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Chemical properties and fermentation behavior of the composts prepared by three composting methods in Malawi

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Soil fertility improvement is one of the urgent issues in Malawi. Since composting by locally available materials is needed for this purpose, the composts were prepared from maize stalk and cattle dung by using three common methods in Malawi. The composts had high alkalinity and relatively high NO_3^- and K contents. N% of composts was determined from the composition of maize stalk and cattle dung, and is expressed by the equation N% = 0.55 - 0.01 x % maize stalk + 0.03 x % cattle dung (r^2 = 0.37). Maize stalk is rich in acid digestion fiber (ADF) (39.3%), which accounts for its slow decomposition, whereas cattle dung is mainly composed of ash (73.5%), which is rapidly degradable inorganic material. The temperature change during fermentation was indicative of compost maturity. Mature composts were exposed to fermentation temperatures exceeding 50°C for a longer period, and had lower pH and higher EC and available N content. The germination rate of rape seeds measured with compost extract was compatible with the absorption value at 465 nm, indicating that these methods are simple and practical for testing compost maturity. The EC difference between wet and dry composts was also useful for identifying the end of fermentation. Low C/N (23) compost demonstrated rapid fermentation relative to high C/N (40, 60) composts, indicating the importance of adjusting C/N in compost fermentation.

Key words: Compost, fermentation, acid digestion fiber, maturity.

INTRODUCTION

The low soil fertility in Malawi is partly attributable to poor crop residue management. An improvement of soil fertility status through organic matter application therefore has been demonstrated (Snapp et al., 1998; Kanyama-Phiri, 2005; Vanlauwe et al., 2015). However organic matter based technologies including compost application despite the fact that compost application is promising for enhancing soil fertility, have remained few (Kumwenda et

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al., 1997).

In 2012, Japan International Cooperation Agency (JICA) conducted a baseline survey of crop residue utilization in the northern districts of Malawi and found that 52.1% of 424 farmers were not utilizing maize residues (70 farmers practiced burning and 151 farmers left the residues in their farms). To confront this situation, the Department of Land Resource Conservation in Malawi has been encouraging compost production and use. The interest in composting has greatly increased as a result of the need for environmentally acceptable animal waste treatment technologies and also the demand for organic fertilizers in organic agricultural production (Sabiiti, 2011),

Simple composting technologies, such as pit composting, are practiced by smallholder farmers in Malawi. However, composting is not commonly practiced due to several reasons, including the lack of knowledge (Mustafa-Msukwa et al., 2011) and difficulty of acquiring materials. Many farmers in Malawi find it difficult to secure compost materials even though maize residue is widely available as maize accounts for approximately 60% of the cropped area (Kumwenda et al., 1997). Therefore, compost making with maize residue will be most feasible in Malawi. However, composts vary considerably in terms of physical and chemical characteristics, which are influenced by material composition and maturity (Integrated Waste Management Board, 2002; Gigliotti et al., 2005). To increase compost use among smallholders, good-quality compost obtainable by advanced maturity techniques is sought.

Compost maturity is primarily governed by compost material and fermentation. A number of maturity and stability indicators have been proposed, including C/N ratio, microbial activity, germination index, cation exchange capacity (CEC), humic substance, dissolved organic matter, NH_4^+ and NO_3^-, and NH_4^+/NO_3^- ratio (Harada and Inoko, 1980; Zucconi et al., 1981; Iglesia and Perez, 1992; Hue and Liu, 1995; Bernal et al., 1998; Paredes et al., 2000; Eggen and Vethe, 2001; Benito et al., 2003; Smith and Hughes, 2004; Goyal et al., 2005; Tang et al., 2006; Pullicino et al., 2007).

Although, many maturity indicators have been proposed, no single maturity indicator can be applied universally as compost materials are so diverse. Therefore, it is necessary to determine the suitable compost maturity indicator for each type of compost. The Sustainable Land Management Promotion Project (SLMP), a collaborative effort between Malawi and Japan, was implemented in November 2011 with the aim of promoting sustainable land management technologies among smallholder farmers in the country. Its objective was to improve soil fertility through compost application. Different types of composts were produced primarily from maize residue. This study was carried out with the following objectives in mind: 1) to characterize compost materials and compost in terms of chemical fertility; 2) to examine fermentation rate by monitoring temperature change, and 3) to identify adequate maturity parameters for use in the field.

MATERIALS AND METHODS

Study site

Compost making was carried out at Mkondezi (MKD) Research Station of the Department of Agricultural Research Services (DARS). MKD is located 11°36'S, 34°18'E at the altitude of 471 m. Mean annual rainfall in MKD from 2002 to 2013 was 1,439 mm. The annual average temperature is 23.5°C.

Compost preparation

Composts were made with three methods (Changu, Windrow and Bokasi) (NRAES, 1992; Japan International Cooperation Agency, 2005; Nalivata, 2007) and environments (shade, plastic and open) (Figure 1). There is no uniform preparation procedure in these three method and varies a lot depending on a place where composting is carried out. Materials used for Changu and Windrow in this study were maize stalk, cattle manure, ash and virgin soil. In addition to these, grass was added for Bokasi. The effects of legume residue (soybean) were also examined by comparing composts with legume addition and no-addition composts. In Changu, the materials were piled up and shaped into cones and were turned regularly during preparation. In Windrow, the materials were layered to form long narrow piles. In Bokasi, the materials were used in small amounts for compost making in a short period (NRAES, 1992).

Compost material and compost analysis

The chemical analysis of compost and compost materials, namely, maize stalk, cattle dung, virgin soil, and soybean residue, was carried out at Lunyangwa Station, DARS. pH, Na and electrical conductivity (EC) were measured after shaking fresh compost samples for 1 h at the soil-water ratio of 1:5. K obtained by NH_4Ac extraction and NO_3^- and Na obtained by water extraction were measured with ion meters (HORIBA LAQUAtwin, models B-731 for K, B-741 for NO_3^-, and B-722 for Na). Available P and S were determined with a spectrophotometer (Bellstone WSP-UV800A) using extracts obtained with Mehlich III (Mehlich, 1984). Total C and N contents were determined by the Walkley-Black method (Walkley and Black, 1934) and by the micro Kjeldahl method (AOAC 1995), respectively. Available N was measured by the boiling decoction method (Yamaki, 2008).

Fermentation involves organic matter decomposition by microbial activity. Therefore, the quality of organic matter greatly affects the decomposition process. Decomposability varies depending on the kind of material; for example, glucose, sugar and protein are easy to decompose, whereas cellulose, lignin, etc. are refractive and need a long time for decomposition. In order to examine the decomposability of compost materials, insoluble lignin and cellulose contents in the compost materials were determined by the Van Soest method (Van Soest, 1996).

Temperature change during fermentation

Temperature changes during composting reflect the fermentation condition and are related to compost quality. Temperature changes were monitored for two consecutive years from 2013 through 2014, from the start of compost making until the time the temperature

Figure 1. Three composting methods (Changu, Windrow, Bokasi) and three environments (shade, open and plastic).

showed no more changes even after turning. Measurement was conducted two times a day at 8 a.m. and 2 p.m., but only data of 8 a.m. were used for analysis as the temperature changes at both times were identical.

Compost maturity

A number of parameters were used to assess compost maturity, including color, odor, shape, water content, pH, EC, K, PO_3^-, N, C/N, germination rate and NH_4^+. Composts were extracted with hot water and the extracts were used in the germination test of rape seeds. The extracts were also used for absorption measurements with a spectrophotometer. Compost maturity indices were determined at the end of fermentation. Ten grams of fresh compost samples was diluted with 100 mL of boiled water and the mixture was filtered after one hour. Absorption of the filtrate was measured at 465 nm with the spectrophotometer. A germination test was conducted using the same filtrate on a Petri dish containing 50 rape seeds on filter paper.

As the C/N ratio of compost material contributes to compost maturity (Guo et al., 2012), three C/N ratios (23, 40, 60) were prepared by changing the mixture ratio of maize residue, rice bran, cow dung to test their effects on fermentation. The difference in ECs between fresh and dry composts is correlated with NH_4^+ generated during fermentation (Yamada et al., 2012). As fermentation proceeds, the difference in ECs becomes smaller due to reduced NH_4^+ generation, and this could be used as a simple indicator of compost maturity. After EC of fresh compost sample was measured, the sample was dried at 105°C and dry EC was measured.

Statistical analysis

Statistical analysis was conducted using JMP 8.0.2 version for Windows (SAS Inc., 2009). Correlation analysis was conducted for the chemical characteristics of composts and the fermentation indices. The Tukey-Kramer HSD test was performed for the F-test at the significance level of either 0.1 or 0.5.

RESULTS AND DISCUSSION

Material composition of compost

Table 1 shows the amounts of compost materials used to make one heap each of the three types of composts. A large amount of compost materials were used to make one heap of Windrow, whereas small amounts were used for Changu and Bokasi. Maize stalk and cattle dung contents varied among the three types of composts. Bokasi had much lower cattle dung content than Windrow or Changu, whereas maize stalk content was almost the

Table 1. Amounts of compost materials (kg) to make one heap each of three types of composts (2014).

Material (kg)	Changu		Windrow		Bokasi	
	+ L	**- L**	**+ L**	**- L**	**+ L**	**- L**
Maize stalk	40	152	200	480	32	32
Cattle dung	114	114	228	115	10	10
Ash	2.5	11	7	3	20	20
Virgin soil	15	15	50	50	50	50
Soybean residue	18		175		28	
Grass					33	33
Total amount (kg)	189	292	660	648	173	145
Maize stalk (%)	21.1	52.1	30.3	74.1	18.5	22.1
Cattle dung (%)	60.2	39.0	34.5	17.7	5.8	6.9

+ L – with legume, - L – no legume

Table 2. Chemical composition of compost materials.

Material	pH	EC	K^+	NO_3^-	Na^+	C	N
		µS/cm	mg/l	mg/l	mg/l	%	%
Maize stalk	7.5	119	38	58	400	14.4	0.06
Cattle dung	8.7	247	68	160	210	0.15	0.23
Virgin soil	6.6	53	7	13	100	0.12	0.025
Soy bean residue	7.4	234	73	63	590	11.6	0.15

same regardless of compost type.

Chemical characteristics of compost materials

General chemical characteristics

Maize stalk pH is 7.5 and cattle dung pH, 8.7 (Table 2). The high pH of cattle dung originates from the high salt content, as shown by the EC value. Maize stalk has an average N content of 0.06%. As NO3- content in cattle dung is almost 20 times its content in virgin soil, compost made of materials containing cattle dung would improve soil chemical fertility. As a general characteristic of plant materials, K and S contents are also high. As K content in Malawi soil is extremely low (Mueller et al., 1993;

Gwosdz et al., 1996; Chilimba and Liwimbi, 2008), the addition of K by compost application would improve soil fertility.

P content in compost materials is low. More than 20 ppm would be necessary for maize growth (Staton, 2014). As all the compost materials have less than 10 ppm P content, P provision by another source would be necessary to achieve sustainable maize yield.

Characterization of compost materials by decomposability

As for organic constituents, not only element composition, but also decomposability should be examined because the fate of decomposition governs nutrient status and soil organic matter contents. Organic matter is composed of labile and refractive fractions according to decomposability (Figure 2). From the point of view of agriculture, labile organic matter stimulates microbial activity, which in turn activates the N cycle in soil. However, its rapid decomposition affects plant growth, leading to N deficiency, which is a common phenomenon when an excess amount of N-rich materials are incorporated into soils. Cattle dung is abundant in inorganic matter, its ash content being 73.5% (Table 3), and the inorganic matter is promptly absorbed by plants.

Refractive organic matter remains in soil for a long time and contributes to the formation of soil aggregates. Due to the presence of refractive organic matter, effective carbon sequestration in soil can be expected. In this regard, the evaluation of compost material decomposability is important. Acid detergent soluble organic matter is a promising indicator of labile organic matter. Portions that are insoluble in acid detergent are called acid digestion fiber (ADF). ADF contains lignin, which is reported to remain in soil for three years. Maize stalk is composed of 39.3% ADF and 54.3% acid-soluble organic matter (Table 3). On the other hand, maize bran contains a small amount of ADF (2.2%) and over 70% acid-soluble organic matter. The less degradable nature of maize stalk than maize bran will influence fermentation behavior if an excess amount of maize stalk is used for compost

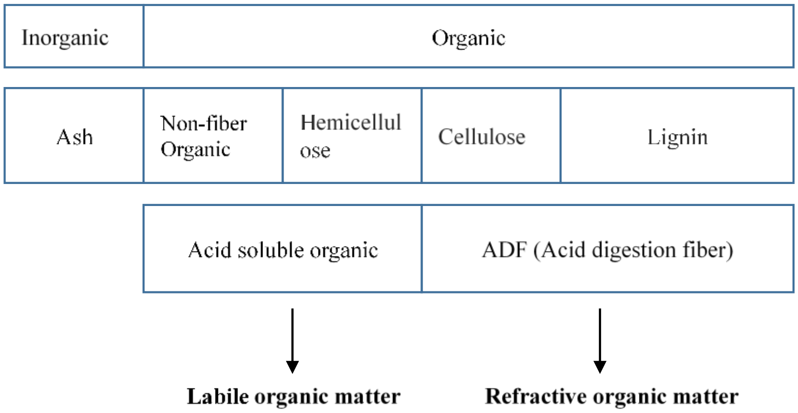

Figure 2. Inorganic and organic constituents in composts and lignocellulosic fibers in organic constituents.

Table 3. Composition of ash, acid-soluble organic matter and ADF in compost materials.

	Ash (%)	Acid-soluble organic (%)	ADF (%)
Maize stalk	6.4	54.3	39.3
Catttle dung	73.5	15.1	11.5
Maize bran	20.3	77.5	2.2

Table 4. Chemical properties of prepared composts (n = 2).

Method	Environment	pH	EC (μS/cm)	C (%)	N (%)	NO_3 (mg/l)	P (ppm)	K (mg/L)	Na (mg/l)	S (ppm)
Changu	Open	8.53	241.6	6.18	0.54	286	6.67	270	534	23.2
	Plastic	8.86	245.0	5.73	0.64	427	7.93	400	607	29.6
	Shade	9.45	168.5	5.97	0.80	625	4.26	325	580	17.9
Windrow	Open	9.11	157.0	3.16	0.53	440	3.38	415	430	20.3
	Plastic	9.37	184.0	6.81	0.47	585	4.04	285	345	22.3
	Shade	9.29	161.0	4.29	0.40	590	3.41	350	560	23.4
Bokasi	Open	9.40	133.5	6.69	0.43	213	5.87	440	375	13.1
	Plastic	9.32	151.5	1.14	0.46	490	8.18	380	495	19.6
	Shade	9.42	184.0	5.15	0.28	550	1.69	315	500	21.8

making.

Compost analysis

The low pH and the high EC in Changu Open/Plastic indicated advanced fermentation (Table 4). In the decomposition (oxidation) of compost materials having a large amount of salts, proton was consumed, resulting in a low pH.

N contents differed according to the compost making method. Changu and Windrow had almost the same N contents, whereas Bokasi showed lower mean N contents (Table 4). N% of composts is influenced by the contents of maize stalk and cattle dung. A larger amount of cattle dung and a smaller amount of maize stalk in Changu and Windrow resulted in more N-rich composts. From 70 compost samples, the following equation was formulated to estimate N% of compost.

N% = 0.55 - 0.01 x % maize stalk + 0.03 x % cattle dung (r^2 = 0.37)

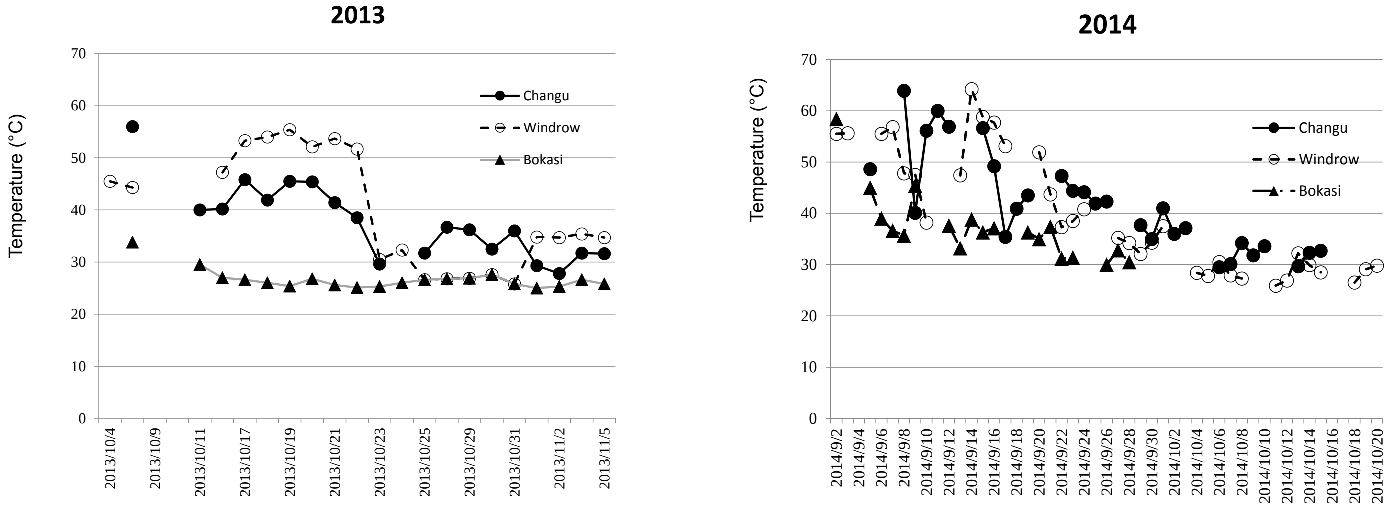

Figure 3. Changes in fermentation temperature of Changu, Windrow and Bokasi in Shade environment in 2013 (left) and 2014 (right).

K content in the Open environment was higher for Bokasi than Changu, whereas K content in plastic was low except for Changu. The results indicate that the increase in temperature brought about by plastic accelerated fermentation and more K was released by fermentation and lost by leaching.

NO3- content was highest in Shade and lowest in Open, indicating that NO3- is easily leached in the open environment. However, NO3- is relatively well preserved in plastic.

C% increased in the order of Windrow, Changu and Bokasi, which corresponded to % maize stalk in compost material (Table 1). The low C% for Bokasi + Plastic was a consequence of a high rate of decomposition. P content differed among the three methods: Changu showed the highest P values, with Bokasi being second and Windrow third.

Temperature changes during fermentation

Temperature monitoring was performed to observe fermentation behavior in the three types of composts. In 2013, the fermentation patterns of Changu and Windrow were almost the same, whereas no fermentation took place in Bokasi as indicated by the lack of temperature rise (Figure 3). The fermentation rate increased in the order of Bokasi, Changu and Windrow, and available N also increased in this order (Figure 5). Windrow was made with the largest amount of compost materials. Because of its large weight, more heat was stored inside the heap, which promoted fermentation.

Pathogenic bacteria, such as fecal coliform bacteria, died rapidly when cow dung temperature exceeded 50°C (Gong, 2007) and weed seeds lost their germination capacity at temperatures higher than 50°C (Feed Innovation Services BV, 2013). Therefore, the number of days with temperatures exceeding 50°C can be used as a key indicator of fermentation.

The number of days with temperatures higher than 50°C was significantly correlated with pH and EC (Table 5). As fermentation proceeds, pH decreases and EC increases. The pH decrease is attributable to the shift from NH_4^+ to NO_3^-, and the EC increase is due to increases in K, Na, Cl and NO_3^- contents during fermentation.

Fermentation temperatures of Bokasi were highest in plastic, followed by open and shade (Figure 4). Plastic promoted the fermentation of Bokasi by maintaining heat inside the compost heap. However, the temperature change in plastic was not markedly different from that in open for the case of Changu. The effects of the environment differed depending on the method, possibly because of the different total volumes and compositions of compost materials (Table 1).

Fermentation rate

The number of days where temperatures exceeded 50°C was related to the fermentation rate. Changu had the highest fermentation rate; it recorded more than 10 days where temperatures exceeded 50°C, whereas Bokasi recorded merely 2 days of over 50°C (Figure 6). Legume addition promoted fermentation and consequently, the number of days where temperatures exceeded 50°C was increased. pH was increased due to the accelerated fermentation by legume addition, but the contents of other nutrients did not change.

The legume effect on fermentation was significant in Changu and Windrow, but not in Bokasi (Figure 6), however there was no significant difference among the

Table 5. Correlation matrix of compost chemical characteristics and fermentation rate.

	Days >50°C	pH	EC	K	NO^{3+}	Na	TC	P	S	TN	C/N
pH	-0.57**										
EC	0.48**	-0.71**									
K	-0.41	0.22	0.09								
NO^{3+}	-0.06	0.19	0.11	0.14							
Na	-0.01	0.08	0.24	0.19	0.20						
TC	-0.18	0.15	0.15	0.09	-0.26	0.16					
P	0.38	-0.44**	0.41**	-0.01	-0.29	0.00	-0.07				
S	0.41	-0.04	0.30	0.05	0.04	0.20	0.07	0.13			
TN	0.01	-0.17	0.34	0.13	-0.04	0.39	0.35	0.16	0.15		
C/N	-0.18	0.28	-0.12	-0.09	0.04	-0.04	0.55**	-0.42**	-0.16	-0.46**	
Av. N	0.51**	-0.47**	0.38	-0.27	-0.31	-0.12	0.08	0.28	0.21	-0.03	0.06

* and ** indicate 1 and 5% level of significance, respectively.

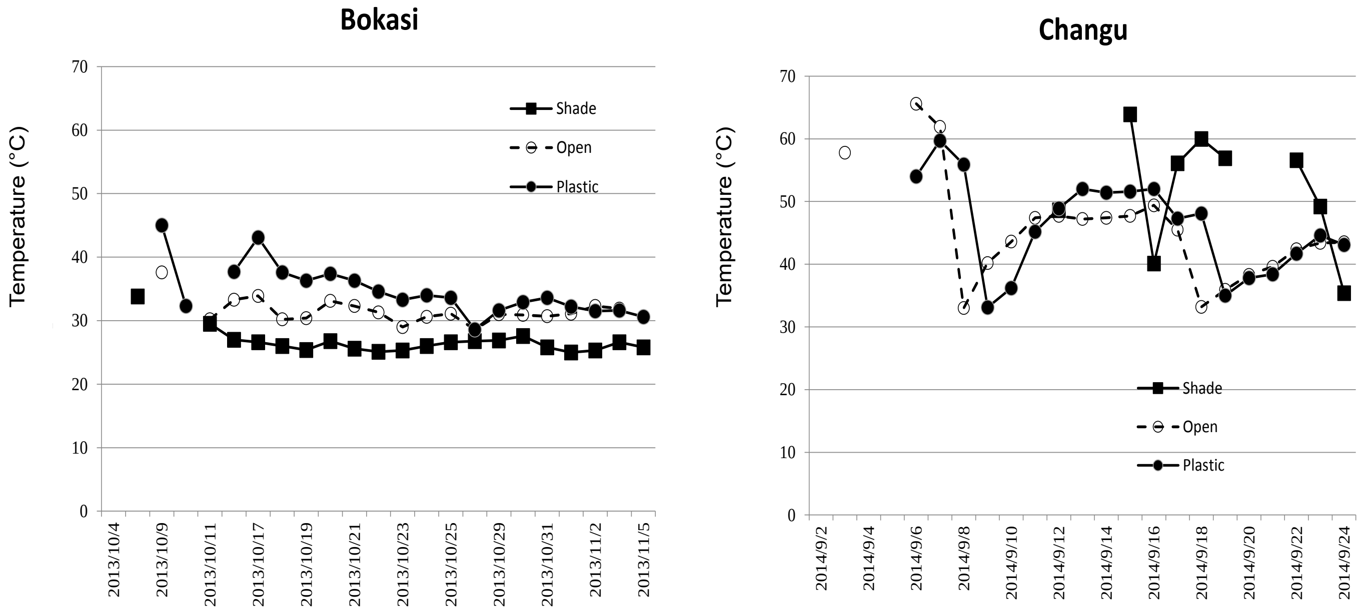

Figure 4. Changes in fermentation temperature in shade, open and plastic environments of Bokasi (left) and Changu (right) in 2014.

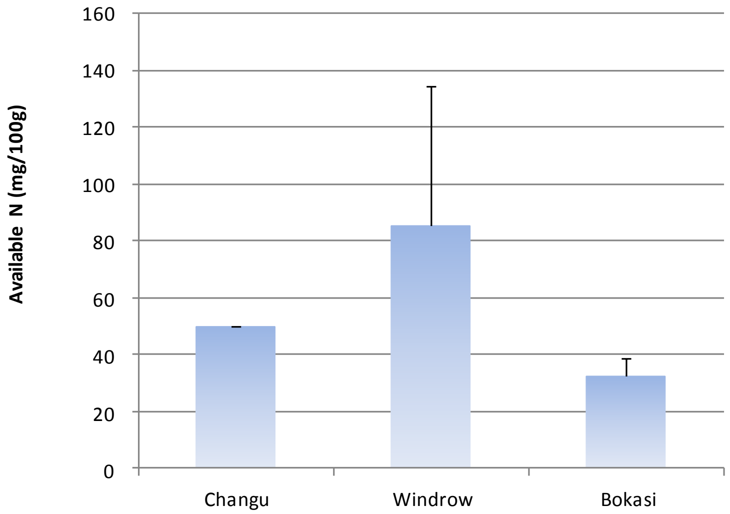

Figure 5. Available N in Changu, Windrow and Bokasi prepared in 2013 (n=3). Error bars indicate standard deviation.

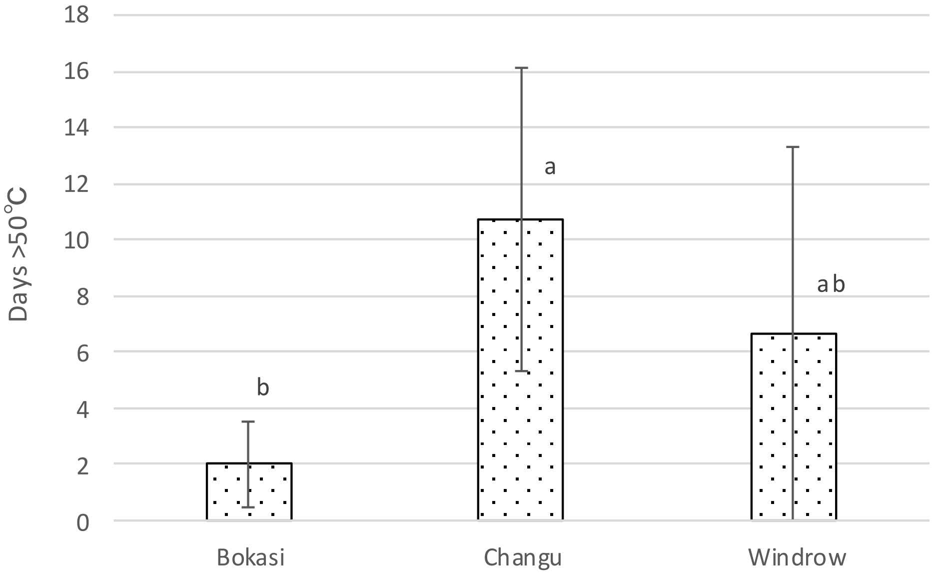

Figure 6. Fermentation temperature difference among the three systems (n=6 in Bokasi and Windrow, n=11 in Changu). Error bars indicate standard deviation and different letters show statistically significant difference between the methods.

environments (open, plastic and Changu), indicating that the environment had little influence on the fermentation.

Compost maturity

The germination test revealed different maturity levels among the three methods (Figure 7). The germination rate was 40% with distilled water, but was increased when the extracts of composts were used. Germination rates increased in the order of Bokasi, Changu and Windrow, and corresponded to the order of available N production (Figure 5). Absorption values of the extracts of composts measured at 465 nm were correlated with the germination rate, as expressed by the following equation.

Germination rate (%) = 9.36 x absorption value (465 nm) + 47.1 (r^2 = 0.38)

Both germination rate and absorption value would be a

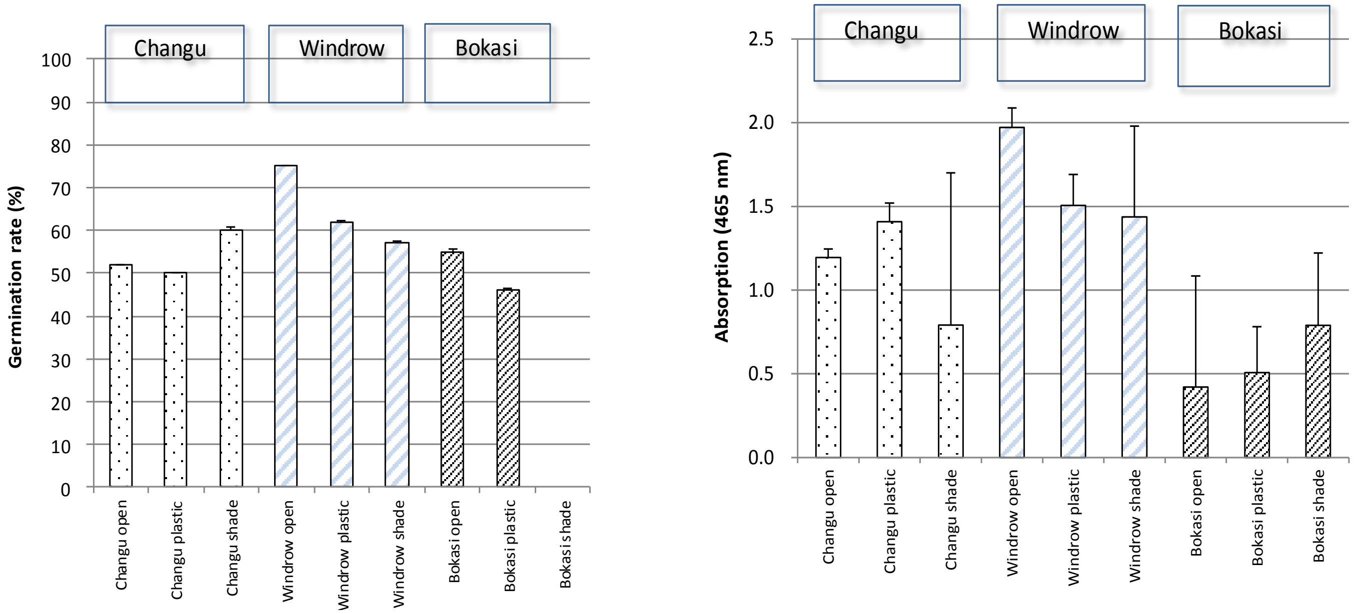

Figure 7. Germination rates and absorption values of composts. Error bars indicate standard deviation.

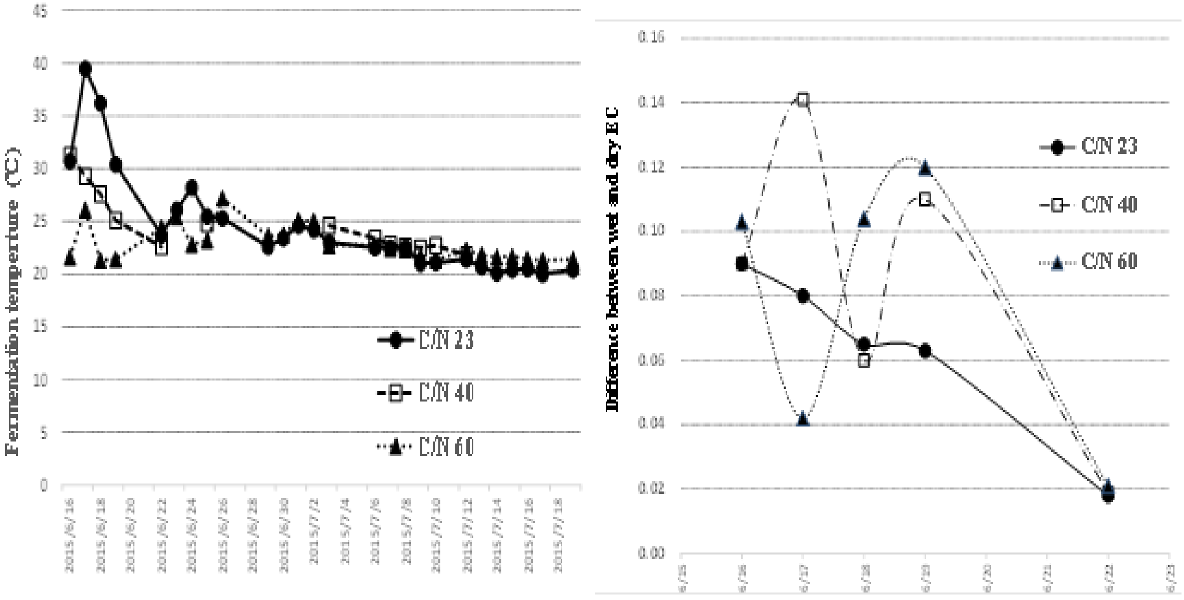

Figure 8. Changes in fermentation temperature (left) and difference between wet EC and dry EC (right) at different C/N ratios in composts.

practical indicator of compost maturity. For the determination of absorption value, a spectrophotometer is necessary, which is useful for handling a large number of compost samples.

Composts having various C/N ratios were prepared by changing the mixture ratio of maize stalk and cattle dung. C/N 23 compost showed a large temperature rise when compared with C/N 40 and C/N 60 composts (Figure 8). Fermentation temperature increased rapidly in the first week but became stable thereafter in C/N 23 compost. The temperature stability was brought about by the rapid decomposition of labile (easily degradable) substrates. The difference between wet EC and dry EC was reduced as fermentation proceeded because NH_3 generated by compost fermentation was diminished. Fermentation was completed in one month because the difference between the two EC values became nearly zero. EC differences in C/N 23 steadily decreased whereas the decrease was rather irregular in C/N 40 and C/N 60. The results indicate that C/N adjustment is important for compost maturity and fermentation at the initial stage.

Conflict of Interests

The authors have not declared any conflict of interests.

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