{a}	0.50^{ns}	3.2
	Range	2.8 - 3.9	3.0 - 3.8	2.7 - 3.7	2.5 - 3.4	2.5 - 6.0		
Width of the pit (m)	Mean	3.1±0.3^{a}	3.2±0.3^{a}	2.9±0.4^{a}	3.0±0.6^{a}	3.1±0.3^{a}	0.31^{ns}	3.0
	Range	2.6 - 3.8	2.8 - 3.8	2.1 - 3.3	2.5 - 4.2	1.7 - 3.5		
Depth of the pit (m)	Mean	1.2±0.2^{c}	1.0±0.1^{ab}	0.9±0.2^{a}	1.0±0.1^{ab}	1.1±0.1^{bc}	0.18*	1.0-
	Range	0.8 - 1.9	0.9 - 1.2	0.5- 1.1	1.0- 1.2	0.6- 1.8		
Volume of the pit (m^3)	Mean	11.6±2.9^{a}	10.9±2.9^{a}	8.0±2.4^{a}	9.1±2.8^{a}	11.8±4.6^{a}	3.18 ^{ns}	10.3
	Range	7.3 - 19.4	7.8 - 15.9	4.5 - 11.0	6.3 - 14.3	2.7 - 22.4		
Compost density (kg/m^3)	Mean	355±132^{a}	381±141^{a}	331±103^{a}	588±275^{b}	363±166^{a}	138.3*	384
	Range	183 - 699	237 - 695	190 - 513	226 - 1087	13 - 806		
Compost moisture (%)	Mean	25.3±16.3^{a}	48.1 ±10.1^{b}	10.6 ±4.3^{a}	25.5 ±6.9^{a}	45.2 ±21.7^{b}	16.4***	33
	Range	2.4 - 53.3	32.6 - 61.8	7.2 - 19.8	18.3 - 36.4	10.8 - 78.6		
Compost produced (t/pit)	Mean	3.2±1.5^{ab}	3.2±1.1^{ab}	2.1±0.9^{a}	4.2±1.7^{b}	2.9±1.6^{a}	1.28*	3.1
	Range	1.1 - 8.4	1.5 - 4.4	1.4 - 4.0	2.0 - 7.8	0.09 - 6.5		
Potentiel compost production (t/pit)	Mean	4.1±2.1^{ab}	4.2±2.1^{ab}	2.6±0.9^{ab}	5.0±1.9^{b}	3.8±1.9^{ab}	1.68*	4
	Range	1.4 - 10.5	2.2 - 8.0	1.5 - 4.0	2.0 - 7.8	0.1 - 7.39		
Production gap (%)	Mean	17.3±20.9^{a}	19.2±18.9^{a}	16.6±20.9^{a}	12.5±23.1^{a}	23.6±21.7^{a}	17.98 ^{ns}	19..43
	Range	0.0 - 63.2	0.0- 45.0	0.0- 44.4	0.0 - 50.0	0.0 - 66.7		

LSD = Least significant Difference; ns= not significant; *p<0.05; **p<0.01; ***p<0.001.
Source: Authors

similar across the region. The pH value of all composts was alkaline and ranged between 7.7 in Gnagna and 8.9 in Gourma. Compost bulk density averaging 384 kg/m^3 decreased as the compost OM content increased (Figure 1).

DISCUSSION

Compost pit characteristics

The dimensions of the compost pits were generally within the range of the one promoted by research and public agricultural extension services in West Africa including Burkina Faso (Blanchard et al., 2012), Mali (Tangara et al., 2012), and Benin (Hinvi et al., 2015) or even in Asia (Misra et al., 2003). These suggested dimensions, 3 to 5 m length, 2 to 5 m width and 1 to 1.2 m deep depending of the availability of the composting raw materials. Similar dimensions were reported in the same area (Coulibaly, 2018) and in the northern part of Burkina Faso (Zongo, 2011). The key dimension remains the depth, as the deeper the pit, the more likely it will become anaerobic; and the more difficulty in turning the pile. Inckel et al. (2005) recommend shallow pits of 0.5 m depth instead of pit of 1.0 m for the ease of turning which will result in better compost quality. The diversity of actors mainly, NGOs, projects, private sector and public extension services, promoting their own compost pits types might contribute to the diversity of compost pits dimension. In fact, these actors condition their subsidies on the adoption of their compost pit type.

Usually, actors subsidize compost pits digging

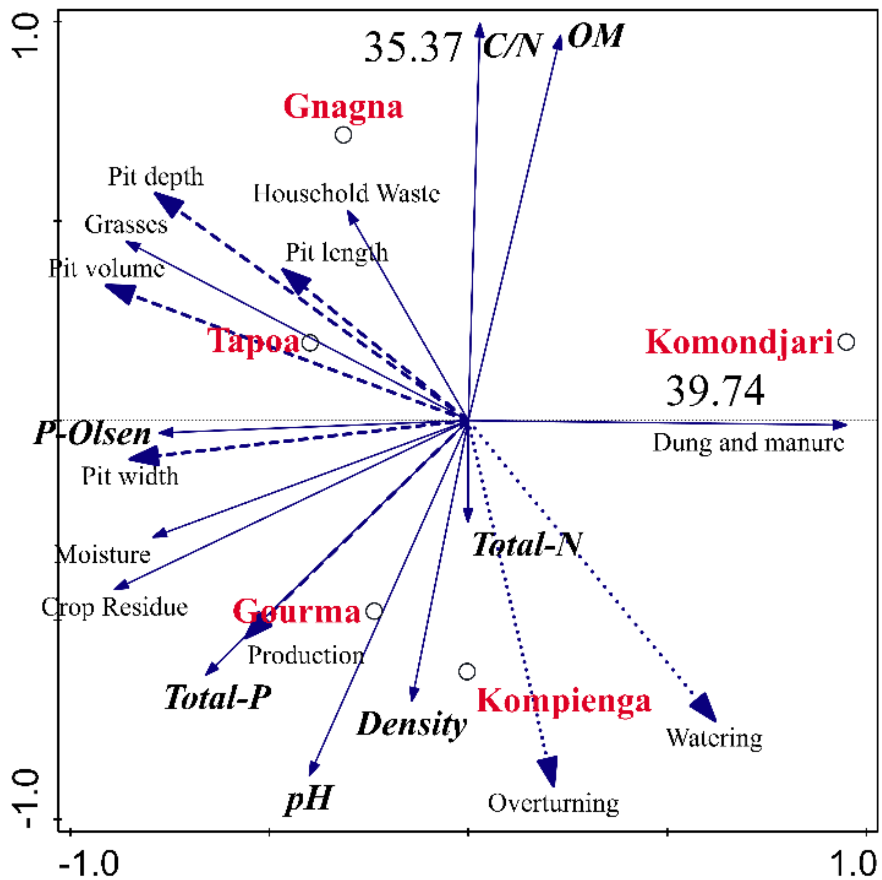

Figure 1. Principal component analysis showing correlation between compost pit dimensions (dashed lines), compost manufacturing operations (dotted lines), compost raw materials (continuous lines), compost production and quality (in black bold) from smallholder farmers in the eastern region of Burkina Faso. The circle indicates the provinces (in red) of the region. Numbers represent the percentage (%) of the variability explained by the first two axes.
Source: Authors

Table 4. Mean values of selected compost chemical characteristics from farmers compost pits in the East region of Burkina Faso. Mean with the same letter within columns are not statistically different at the 5%.

Province	pH	OM (%)	C/N	Total-N (g/kg)	Total-P (mg/kg)	P-Olsen (mg/kg)
Gnagna	7.7^{a}	30.4^{b}	21.4^{b}	8.55^{a}	3524^{a}	194^{ab}
Gourma	8.9^{c}	17.9^{a}	12.4^{a}	9.79^{a}	5068^{a}	178^{ab}
Komondjari	7.8^{a}	29.0^{ab}	17.4^{ab}	9.28^{a}	2525^{a}	128^{a}
Kompienga	8.7^{bc}	16.1^{a}	11.2^{a}	8.64^{a}	4147^{a}	215^{ab}
Tapoa	8.4^{b}	26.2^{ab}	16.6^{a}	9.56^{a}	3620^{a}	271^{b}
level of significance	***	*	**	ns	ns	*

ns= not significant; *p<0.05; **p<0.01; and ***p<0.001.
Source: Authors

and cementation, the two costly components in compost pits construction. The percentage of stabilized composts pits reflected the support of NGOs, projects and government. Without support, farmers cannot afford digging and material for cementation. For instances, aboveground pits were cheaper as there were built with "banco bricks" made of clay mud and straw, but they are short-lived.

Compost production

In the Eastern Region of Burkina Faso, the average compost production per pit was 3.1t and the potential was 4t (Table 3). Zongo (2011), analyzing the contribution of government's "compost pits' operation" in the crop yield improvement in the northern regions of Burkina Faso, reported an average compost pit production of 2.4t. The higher value reported in our study might be explained by the higher availability of compost raw material. In fact, the East region of Burkina is known as breeding zone and transhumance corridor toward Benin, Niger and Togo which might explain the high percentage of livestock dung and farmyard manure. Farmers are also breeders and then own raw compost materials. In Burkina Faso, Zougmoré et al. (2000), conducting a study to calibrate farmer units for compost quantification, reported that a compost pit of 5 m × 5 m × 1 m need a total of 47 carts of sorghum straw (1 645 kg) and 2 carts of cow dung (412 kg) leading to a production of 1.42 t of dry compost. Another study from Blanchard et al. (2012) with an pit dimensions of 3 m × 3 m × 1.2 m used a total of 12-16 carts of sorghum or cotton straw (1 500-2 000 kg) and 3-4 carts of cow dung (375-500 kg) to produce 0.9-1.2 t of compost.

In the research conditions, the quality of compost raw material used (only crop residues and cow dung) and the good compost processing such as watering and returning explain the lower compost produced per pit as compared to famers compost' pits. In fact, farmers used in addition to crop straw and cow dung other raw material with higher densities such as rock phosphate and household refuse along with soil.

Research recommends applying 5t of dry compost per ha every two years; however some agricultural actors' idea stipulates that compost produced from a single pit is dedicated to 1 ha. Our study and that from research (Blanchard et al., 2012; Zougmoré et al., 2000) provide clear evidence that this assertion is not verified. To amend 1ha of field, there is a need for 2 pits of compost produced by smallholder's farmers or 4 pits of compost produced in research conditions. However, the quantity of compost per pit produced by smallholders farmers could be enough for an annual application which is 2.5 t/ha.

The compost pit volume was similar across provinces while the potential production per pit showed difference. This shows that the quantity of compost produced per pit did not relate to the pit volume but rather to the compost density or volume, and then to the compost manufacturing process. The existing compost production gaps could be explained by several factors including the inappropriate compost pit dimensions, the lack of raw material due to competition between energy sources, building material and composting.

Compost quality

The results of the study conducted on smallholder farmers' compost generated data on their physical and chemical characteristics. These results support our hypothesis that compost characteristics differ among smallholders farmers.

Standard specifications for compost from Africa are lacking. In our study, compost quality was evaluated based on a set of physical (bulk density) and chemical characteristics including pH, major nutrients (total-N and total-P) and available phosphorus (P-Olsen). These characteristics except the bulk density are usually reported to define farmers' compost quality used in conventional agriculture in Sub Sahara Africa. In fact, several studies using compost across the country, reported only chemical characteristics of compost such as pH of 7.2; OM ranging from 21-35%; total-N ranging from 7-22 g/kg and C/N ratio ranging from 10-21 (Gnankambary, 2007, Koulibaly et al. 2015; Soma et al, 2017). Bulk density was not reported.

The pH of the compost was moderately alkaline (7.4–8.4) to strongly alkaline (>8.5) which are within the range of recommended pH of finished compost (Dadi et al., 2012), and are compatible with crops cultivated in the area. Compost with alkaline pH bound heavy metals limiting then their availability but also can induce micronutrient deficiency (Li et al, 2021). One explanation of the alkaline pH of our compost could be the additives component such as Burkina rock phosphate and/or ashes which increase the compost content of bases cations and then the pH. Another explanation could be the release of ammonium (NH_4^+) resulting from the biodegradtion of organic raw material. This NH_4^+ acts as alkali and causes the compost pH to increase, generally above 8 (Wichuk and McCartney, 2010). De Bertoldi et al. (1983) indicate that organic material can be composted in a broad pH range (3-11), with optimal values between 5.5 and 8.

Values around neutrality are optimal for microorganisms' development. However, fungi are more tolerant to a wide range of pH than bacteria. Different results of the pH values indicate compost maturity does exist. Several studies in Burkina Faso reported a mature compost with a pH around neutral 7.2-7.6 from sorghum straw (Gnankambary, 2007, Soma et al., 2017), rice straw (Lompo et al., 2009), and jatropha cake (Pouya et al., 2020); while Koulibaly et al.(2015) reported lower pH of 6.4 with cotton straw compost. On the contrary, Cayuela et al. (2008) find the stabilized olive mill waste compost pH of 9.5 which correlated well with other indicators of stability and maturity. The diversity of results indicated that pH-value of compost is highly dependent on the raw material and the composting processes. We could not find compost quality standards for Burkina Faso or Africa. And then, the pH of our compost were in agreement with compost quality standards for compost used in agriculture in Thailand (5.5-8.5), Great Britain (7.5-8.5) and Switzerland (pH<8.2) (Dadi et al., 2012).

High bulk density implies high compaction leading to low porosity for air and water circulation. This could be detrimental if composting process is still on going. The density reported in our study could be related to the physical characteristics of raw material used. For example, low density composts in Komondjari were primarily composed of livestock dung and farmyard manure while Kompienga composts contain crop residues. The bulk densities observed in our study were similar to those reported by Mamo et al. (2021) producing compost from rice straw with different supplement addition and by Vázquez and Soto (2017) and Azim et al (2017) in the review paper for different type of compost. We observed that the bulk density increased with the decrease of the OM content. Similar trends were reported by several studies and attributed to the higher mineral matter content and lower porosity implying lower water retention capacity (Khater, 2015; Azim et al., 2017; Vázquez and Soto, 2017).

The nutrient content of the compost is influenced by the initial chemical characteristics of raw materials as well as composting conditions such as watering, turning and duration of the composting process. OM content of our compost were similar to those reported in West Africa (Bissila and Payne, 2006; Gnankambary, 2007, Soma et al, 2017). The compost from Kompienga and Gourma had the lower OM content which could be explained by the quality of the raw material and by the composting process leading to better decomposition. These two provinces had more watering and overturning could imply better organic matter decomposition as indicated by their lower C/N ratios. The C/N ratio is a master parameter widely used as compost stability and maturity indicator. A range of C/N values, generally between 10 and 20, have been reported to characterize the stability and maturity of finished compost. The following limits have been reported: ≤20 (Bhat et al., 2017), 15 to 20 (Rosen et al., 1993), 10 to15 (Sullivan and Miller, 2001), < 12 (Bernal et al, 1998) and approximately 10 (Kuo et al., 2004). Moreover, for Indian and Italian standards for instance, the C/N ratio for commercial compost is <20 and <25 respectively. The C/N ratios of our compost were within the range of the threshold values defined for stable and mature compost implying that they would be considered as good quality. In addition, application to soil of compost with a C/N ratio similar to that of the soil may not alter the microbial equilibrium of soil. This adds to the evidence that our compost would be suitable for application to our soil having generally C/N 10 to 15. In fact, these composts produced have been applied in the farmer fields and no phytotoxicity has been noticed (Pouya et al., 2021).

The total-N content of the compost which is nearly 10 g/kg is a typical value of compost (Bissila and Payne, 2006; Gnankambary, 2007, Soma et al, 2017). This results contrast to those of Blanchard et al. (2014) who found half of our values for farmers' compost in Western Burkina Faso. These composts were produced in the field with crop residues (cotton, millet and sorghum straws and grasses) and small amount of cattle dung.

Compost P-content was similar to that reported in the previous studies conducted in West Africa (Bissila and Payne, 2006; Gnankambary, 2007, Soma et al., 2017) and is in agreement with Indian compost regulations. Total-P content was similar across the villages which could be related to the large variability in the data due to the raw material and the addition of P through household waste and other adjuvants such rock phosphate from Burkina Faso. Interestingly, the plant P-availability representing around 5% of total-P is immediate P source for plants and microbes. The soil in Sub Saharan African is known to be P-limiting soil, and then applying this compost could help to alleviate this challenging issue. In fact, in addition to supplying P in organic and mineral forms, compost could bind the P-fixation site in the soil colloids surface and then embed P-fixation which makes P more present in the soil solution.

Conclusion

Composts produced in the pit by smallholder farmers in the Eastern region of Burkina Faso were evaluated for their quantity and physical and chemical properties. The quantity and quality issues were province-specific. The quantity of the compost produced per pit (3.1 t/pit) is less than the recommended rate. However, this quantity per pit can be recommended for an annual application which is 2.5 t/ha. Regarding the bulk density and chemical characteristics including pH, organic matter, C/N, and total-N content, these composts could be qualified as good mature and stable composts. Application of these composts is therefore instrumental for improving mineral fertilizer efficiency and soil productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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