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Use of Various Organics Substrates and Evolution of Chemical Parameters during Composting of *Panicum maximum Jacq* and *Oriza sativa L.* Straw

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The present study was initiated with the objective of evaluating the quality of composts obtained from different organic substrates.

Place and Duration of Study: The test was conducted at the research station of the INERA (Institute of Environment and Agricultural Research) of Farako-Bâ in western Burkina Faso.

Methodology: Aerobic composting was conducted through use of compost heaps composed of various organic and plant substrates, and physical and chemical parameters were measured during the process. Two types of biomass comprising *Oriza sativa* and *Panicum maximum* straw and two types of substrates including cattle manure and poultry manure were subjected to windrow composting. Two treatments were defined with the combination of rice straw + cattle manure (T1) and the combination of *Panicum maximum* straw + poultry manure (T2).

Results: The study showed that the composts from both treatments gave basic pH for water and low C:N ratios (> 20) and were rich in mineral elements. The best quality compost is obtained in T2

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with values of total P (0.52%), Ca (2.05%) and Mg (0.62%) higher than those of T1 by 44%, 39% and 39% respectively.

Conclusion: This study highlights the possibility of composting these substrates, which may contribute to improving the organic matter requirements of the soil.

Keywords: Rice straw; Panicum maximum straw; compost; manure; poultry manure; nutrient.

1. INTRODUCTION

Agricultural development in sub-Saharan African countries is impeded by several unfavorable factors, including low soil nutrient and organic matter levels [1]. Several studies conducted in Burkina Faso have shown that the organic matter content of most soils has declined to a critical level of less than 1% organic matter in many areas [2,3].

Agriculture in Burkina Faso thus faces a major challenge, namely producing more food for a rapidly growing population on degraded or unfertile soils. To cope with soil degradation, farmers use fertilization strategies that are mainly based on the use of mineral fertilizers, with organic soil amendments being somewhat neglected, despite the fact that they are essential for improving and maintaining soil fertility [4,5]. In effect, many studies have shown the effects of organic matter inputs on the physical, chemical, and biological properties of soils [6,7,8]. Organic matter has an important role in maintaining soil fertility and is a significant source of nutrients such as nitrogen, phosphorus, potassium and sulfur [2,9]. In more recent years, due to demographic pressure, soils have been intensively used over extended periods of time without fallowing; this leads to a decrease in soil fertility and significant changes in physical, biological and chemical properties of soils [3].

The use of organic matter as an amendment after composting is a promising strategy for increasing the organic matter content of degraded agricultural soils and reducing or even reversing the degradation process [2,6,8]. In order to improve crop productivity, the production and use of good quality, inexpensive compost is an important challenge.

In Burkina Faso, compost is mainly produced from crop residues, which are usually insufficient in quantity to meet demand from the agricultural sector. This is because compost production is hindered by competing needs for crop residues, as they can either be used in agricultural production as a soil amendment (incorporating crop residues into the soil through tillage) or as livestock feed [10]. Utilization of other less frequently used residues such as rice straw and *Panicum maximum* could be a solution to increase the availability of residues for composting. Furthermore, the quality and stability of compost depends on the composition of the materials used for its production [11] and on the way it is produced [12].

A variety of organic substrates such as cow and poultry manure are produced as byproducts of the animal agricultural sector and are subsequently used by farmers in compost production [10,13].

Some studies have shown that poultry droppings and manure are rich organic substrates that could be used in composting [10,5,13].

The technique of composting in piles can be used as an economic means to produce a large quantity of high-quality organic compost if best practices are followed [4]. Combining often unused crop residues with animal agriculture byproducts such as cow manure and chicken manure can help improve the quality of the compost and increase the availability of organic matter for crops [5].

In the context of tropical soils which are often low in organic matter, it is important to investigate the best ways to produce a larger quantity of high-quality compost through using crop residues and livestock manure which are available locally?

This study of the effects of different organic substrates on chemical composition of compost produced from rice straw and *Panicum maximum* straw was conducted to evaluate the quality of composts obtained from different organic substrates.

2. MATERIAL AND METHODS

2.1 Study Site Description

The experiment was conducted at the Farako-Bâ research station in Bobo-Dioulasso, Burkina

Faso. The research center is owned and managed by the Environment and Agricultural Research Institute (INERA) of the National Center for Scientific and Technological Research (CNRST), a Burkinabè government research entity. The research station is located at 11°05' 35.3" N latitude, 4°19' 59.6" W longitude. Temperatures typically range from a minimum of 10°C to a maximum of 37°C. Evapotranspiration is quite high, varying on average between 1700 mm and 1800 mm per year [4]. The rainy season typically begins at the end of May and ends in mid-October.

2.2 Study Conceptual Framework and Composting Method

The composting process for the two types of organic substrates was performed using the windrow method in a simple non-randomized block design with three replications. Two treatments were set up per organic substrate:

- T1 : Rice straw + Cattle manure
- T2: *Panicum maximum* straw + Poultry manure

The different compost piles were watered every three days. The piles were turned every three weeks and a sample was taken for the determination of the following chemical parameters: pH, total organic matter, total carbon, total nitrogen, total phosphorus, total potassium, calcium and magnesium.

The study conceptual framework is presented in Fig. 1. The framework shows the composition of both treatments, with their respective plant and animal manure components. It also shows that three turnings are performed, with samples taken at each turning and again when the compost has reached maturity.

2.3 Experimental Equipment

2.3.1 Composted material

Two (2) types of straw were used. These were rice straw and *Panicum maximum* straw, the chemical characteristics of which are provided in Table 1.

Photos 1 and 2 are respectively those of *Oriza sativa* (rice) straw and *Panicum maximum* straw, respectively.

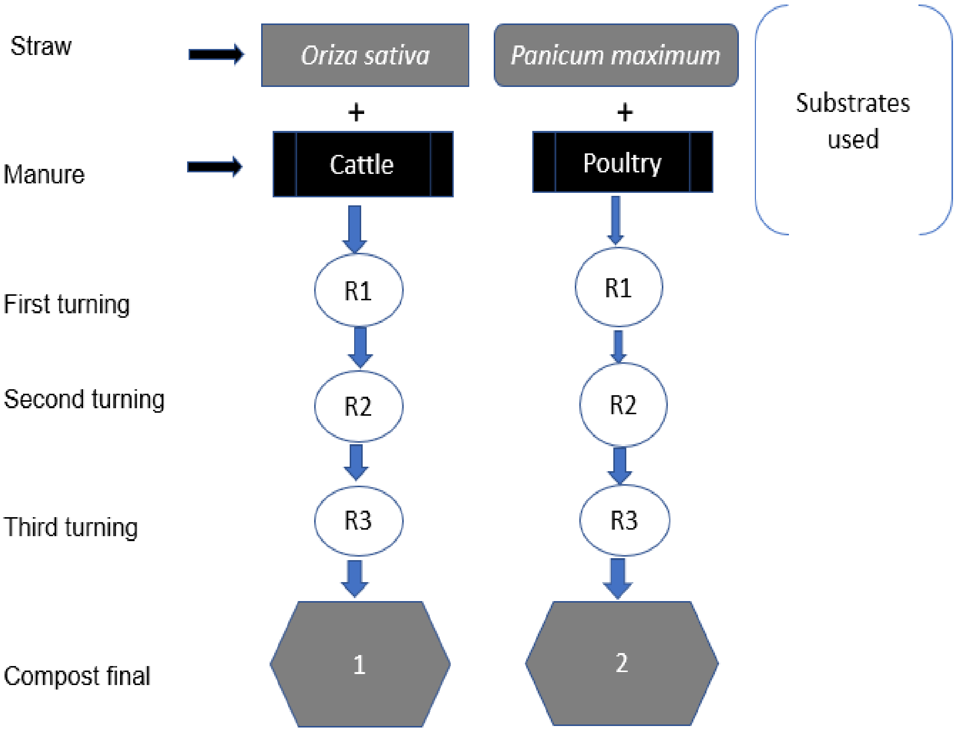

Fig. 1. Study conceptual framework

Table 1. Chemical characteristics of the straws used

Straw	C (%)	N (%)	C :N	P (%)	K (%)	Ca (%)	Mg (%)
Panicum maximum	52.18	0.97	53	0.07	3.29	0.85	0.22
Oriza sativa	43.14	1.01	42.71	0.09	2.33	1.02	0.16
SD (±)	5.45	0.013	4.58	0.02	0.49	0.31	0.07

Photo 1. Dry *Oriza sativa* straw

Photo 2. Fresh *Panicum maximum* straw

The straws were obtained from the experimental plots of the INERA Farako-Bâ research station.

2.3.2 Organics substrats used for composting

Two types of manure were also used as a source of the micro-organisms required for the decomposition of organic matter. These are cattle manure (Photo 3) and poultry manure (Photo 4) and the chemical characteristics of which are presented in Table 2.

Cattle manure and poultry manure were collected in the cowshed of the INERA Farako-Bâ research station.

2.4 Data Collected and Analyzed

The composting process lasted 14 weeks. During this process, three consecutive turnings were conducted, noted as R1 (at two weeks), R2 (at six weeks), and R3 (at nine weeks). During the composting process, three incremental samples were taken immediately after each turning as well as at the end of the composting period. A total of 24 samples were taken in order to evaluate the pH-water evolution and the degradation process of the organic matter. At the end of the composting process, samples were taken, dried in the shade and packaged for chemical analysis at the INERA Farako-Bâ laboratory in Burkina Faso.

The following analytical methodologies were used to test the samples collected from the compost piles: pH [14], total nitrogen [15,16], total carbon [16], total phosphorus [17], total potassium [18], and calcium and magnesium [19].

Table 2. Chemical characteristics of the organic substrates used

Substrate	pH_water	C (%)	N (%)	C :N	P (%)	K (%)	Ca (%)	Mg (%)
Cattle manure	8.39	38.45	1.84	21	0.13	3.98	0.51	0.16
Poultry manure	6.90	42.96	3.39	13	0.23	2.19	2.24	0.68
SD (±)	1.21	2.09	1.49	9.76	0.08	1.06	1.93	0.57

SD: Standard deviation

Photo 3. Cattle manure

Photo 4. Poultry manure

The data were entered using Microsoft EXCEL 2010. All measured parameters were subjected to analysis of variance (ANOVA) in order to compare their averages at the threshold of 5% by Fisher's test using XLSTAT 7.5.2 software.

3. RESULTS

3.1 Evolution of pH-water, Ca and Mg Levels during Composting

Table 3 shows the variation in pH-water and exchangeable cation content of the different treatments at each pile turning. The statistical analysis reveals very highly significant differences between the treatments at the threshold of 5% for the parameters determined.

Treatment T1 gives the highest pH-water values at the first two turnings; but at the third turning, the highest pH can be observed in Treatment T2. A decrease in pH was observed in treatment T1, from 8.25 at R1 to 8.14 at R3. As for treatment T2, there was an increase in pH-water from 7.22 at R1 to 8.22 at R3 during the composting process. As for Ca and Mg content, treatment T2 gives levels two times higher than those of treatment T1. In general, we can observe an increase in Ca and Mg content during composting with both treatments.

Table 3. Variation of pH, Ca and Mg during composting

Treatment		*T1*	*T2*	SD (±)	Prob	Sig.
R1	pH	8.25^{a}	7.22^{b}	1.61	P<.001	VHS
	Ca (%)	0.58^{b}	1.29^{a}	0.94	P<.001	VHS
	Mg (%)	0.18^{b}	0.39^{a}	0.57	P<.001	VHS
R2	pH	8.15^{a}	7.61^{b}	0,76	P<.001	VHS
	Ca (%)	0.66^{b}	2.11^{a}	1.09	P<.001	VHS
	Mg (%)	0.20^{b}	0.64^{a}	0.32	P<.001	VHS
R3	pH	8.14^{b}	8.22^{a}	0.09	P<.05	S
	Ca (%)	0.81^{b}	2.05^{a}	1.21	P<.001	VHS
	Mg (%)	0.25^{b}	0.62^{a}	0.29	P<.001	VHS

Sig: Significant; VHS: Very Highly Significant. The values followed by the same letter in each line are not statistically different at the threshold of 5% in Newman Keuls test. T1: Rice straw + Cattle manure; T2: Panicum maximum straw+ Poultry manure. R1: First turning; R2: Second turning; R3: Third turning. SD: Standard deviation

3.2 Evolution of Carbon and Major Nutrient Content

Table 4 shows the evolution of chemical parameters according to the different treatments during the three turnings. The statistical analysis reveals very highly significant differences for total P and total K and significant differences for C/N ratios between treatments at the threshold of 5%. During the composting process, treatment T2 gives total P levels two times higher than those of treatment T1 in all turnings (R1, R2 and R3), i.e. 0.31, 0.55 and 0.59% respectively. Treatment T2 also provides the lowest C:N ratios during the second and third turning, i.e. 18.12 and 17.99 respectively. A general decrease of the C:N ratio is also observed during the composting process. Treatment T1 gives the highest total K ratios at the first and second turning, 3.05% and 2.71% respectively.

3.3 Chemical Characteristics of the Composts Obtained

The two final composts have alkaline pH, i.e. 8.25 for treatment T1 and 8.23 for treatment T2. They have high organic matter levels, i.e. above 30%, and a C:N ratio between 15 and 20, i.e. 17.31 and 15.12 respectively for T1 and T2. The treatment T2 provides the lowest C:N ratio but it gives levels of total P, Ca and Mg twice higher than those of T1. Total P, Ca and Mg levels are respectively 0.52%, 2.05% and 2.14% for treatment T2. Treatment T1 gives the best total K level of 2.14%.

Table 4. Evolution of chemical parameters (C, N, P et K) during composting

Treatment		***T1***	***T2***	SD (±*)*	P	S
R1	C (%)	40.20	40.42	0.19	*P >.06*	NS
	N (%)	1.50	1.44	0.22	*P >.06*	NS
	C:N	26.73	28.15	1.72	*P >.06*	NS
	P (%)	0.18^{b}	0.31^{a}	0.11	*P<.02*	S
	K (%)	3.05^{a}	1.59^{b}	0.96	*P<.004*	HS
R2	***C (%)***	38.93^{a}	29.18^{b}	11.81	*P<.0004*	THS
	N (%)	1.60	1.61	0.18	*P>.73*	NS
	C:N	24.37^{a}	18.12^{b}	7.12	*P<.0001*	VHS
	P(%)	0.20^{b}	0.55^{a}	0.27	*P<.0001*	VHS
	K (%)	2.71^{a}	1.35^{b}	1.94	*P<.0001*	VHS
R3	***C (%)***	33.03	33.50	0.27	*P>.05*	NS
	N (%)	1.73^{b}	1.86^{a}	0.31	*P<.01*	S
	C:N	19.08^{a}	17.99^{b}	3.2	*P<.02*	S
	P (%)	0.22^{b}	0.59^{a}	0.13	*P<.0001*	VHS
	K (%)	1.90	1.93	0.14	*P>.54*	NS

NB: P: Probability; S: Significant; NS: Not Significant; HS: Highly Significant; VHS: Very Highly Significant. Values followed by the same letter in each column are not statistically different at the threshold of 5% in Newman Keuls test. T1: Rice straw + Cattle manure; T2 : Panicum maximum straw + Poultry manure. R1: First turning; R2: Second turning; R3: Third turning. SD: Standard deviation

Table 5. Chemical composition of the composts obtained

Treatment	pH_water	MO %	N %	C :N	P %	K %	Ca %	Mg %
T1	8.25	52.42	1.76	17.31 a	0.20 b	2.14 a	0.90 b	0.27 b
T2	8.23	49.95	1.92	15.12 b	0.52 a	1.61 b	2.05 a	0.62 a
SD (±*)*	0.16	1.98	0.27	2.04	0.31	1.02	2.68	0.13
Probability	P<.54	P<.34	P<.14	P<.002	P<.004	P<.02	P<.04	P<.04
Significance	NS	NS	NS	HS	HS	S	S	S

S: Significant; NS: Not Significant; HS: Highly Significant. The values followed by the same letter in each column are not statistically different at the threshold of 5% in Newman Keuls test. T1: Rice straw + Cattle manure; T2: Panicum maximum straw + Poultry manure. SD: Standard deviation

4. DISCUSSION

In the context of our study, our results showed significant differences ($p < .05$) in pH between the two treatments during the composting process. It should be mentioned that pH can serve as an indicator for full maturity of a substrate such as compost, and that normal pH values would be between 7 and 8 [14]. Furthermore, it reflects the biological activity that occurs during the composting process, which proceeds in several phases, including mesophilic, thermophilic, cooling, and curing phases, each of which are associated with successive development of distinct microbial communities [20,21]. Changes in pH during each successive turning followed the same trajectory in each of the treatments. The chicken manure, which had a pH of 8.25 at the outset, exhibited decreasing pH over time. This is likely due to an increase in the production of organic acids during the mesophile phase, which permit the creation of favorable conditions for proliferation of mesophilic flora, because the organic substrate had a high pH at the outset.

A study conducted by [22] revealed that CO_2 production during aerobic degradation contributed to acidification of the substrate through its dissolving in water and the production of carbonic acid. Previous studies highlighted that ammonia volatilization becomes frequent at pH values above 8.00, impacting compost quality [23,24]. Nevertheless, the chicken manure (pH = 6.90) started out neutral but became basic by the end of composting (pH = 8.23) for treatment T2 (see Table 5). A study conducted by [20] showed that compost may become more alkaline due to production of ammonia gas. This alkalinization phase is the result of two processes: first, the production of ammonia resulting from the degradation of protein amines during the ammonification process, and second, the freeing of bases present in organic matter [25,26,27]. The ammonia that is generated during this process through chemical reactions partly neutralizes acidic substances present in the substrate [28,29]. Other studies revealed an increase in pH going from 5.40 at the outset to 8.50 after 57 weeks of composting plant residues mixed with household waste, concluding that the composting process is always accompanied by a phenomenon of alkalinization [29,20].

Furthermore, it is important to note that through turnings, primary materials which are rich in carbon are subsequently decomposed and gradually become available to decomposer microorganisms. During this process, adding water to the compost during each turning ensures that conditions favorable to compost formation are maintained, in particular through ensuring high levels of biochemical activity [21,30].

Our results show a statistically significant difference in Ca and Mg concentrations for the two treatments ($p < .05$) during the composting process and for samples of the finished compost. Higher Ca and Mg concentrations in T2 can be explained by the relatively higher concentration of these elements in the base substrate from which this compost was formed. In essence, the Ca and Mg content of chicken manure is four times as high as that of the cow manure. The increase in Ca concentration is likely due to Ca becoming liberated in the compost through gradual transformations in the composition of the base substrate. In these conditions, according to [2], as microorganisms proliferate in the substrate, they induce a higher mineralization rate of the organic matter in the substrate, and the quantity of CO_2 produced is a function of the microbial population, its diversity, the metabolic enzymes which are secreted, and the composition of amendments applied to the compost.

During the composting process, the C:N ratios of the different treatments dropped considerably. The C:N ratio is of utmost importance in compost formation; it is one of the parameters often used to evaluate the level of maturity of a compost. During the three turnings (T1, T2, and T3), this ratio became smaller in magnitude over time for both treatments (from 26.73 to 17.31 for treatment T1 and from 28.15 to 15.12 for treatment T2). Nevertheless, the rate of compost curing depends on the mineralization rates of plant residues and manures added to the compost as well as the equilibrium between the various mineral elements [30,20,31].

We found that this parameter varied considerably between the two treatments. This decrease can be explained by the fact that microorganisms consume greater quantities of carbon (the primary component of organic molecules) than they do nitrogen. The decrease in the C:N ratios is due to carbon release and/or transformation [30,32].

The low C:N ratios that we found can be explained by the fact that mineralization is a function of the type of animal manure and plant residues added to the compost, and the slow rate of polymer breakdown for lignin and cellulose [33,34]. Furthermore, consumption of carbon following organic matter degradation can partly explain this phenomenon. The organic matter content of the compost is essential to improve or maintain soil fertility due to the positive physical, chemical, and biological effects it provides [11,6,33]. The organic component was mineralized into stable compounds by microbial activity, which explains the decrease in organic matter levels throughout the composting process [30]. Additionally, a study conducted by [35] revealed that during the composting process, several different carbon transformations occur, including oxidation of easily degradable carbon compounds, methanization in anaerobic zones in deeper areas of the compost pile or in aggregate matter, production of organic acids from carbohydrates or lipids, enzymatic attacks on carbon compounds producing carbohydrates, and dissolving of CO_2 in water. It should be noted that manure was one of the best activating agents for starting the organic matter decomposition process, because it contains a relatively high level of biodegrading microorganisms. Our results are similar to those of [36], who noted a considerable decrease in the portion of dry matter during the composting process of rice crop residues in treatments where manure was added to the compost. In contrast, the C:N ratio of treatment T2 in our study was higher, which can explain the relatively rapid nitrogen mineralization that occurred in our study and as such, its relatively high availability in the compost [20].

The two treatments experienced a varying rate of phosphorus content throughout the composting process. It is worth noting that phosphorus is not a volatile element, and it is much less prone to leaching than nitrogen due to its relatively immobile nature [37]. The phosphorus richness of treatment T2 can be explained by the high P content in the chicken manure that was added to this treatment (0.23%). Other studies have shown that variations in P content of different composts are linked to the type of substrates used in creating the compost [21,38]. Treatment T1 had the highest K concentration, which can also be explained by the high K content in cow manure.

The final compost samples exhibited interesting characteristics and revealed several properties related to compost quality Concentrations of P_{total}, Ca, and Mg in treatment T2 were twice as high as those in T1. These conditions can also be explained by high P, Ca, and Mg content in chicken manure (0.23, 2.24, and 0.68 percent, respectively).

According to other researchers, variations in P content in compost depend in part on the type of substrate used [38,21]. Treatment T1 had the highest K content, which can be explained by the high K content of cow manure [13]. Treatment T2 exhibited lower C:N ratios and higher P, Ca, and Mg content when compared with treatment T1. Our results corroborate those of [20], who showed that composts based on manure from broiler chickens and layer chickens had higher N, P, and K content than those with a base of cow manure.

In a general manner, it should be noted that decomposition dynamics of organic substrates have a direct influence on the release of plant nutrients that these organic residues contain. In this study, these results also reveal information about the quantity of plant residues, the biochemical composition of plant residues, and humidity, all of which could be considered as determining factors in the plant residue decomposition process [34].

5. CONCLUSION

The present study was conducted to evaluate the effect of substrate types on chemical parameters during the composting process and on the final composts. The composts obtained have basic pH-water and low C:N ratios and are rich in major mineral elements. Therefore, the composting of organic substrates improves their chemical parameters. We can also note that the compost based on poultry manure and *Panicum maximum* straw is of higher quality than that based on cattle manure and rice straw, because it gives the lowest C:N ratio and the highest N and P, Ca and Mg contents. However, it would be important to continue this study in order to evaluate the effect of these composts on crop production and the physical and chemical parameters of the soil and assess the economic benefits of the composts produced. Additionally, trials on toxicity of compost samples should also be undertaken in order to better understand the presence of any toxic products.

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