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Standardizing the Quality of Composts Using Stability and Maturity Indices: The Use of Sawdust and Rice Husks as Compost Feed Stocks

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Abstract

Many organic materials found in urban areas of sub-Saharan Africa have not been exploited for the development of feedstock specific quality standards of compost especially for use as soilless media. The objective of this study was to determine feedstock specific quality standard of compost using referenced stability and maturity indices and establish a simple model for predicting compost maturity based on different feedstock. Two sawdust feedstocks from *Daniellia oliveri* sawdust (single sawdust) and *Daniellia oliveri* + *Chrysophylum albidum* sawdust (mixed sawdust) including one rice husk feedstock were composted individually with poultry manure in three volumetric ratios of 2:1, 3:1 and 4:1. The 2:1 *Daniellia oliveri* sawdust compost achieved acceptable values for stability and maturity parameter at 8th week, and had the highest nitrogen (N) level (2.46%) and lowest carbon to nitrogen (C:N) ratio (15). In terms of associative relationships for single species sawdust compost, total nitrogen (TN) accounted for 93% of the variation in the C:N content of the compost. In the mixed species sawdust compost, TN explained 87% of the variation in the C:N. Total nitrogen only explained 77% of the variation in the C:N content of the rice husk compost. The study established an empirical relationship between TN and compost maturity and concluded that using stability and maturity indices and their relationships established in this study as standard, compost of higher quality could be obtained within the shortest possible time irrespective of the feedstock used.

Keywords

Compost Maturity, Nutrient Recycling, Waste Management, Soilless Media

1. Introduction

Nutrient recovery from organic waste through re-use and recycling has been proposed for the management of biomass, manures and municipal solid waste (MSW) in the West Africa sub-region, including Ghana [1]-[8]. Composting has received significant attention as an evironmental sustainable way of recovering nutrients from biomass, manures and the organic fraction of MSW. Improper disposal and or burning of biomass are implicated in reducing urban air quality, increasing the greenhouse effect from CO_2 and NO emissions and significantly contributing to global warming and climate change [9]. Dumping of raw manures into water bodies leads to eutrophication and nitrates buildup with adverse consequences on aquatic life [10] [11].

In Ghana, recovery of nutrients from the huge quantities of sawdust, rice husk and poultry manure generated in urban areas could significantly reduce the import bill of inorganic fertilizers and drastically minimize the environmental impact of current waste disposal options. Issaka *et al.* [12], reported that 3.2 million Mt of manure comprising poultry, cattle, sheep, goat and pig manure is produced annually in Ghana. This constituted 48,695.7 Mt, 43,883.5 Mt, and 20,919.7 Mt equivalents of N, P and K, respectively. In addition, over 366,000 Mt of rice straw and 63,000 Mt of rice husk are produced annually, equivalent to some 2528 Mt, 990 Mt and 5450 Mt of N, P and K respectively. About 4159×10^3 Mt of crop residues and 360×10^3 Mt of logging residues (comprising 16% - 25% of sawdust) are also produced annually [13].

Unfortunately, most of these wastes generated are not backed by any properly planned disposal schemes or composting systems and therefore become an environmental nuisance with serious adverse effects. But these adverse environmental effects could be eliminated by composting the organic wastes to provide nutrient-rich substrate for crop production. However, production of good quality composts requires good knowledge of the nature of feedstocks and good methods of composting. To ensure universal usage of compost, there is the need to standardize feedstock combinations and composting methods in the way that could influence compost stability and maturity indices [14] [15] [16]. Compost stability refers to the relative impact of the compost product on nutrient availability and the consistency of physical properties of the soil, whilst maturity is defined as the degree or level of completeness of composting. Immature compost may cause N starvation, delayed plant growth and phytotoxicity [17]. They may also contain harmful microbes, weed seeds and have unpleasant odors [18]. Compost quality parameters commonly used as stability and maturity indices include TN, C, C:N ratio, NO_3-N, NH^4-N, EC, pH and microbial respiration [19]. Stabilized and matured compost N mineralization has higher levels of NO_3-N and lower levels of NH^4-N [18]. Compost temperature and pH have also been reported as good indicators of the progress of composting. The pH of compost depends partly on the nature of the initial feedstock. Lignin decomposition is reported to occur at higher temperature. Feedstock of higher C:N is known to generate higher pH and ammonia gas during composting. The pH levels less than 5 or more than 8 inhibits N mineralization [20]. Nitrogen release in sawdust for instance was found to correlate positively with total nitrogen and negatively with pH [21]. The EC indicates the soluble salts content of the compost and affects seed germination and root development. Higher EC is noted to cause severe phytotoxicity [22]. Acceptable range of EC is between 0.75 and 2.35. Tender plants are sensitive to EC of 3.5 - 5 and compost of this EC content need to be diluted for tender plants. Compost with EC of 5 or more needs to be applied in lower concentrations or used as mulch for established plants [23]. Although a number of studies have focused on compost quality using the above indices, very few or none have focused on establishing relationship between compost quality indices in different feedstock with varying C:N ratios. It is very important to determine the quality of compost using the above indices and also establish an empirical relationship between stability indices and C:N as an index of compost maturity [19]. Therefore, the objectives of this study were to determine feedstock specific quality standards of compost using referenced stability and maturity indices and establish a simple model for predicting compost maturity for different feedstocks.

2. Materials and Methods

The experiment was carried out between April and June, 2014, at the at the Nyankpala campus of the University for Development Studies, Tamale, Ghana. The campus lies on latitude 9˚25'N and longitude 9˚58'W and it is 185 m above mean sea level [24]. Ambient temperature within the study period ranged between 23˚C - 32˚C. The average relative humidity ranged from 69% - 85%. There was 8 hours of daily sunshine over the experimental period.

2.1. Materials, Feedstock and Composting Process

Poultry manure and 2 feedstocks, namely rice husk and sawdust, were the materials used in the study. The Poultry manure was obtained from a battery cage house of the Animal Science Department at the Nyankpala Campus. Rice husk was obtained from the Savannah Agriculture Research Institute rice milling house, near the Campus and the sawdust was obtained from the Tamale wood market. There were two types of sawdust, namely, the single sawdust (SS) from *Daniellia oliveri* tree (African copaiba balsam tree) and the mixed sawdust (MS) from *Daniellia oliveri* and *Chrysophylum albidum* (white star apple tree) in a 1:1 (v/v) formulation. Compost bins were constructed as wooden boxes with dimensions of 90 cm × 90 cm × 90 cm. The inner wall of the bin was lined with a 200 µm-plastic films to preserve moisture and heat within the bins. The boxes were closed and kept in the open air during composting. The feedstocks combinations used on dry weight basis as treatments were 2 parts single sawdust: 1 part poultry manure (as 2SS), 3 parts single s sawdust: 1 part poultry manure (as 3SS), 4 parts single sawdust:1 part poultry manure (as 4SS), 2 parts mixed sawdust: 1 part poultry manure (as 2MS), 3 parts mixed sawdust: 1 part poultry manure (as 3MS), 4 parts mixed sawdust: 1 part poultry manure (as 4MS), 2 parts rice husk: 1 part poultry manure (as 2RH), 3 parts rice husk: 1 part poultry manure (as 3RH) and 4 parts rice husk: 1 part poultry manure (as 4RH). Each compost box was filled with a formulated mixture of feedstock plus poultry manure giving a total of nine compost boxes. The mixtures were watered to keep the moisture content at 60%. The mixtures were turned or aerated by scooping out mixtures and refilling so that the top part of the mixtures in box goes to the bottom of the box after turning. Aeration was done three times before the expected maturity period of eight weeks. Compost temperature was measured daily for 60 days using a Thermo-couple thermometer. The rice husk and sawdust feedstock and poultry manure were analyzed for physical and chemical properties before composting. During the composting, a total of twelve compost samples were taken from each treatment for physical and chemical quality analysis at two weekly intervals over 12 weeks. The parameters that were measured during composting included CO_2 evolution, electrical conductivity, organic carbon, total nitrogen and mineral nitrogen (NH_4-N and NO_3-N).

2.2. Analytical Methods

Total N was determined using the Kjeldahl digestion method [25]. Organic C was determined by the modified Walkley-Black Wet Oxidation method as outlined by Nelson and Sommers [26]. Organic C in compost and feedstock was determined by the Complete Oxidation procedure adapted from Heanes, [27]. Phosphate, calcium potassium and magnesium were determined by the colorimetery method by Watanabe and Olsen [28]. Electrical conductivity (EC) was determined by inserting the electrode of the EC meter into the compost sample suspension [29]. Crison Basic EC meter CM39P was used for the determination of EC. Crison Basic pH meter PH29P was used for the determination of pH. The concentrations of nutrients in compost and in soil samples (nitrate nitrogen, ammonia nitrogen) were done using UV/VIS spectrophotometer. Nitrate as nitrogen was determined by the Hydrazine Reduction Method [30]. Ammonia as ammonium nitrogen was determined by the Indophenol Blue Method [31]. Lignin and cellulose were determined following the method by Van Soest [32]. Rate of respiration (CO_2 evolution) was determined following the methods of [33]. Media moisture and temperature were determined in-situ, using a Thermo-couple thermometer and portable moisture meter respectively (Hanna instruments, Madrid Spain).

2.3. Data Analyses

Data on quality of feedstock treatments (poultry manure, sawdust, rice husk) were analyzed using analysis of variance (ANOVA), in Gentstat version 9.2. Least significant differences (LSD) were calculated and the probability of treatment means significantly different was set at $p = 0.05$. Data on compost quality were analyzed by ANOVA using STATISTIX version 10 and Tukeys Honestly Significant differences were calculated at 5% level of probability (p = 0.05). Relationships between stability indices were established using correlation and regression analysis.

3. Results

3.1. Physico-Chemical Properties of Poultry Manure and Feedstocks

Poultry manure as compared to the other feedstocks, was significantly higher ($p = 0.017$) in N (4.37%), P (1.05%), ($p = 0.044$), K (4.10%); $p = 0.030$, Ca (4.47%); $p = 0.010$, Mg (3.1%); $p = 0.002$ and higher in density (0.5 g/cm^3); $p = 0.003$. For the other parameters, all feedstock had similar nutrient content. The MS was highest in moisture content (12.1%); $p = 0.001$, total organic carbon (TOC) (45.1%); $p < 0.001$, cellulose (42.1%); $p < 0.001$ and lignin (23.7%); $p = 0.040$. The SS was highest in EC (8.7 mS/cm^3); $p = 0.001$ (Table 1). The SS feedstock had the highest C:N ratio of 170 than MS feedstock (110.19) and RH feedstock (106.23).

3.2. Temperature Profile during Composting

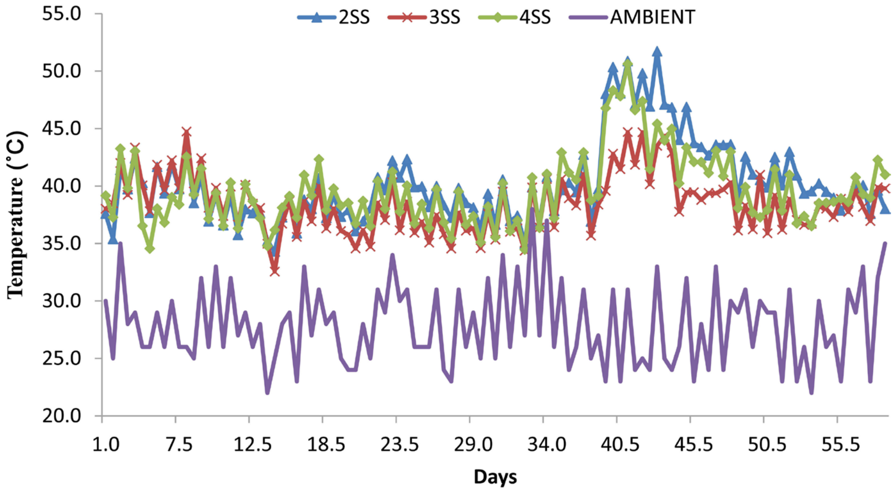
The 2SS and 3SS maintained temperature above 40˚C (thermophilic temperature) for one week before falling below 40˚C (mesophilic). The 4SS could only maintain the temperature for four days. Turning the compost resulted in increasing the temperature to 43˚C. The highest peak temperature (51˚C) was attained in 2SS compost at 43 days and 50˚C for 4SS at 41 days. After 43 days, the

Table 1. Physico-chemical properties of poultry manure, rice husk, single sawdust and mixed sawdust.

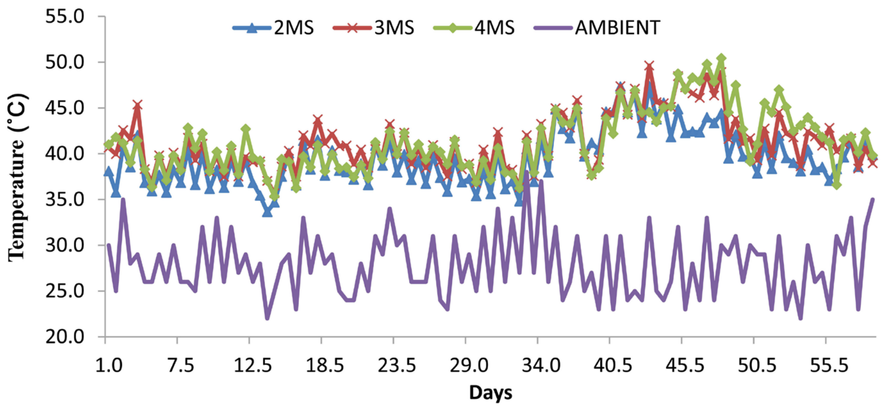
Properties	Poultry manure	Rice husk	SS	MS	LSD	*p*-value
N (%)	4.37 ± 0.28	0.38^a	0.25^b	0.41^a	0.085	0.017
P (%)	1.05 ± 0.03	0.43^a	0.21^b	0.15^c	0.015	0.044
K (%)	4.10 ± 0.11	1.81^a	1.34^b	0.72^c	0.093	0.030
Ca (%)	4.47 ± 0.08	0.82^c	1.26^b	1.32^a	0.060	0.010
Mg (%)	3.19 ± 0.02	0.73^b	0.91^a	0.66^c	0.028	0.002
Moisture (%)	9.45 ± 0.50	7.10^c	11.30^b	12.13^a	0.550	0.001
EC (mS/cm^3)	4.00 ± 0.30	3.55^b	8.73^a	3.41^b	0.230	0.001
Density (g/cm^3)	0.50 ± 0.01	0.25^b	0.28^a	0.25^b	0.015	0.003
OC (%)	25.40 ± 1.00	40.37^c	42.50^b	45.18^a	1.082	<0.001
Cellulose (%)	23.87 ± 0.08	27.74^c	32.75^b	42.11^a	0.093	<0.001
Lignin (%)	11.77 ± 0.70	21.68^c	23.15^b	23.74^a	0.225	0.040
C:N	5.81	106.23	170	110.19		

*Adopted and modified from Abubakari *et al.*, 2017.

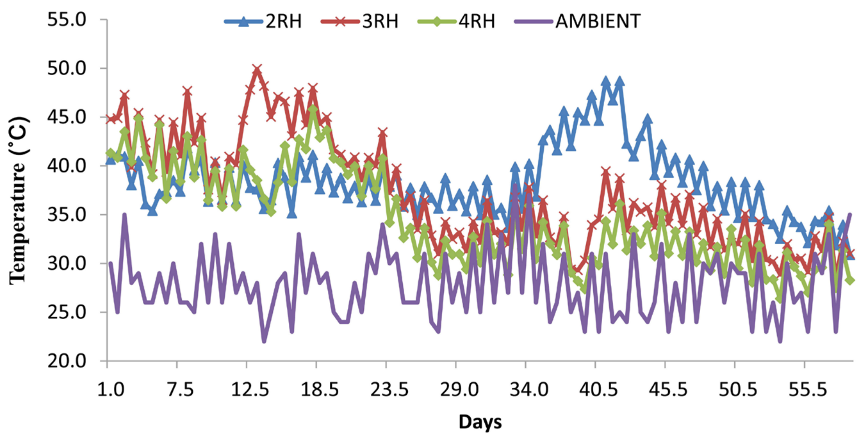
temperature dropped below 40˚C and close to ambient temperature of 35˚C. (Figure 1(a)).



(a) SINGLE SAWDUST COMPOSTS



(b) MIXED SAWDUST COMPOSTS



(c) RICE HUSK COMPOSTS

Figure 1. (a) Temperatures of the various *single species* composts in comparison with the ambient temperature; (b) Temperatures of the various *mixed species* composts in comparison with the ambient temperature; (c) Temperatures of the various rice husk composts in comparison with the ambient temperature.

In the mixed sawdust compost, temperature in rose to 41˚C overnight for 2MS and 4MS. Within the same period, temperature in the 3MS compost rose to 45˚C. These temperatures were maintained for three days before falling to values below 40˚C. After turning the compost at one week, the temperature fluctuated between thermophilic and mesophilic states until it fell to ambient temperature levels at day 43. Turning the compost at this stage increased temperatures to 49˚C for 3MS and 50˚C for 4MS. There was a sharp drop in temperature to ambient levels in all three mixed sawdust compost (Figure 1(b)).

In all the rice husk compost, temperatures rose above 40˚C within 24 hr. of composting. Between 3 and 8 days, the 3MS attained the highest temperature of 47˚C. At 33 days temperature in all the ratios fell to ambient levels. After the compost at 33 days, the 2SS attained peak temperature of 45˚C - 48˚C and maintained this range of temperature for 5 days (Figure 1(c)).

3.3. CO_2 Evolution during Composting

The CO_2 evolution was similar for all compost treatments. At the start of composting, CO_2 level ranged from 100 - 129 mg/kg/h. The CO_2 level rose to 268.5 mg/kg/h at 2nd week of composting. At the 4th week, CO_2 increased to 306.1 mg/kg/h and then declined to values between 84.95 and 116.47 mg/kg/h. When the compost was turned for curing at the 12th week, the CO_2 level increased (not significant) slightly especially 4MS based compost (Figure 2).

3.4. Changes in pH

At the start of composting, the pH of 4MS based compost (pH of 8.8), 2MS and 3MS based composts (each having pH of 8.5), were highly alkaline compared to the 2SS based compost (pH of 7.8) was slightly alkaline. At 2nd week of composting, pH values dropped to values ranging from neutral in 3MS based compost (pH value of 7.0) to slightly acidic in 4SS based compost (pH of 6.5). There

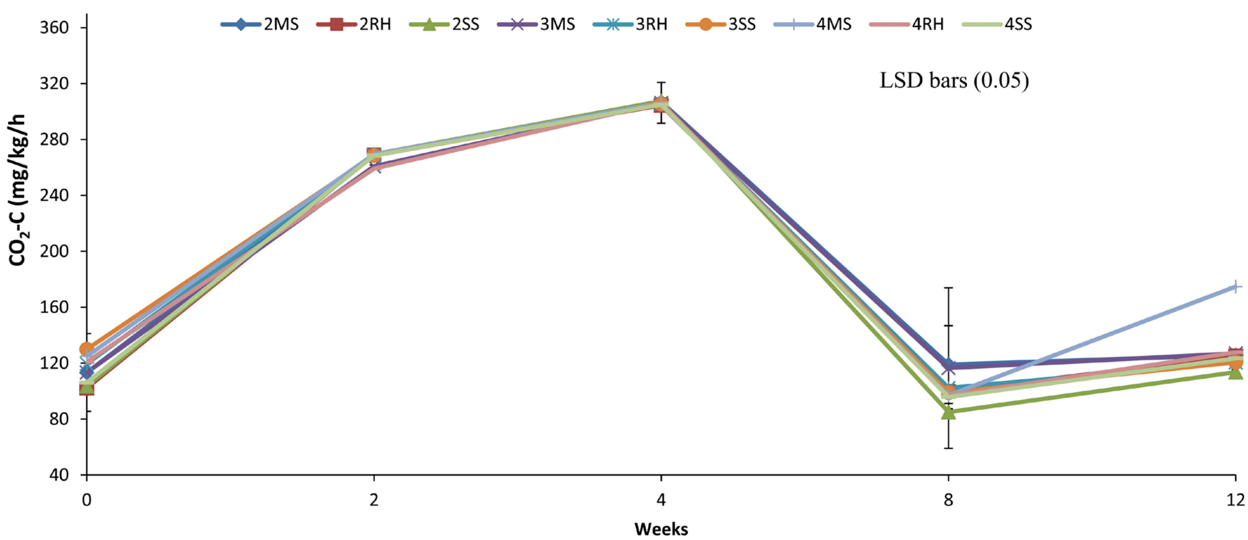


Figure 2. CO_2 evolution trends for the different compost types over the period of composting.

were no significant differences in pH values between 2nd and 6th week of composting. At 8 - 12th week, the 3MS and 4MS based composts had neutral pH higher than all other treatments. The 3RH, 4RH and 2MS based composts were slightly acidic, with pH (6.8) lower than all other treatments (Figure 3).

3.5. Changes in Electrical Conductivity

At the start of composting of the 2SS based compost had the highest EC of 3.9, significantly greater than 3SS and 4SS based composts, which had the least EC of 2.7 and 2.2, respectively (Figure 4(a)). After 2nd week of composting, all three SS based composts had similar ECs. After 4th week of composting however, 4SS based compost had significantly higher EC than 3SS based compost which had the lowest. Showing consistency, after 8th week of composting, 4SS based compost continued to have the highest EC, significantly greater than those of 2SS and 3SS based composts. However, at 12th week of composting, all three SS based composts recorded similar EC (Figure 4(a)). From the start of composting till 8th week of composting, all the three MS based compost had similar EC. After 4th and 8th week of composting, the 2MS and 3MS based compost had significantly higher EC than the 4MS based compost which had EC value of 1.7 mS/cm^3. However, after 8th week of composting, all three MS based composts had similar EC values (Figure 4(b)).

At the start of composting, the 2RH based compost had EC of 3.9 significantly higher than 3RH and 4RH based composts with ECs of 2.9 and 2.8 respectively. After 2nd and 4th weeks of composting, the 2RH and 3RH based composts had significantly lower EC than 4RH based compost. However, at 8th week and 12th week of composting, all the three rice husk composts had similar EC (Figure 4(c)).

3.6. Stability and Maturity Indices of the Mature Compost

At 4th week of composting, 4MS based compost shows the highest C:N ratio,

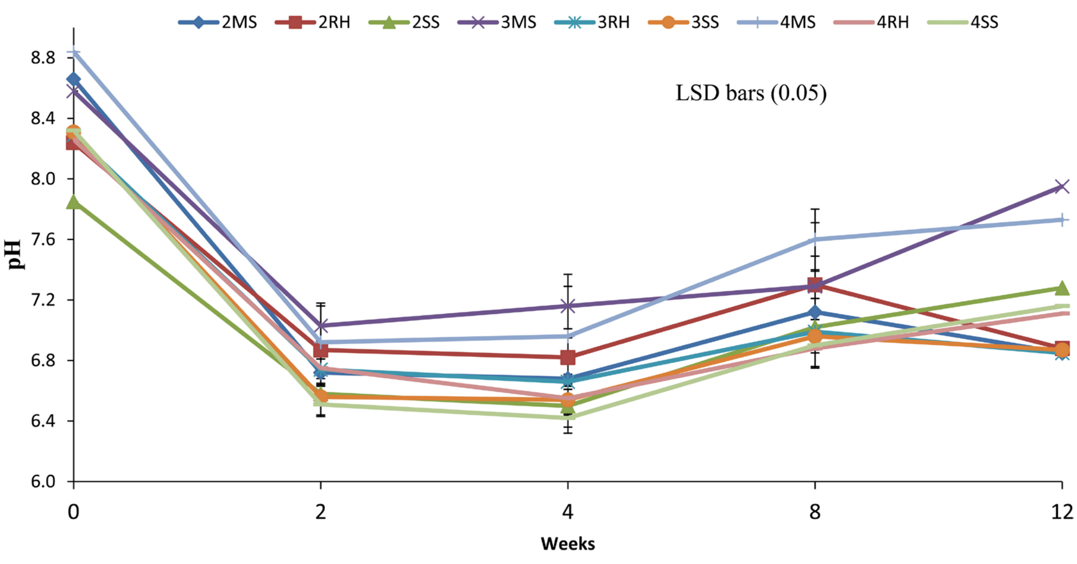


Figure 3. pH profile of the compost types over the period of composting.

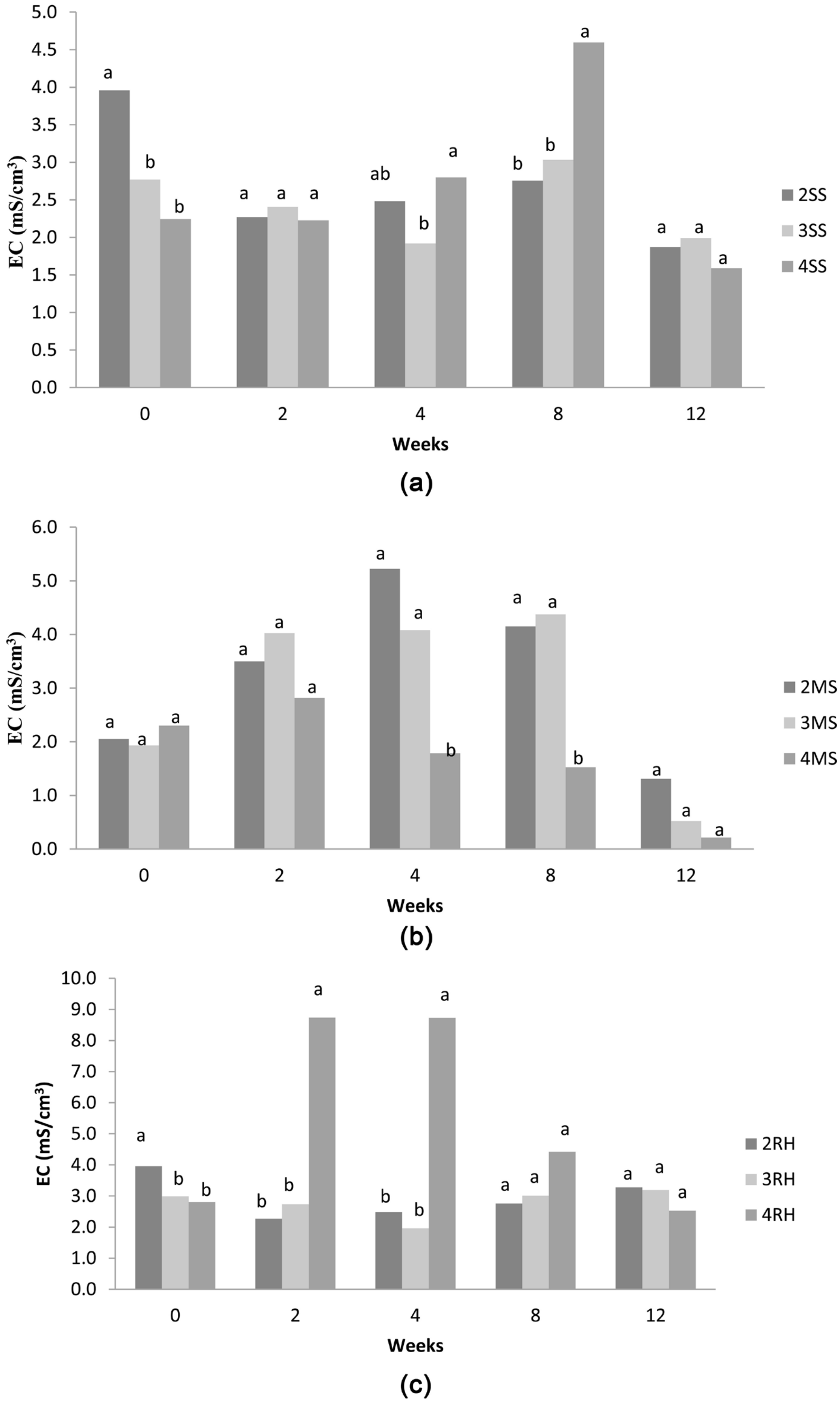


Figure 4. (a) Electrical conductivity profile of single species compost for 12 weeks of composting; (b) Electrical conductivity profile of mixed species *Daniellia oliver*i + *chrysophylum albidum* compost for 12 weeks of composting; (c) Electrical conductivity profile of rice husk compost for 12 weeks of composting.

significantly greater than the rest of the composts, except that of 3MS based compost which was similar (**Table 2**). The least C:N ratio was shown by 2RH based compost. At 8th week of composting, 4MS based compost continued to show the highest C:N ratio, significantly greater than all the other composts. The least C:N ratio was shown by 2RH based compost. However, at 12th week of composting, 4RH based compost had the highest C:N ratio, significantly greater than the rest of the composts. The least C:N ratio was recorded by 2SS based compost. In comparison to the referenced quality standards, all the composts had attained maturity at 12th week of composting, except 4RH based compost which had C:N ratio still above the standard (Table 2).

3.7. Compost Quality at Maturity

The 2SS based compost showed significantly highest total nitrogen content (2.46%), whereas the 4RH based compost showed the least (1.32%). The 2MS based compost had the highest carbon content (39.62%), while the 4RH base compost had the lowest carbon content (33.28%). The highest C losess occurred in 4RH compost and the least C losses occurred in 4SS. The NH_4-N level was highest in 2MS based compost (215.98 mg/kg) and lowest in 4SS based compost (23.45 mg/kg). The 2SS based compost showed the lowest C:N value (15.76) whereas the 4RH based compost had the highest C:N value of 26:23. The 2SS had the highest EC of 1.87 mS/cm^3 whereas 4MS had the lowest EC value of 0.22 mS/cm3 (Table 3).

3.8. Relationships between Maturity Indices and Maturation during Composting

In terms of associative relationships, for single species sawdust compost, the following correlations were found; Total nitrogen (TN) and pH (r = −0.80, p <

Table 2. C:N ratio value as affected by duration of composting.

Compost type	C:N ratio		
	4 weeks	8 weeks	12 weeks
2SS	29.69	24.55	15.76
3SS	32.48	30.45	18.83
4SS	31.22	28.50	20.25
2MS	30.15	29.34	22.50
3MS	40.74	30.69	20.79
4MS	43.38	36.00	20.83
2RH	26.43	24.25	19.31
3RH	28.08	27.73	20.44
4RH	32.33	33.18	26.23
p-value	0.005	0.030	<0.001
LSD (0.05)	5.166	3.81	3.43

Reference compost quality standard, C:N ratio of 15 - 25 (Sæbøa and Ferrini, 2006).

Table 3. Summary of quality indices of the mature composts at 12 weeks of composting.

COMPOST	Macro nutrients (%)			Mineral nitrogen (mg/kg)		C:N	pH	EC (mS/cm^3)
	N	C	C** Losses	NH_4-N	NO_3-N			
2SS	2.46	38.40	8.6	38.28	1117.81	15.76	7.28	1.87
3SS	2.11	39.31	6.92	38.80	1138.6	18.83	6.85	1.99
4SS	2.04	40.99	2.63	23.45	1126.27	20.25	7.11	1.59
2MS	1.82	39.62	13.28	215.98	811.60	22.50	6.85	1.31
3MS	2.02	41.05	9.87	81.16	379.23	20.79	7.95	0.52
4MS	2.02	40.90	10.22	102.91	394.85	20.83	7.73	0.22
2RH	1.68	31.711	11.25	76.45	827.89	19.31	6.85	0.33
3RH	1.61	31.88	20.28	163.94	958.51	20.44	6.85	0.58
4RH	1.32	33.28	16.93	212.78	567.64	26.23	7.11	0.86
p-value	<0.001	<0.001	-	0.001	<0.001	0.1031	0.001	<0.001
Tukey's HSD (0.05)	0.6891	5.2662	-	165.84	367.62	9.7644	05153	0.1254
Compost Standard***	-	-	-	<500	200 - 1000	15 - 25	6 - 8	0 - 4

C** = losses based on initial feedstock carbon value; ***Sæbøa and Ferrini, 2006. 2SS = two parts of single species sawdust to one part poultry manure; 3SS = three parts of single species sawdust to one part poultry manure; 4SS = four parts of single species sawdust to one part poultry manure; 2MS = two parts mixed species sawdust to one part poultry manure; 3MS = three parts mixed species sawdust to one part poultry manure; 4MS = four parts mixed species sawdust to one part poultry manure; 2RH = two parts rice husk to one part poultry manure; 3RH = three parts rice husk to one part poultry manure; 4RH = four parts rice husk to one part poultry manure.

0.001, n = 40); TN and C:N (r = −0.96, $p < 0.001$, n = 40); TN and CO_2 (r = −0.83, $p < 0.001$, n = 40) and CO_2 and pH (r = −0.91, $p < 0.001$, n = 40).

For mixed species sawdust compost, the following correlations were found. Total N and pH (r = 0.567, $p < 0.001$, n = 40); TN and C:N (r = −0.94, $p < 0.001$, n = 40); TN and CO_2 (r = −0.73, $p < 0.001$, n = 40) and CO_2 and pH (r = −0.56, $p < 0.001$, n = 40).

For rice husk compost, TN was significantly and positively correlated with pH (r = 0.656, $p < 0.001$, n = 40) but negatively correlated with C:N (r = −0.880, $p < 0.001$, n = 40) and CO_2 (r = −0.642, $p < 0.001$, n = 40). The CO_2 was negatively correlated with pH (r = −0.710, $p < 0.001$, n = 40).

Total nitrogen was related to the C:N content of the compost depending on the base material of the compost. For single species sawdust compost, total nitrogen accounted for 93% of the variation in the C:N content of the compost in the relationship;

$$Y_{(C/N)} = 50.099 - 14.502 X_{(TN)};\ R^2 = 0.93;\ p < 0.001; n = 40, \quad (1)$$

However, for mixed species sawdust compost, total nitrogen explained 87% of the variation in the C:N content of the compost in the relationship;

$$Y_{(C/N)} = 58.455 - 19.541X_{(TN)}; R^2 = 0.87; p < 0.001; n = 40, \quad (2)$$

Total nitrogen explained 77% of the variation in the C:N content of the rice husk compost in the relationship;

$$Y_{(C/N)} = 47.126 - 16.795X_{(TN)}; R^2 = 0.77; p < 0.001; n = 40, \quad (3)$$

4. Discussion

4.1. Chemical Characterization of Feedstock and Compost

MS feedstock was found to have higher OC and more lignin than SS feedstock and rice husk. However, the SS feedstock had the highest initial C:N compared to MS and RH. In characterizing feedstock for composting, the C:N ratio is critical as it determines the length of the thermophilic phases and also the maturity of and stability periods of the final compost. The optimum C:N ratio for matured and stabilized compost is 12:1 to 15:1 [19]. A C:N ratio less than 10:1 indicates situations of incomplete composting associated with higher levels of N manures. C:N ratio values of more than 25:1 indicate presence of raw carbonaceous materials which when applied to soil results in severe N drawdown [19]. Leconte *et al.* [14], characterized poultry manure and found that it had high N concentration (N = 3.7%) and low organic carbon (29%) compared to sawdust (N = 0.6, and C = 53.2%) and rice husk (N = 0.4% and C = 42.0%). Poultry manure was also found to a have high pH (8.0) and Ca (19.4%) concentration.

4.2. Compost Temperature and CO_2 Evolution

Leconte *et al.* [14], reported that, the high temperatures associated with the composting process was due largely to organic matter breakdown, increasing microbial population and activity and reducing supply of O_2. During the first 4 - 5 days, the compost pile is characterized by fermentation which results in enhanced breakdown of highly lignified carbonaceous materials. This stage is associated with significant multiplication of microorganisms. The nature of carbonaceous materials ultimately determines the length of the thermophilic phase [15]. Higher values of respiration (340 - 466 mg/kg/h) were reported at early stages of composting decreasing to 37 - 90 mg/kg/h by maturity period of compost [14]. Although increasing microbial respiration was correlated with increasing compost temperature [34], Leconte [14] found the reverse and attributed that to thermic inertia which was thought to be the result of exothermic hydrolysis.

4.3. Compost Moisture, pH and Electrical Conductivity

Decreased pH may result from anaerobic conditions in compost which leads to the accumulation of organic acids such as acetic acid and propionic acid. The presence of these acids in the potting media causes the media to become toxic to seeds and seedling development [35]. Generally, the pH of a compost depends partly on the nature of the initial feedstocks. Feedstocks of higher C:N ratio are known to generate higher pH and ammonia gas during composting whiles N_2O emissions are known to be highest at low pH. Moreover, there is stabilization of pH as a result of ammonia volatilization and H^+ release from microbial nitrification [15]. Therefore, for N mineralization to be uninhibited, the pH levels should not be less than 5 or greater than 8 [20]. In the present study, nitrogen release in sawdust was positively correlated with TN and negatively with pH [21].

Furthermore, the EC values at the end of composting for all the nine compost types were lower than the referenced compost quality standard, an indication that the composts could not be a source of toxicity to seeds or seedlings that would be planted in them. EC, a measure of soluble salts content of the compost, affects seed germination and root development and higher levels cause severe phytotoxicity [36]. If the EC is less than 0.75, the media will require nutrient supplementation. Acceptable range of EC is between 0.75 and 2.35. Consequently, in the present study, 2RH, 3RH, 3MS and 4MS composts would require nutrient supplementation since their EC values were below 0.75. Increase in EC could be due to release of mineral salts that occur during the active phase of composting [37]. Composts with EC of 5 or more needs to be applied in lower concentrations or used as mulch for established plants [23].

4.4. Quality and Stability Indices of Mature Compost

The quality of compost produced in this study was influenced not only by the nature of bulking materials (carbonaceous materials) but by the amount of poultry manure (N level) incorporated. The 2:1 ratio of SS to poultry manure (33% of poultry manure addition) resulted in the highest N level of 2.46% in SS based compost compared to 3:1 ratio (or 25% addition of poultry manure) with N level of 2.11% and 4:1 ratio (or 20% poultry manure addition) with 2.02% N level. In the RH based composts, the same pattern was seen in the RH based compost where higher addition of poultry manure resulted in higher N level in the matured compost. However, in the MS based composts, the reverse is the case where higher addition of compost actually resulted in lower levels of N in the final compost. In SS based composts, C losses were higher in 2SS compost where there was higher amount of poultry manure incorporated during composting and the least carbon losses occurred in 4SS composted where there was lower addition of poultry manure was used during composting. In the MS and RH based composts, carbon losses did not appear to be related to the amount of poultry manure added during composting. The quality of composts produced in the present study is comparable to composts produced elsewhere using different feedstocks [14] [38] [39] [40]. However, the SS based compost had higher (1117.81 mg/kg - 1138.6 mg/kg) than recommended levels of NO_3-N. All the C:N values found in the compost produced except 4RH, were within levels acceptable for stabilized compost (15:1 - 25:1). In the present study, correlation analysis highlighted significant relationships among the compost maturity indices. In all the different feedstock used, TN was always positively correlated with pH, but negatively correlated with C:N and CO_2. This finding was significant as it indicated that as the degradation of carbon leads to the accumulation of nitrogen, pH reaches alkaline levels. This is associated with matured compost and CO_2 values decline because of reduced microbial activity associated with maturity. The empirical relationship established between TN and C:N indicates that although TN is the dominant factor explaining variation of C:N and hence compost maturity, the extent to which TN could explain variation in CN depended on the nature of carbonaceous materials.

5. Conclusions

The study has clearly demonstrated that irrespective of the nature of the feedstocks, quality composts with acceptable stability and maturity indices could be derived within the time frame of 8 to 12 weeks.

In this study, the 2SS achieved maturity and stability indices at 8 weeks of composting, had the highest N level (2.46) and lowest C:N ratio (15). Furthermore, the NH_4-N, pH and EC were also within the recommended quality indices specified for highly stabilized quality composts. As a consequence of this, there is the potential to convert wastes that cause environmental pollution into very useful media for agricultural use in open fields and in greenhouses which currently has very limited media alternatives for quality crop production.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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