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https://doi.org/10.5109/2339104

出版情報：九州大学大学院農学研究院紀要. 64 (2), pp.205-211, 2019-09-02. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **64** (2), 205–211 (2019)

Efficiencies of a Commercial Microbial Inoculant and Poultry Litter in Composting Dry Maize Stovers

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(*Received May 8, 2019 and accepted May 8, 2019*)

Although animal manures have for years been used to amend the C: N ratios of lignocellulosic wastes to hasten the composting process, their efficiencies in comparison to commercial microbial inoculants are hitherto undocumented. This study purposed to compare the efficacies of a commercial microbial inoculant and poultry litter in composting organic wastes with high C: N ratios such as maize stovers. The experiment was laid in a completely randomised design (CRD) with four treatments and these were; stovers + poultry litter (S.P), stovers + Bio–soils compost$^+$ (S.B), Stovers + Poultry litter + Bio–soils compost$^+$ (S.P.B) and stovers alone (S). Bio–soils compost$^+$ was the commercial microbial inoculant used in this study. Each treatment was replicated thrice. Composting materials were randomly picked weekly for the laboratory analysis of pH, ammonium and nitrate nitrogen, water–soluble carbon (WSC), Carbon–dioxide evolution rate, nitrogen (TN), phosphorus (P), total organic carbon (TOC) and potassium (K). The data obtained were analysed for variance and compared with compost maturity and stability indices already established by various former studies. Stovers composted with a combination of poultry litter and Bio–soils compost$^+$ did mature not only the earliest but also had the highest nutrient value. There were no noticeable differences in the composting rates of poultry litter and Bio–soils compost$^+$ as stovers composted with either of them matured and stabilised almost at the same time. Additionally, stovers composted with poultry litter had higher nutrient compositions of NPK. Therefore, in cases where animal manures like poultry litter can be readily or cheaply accessed, purchasing commercial inoculants is not necessary but in cases where animal manures are not readily available, the microbial inoculants are a viable option.

Key words: Dry maize stovers, Composting, Microbial inoculants, Poultry litter, Compost stability and Maturity

INTRODUCTION

Many farmers, especially in developing countries, burn crop residues as a quick method of preparing for the next growing season (Sabiiti, 2011). However, burning agricultural wastes releases pollutants such as carbon dioxide, nitrous oxide, nitrogen dioxide and particles (smoke carbon), (Ezccura *et al.*, 2001), and fine particulate matter (Aneja *et al.*, 2008) into the atmosphere. 10% of the global fine particulate matter burden is ascribed to burning crop residues (Pozzer *et al.*, 2017). Turning these organic wastes into compost can help to not only sustainably recycle plant nutrients (Wiesman Zeev, 2009; Zahangir, 2017) but also improve environmental quality (Taiwo, 2011; Jara–Samaniego *et al.*, 2017). Compost is a valuable resource for soil amelioration and or organic fertiliser (Fischer and Glaser, 2012).

However, high C: N ratios of most of the crop residues imply that a lot of time is required before mature and stabilised compost can be obtained which discourages many farmers from composting them. While the optimal C: N ratios as necessary for a rapid, aerobic composting process are between 25 and 35 (Bernal *et al.*, 2009), most cereal wastes have C: N ratios over 40. Traditionally, these lignocellulosic wastes have always been amended with nitrogen–rich animal manures (Szogi *et al.*, 2015) but the usage of commercial microbial inoculants (Effective micro–organisms) has gained traction in the recent past. Although several studies have been conducted to assess the efficiency of the commercial inoculants in composting, there hasn't been much consensus among those studies. For example, research by Ohtaki *et al.* (1998) revealed that inoculations could enhance the decomposition of organic materials and reduce odorous gas emissions. This observation was later substantiated by Beidou *et al.* (2005) who reported that an inoculum containing Bacillus azotofixams, Bacillus megaterium, B. mucilaginosus and Trichoderma sp was very efficient in accelerating the degradation rate and stabilisation of the composting products. Also, Vargas–Garcı'a *et al.* (2007), concluded that the composting process could be improved by the addition of microorganisms appropriate for the characteristics of the raw materials used. Inoculation with thermo–tolerant and lipolytic microbes enhanced decomposition of food waste and shortened the maturation time in vessel com-

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posting as concluded by Tsai *et al*. (2007) and Ke *et al*. (2010).

Conversely, however, a study by Karnchanawong and Nissaikla (2013) concluded that it might not be necessary to add commercial inoculants to facilitate composting of household organic waste due to the slight improvement of the finished compost. Additionally, a study conducted by Abdullah *et al*. (2013) to determine the effects of using a mixed bacterial solution as a starter culture on kitchen–waste composting found no apparent differences in compost with an added starter culture. The urge to discerning the relative composting efficiencies of animal manures (commonly used to amend wastes with high C: N ratios) and the commercial microbial inoculants vindicated this study.

MATERIALS AND METHODS

The experiment was laid in a completely randomized design (CRD) with 4 treatments which included; Stovers + Poultry litter (S.P), Stovers + Bio–soils compost$^+$ (S.B), Stovers + Poultry litter + Bio–soils compost$^+$ (S.P.B) and Stovers (the control) (S).

Maize stovers were chopped into small pieces to improve the rate of decomposition by micro–organisms. The commercial inoculant (Bio–soils compost$^+$) was mixed according to the manufacturer's instructions and sprinkled over the chopped maize stovers of S.B, and S.P.B. Squared outdoor composting boxes were used with each side measuring 1.5 metres. Temperatures and the moisture content of each composting unit were regularly monitored and the latter adjusted accordingly. All composting materials were turned on a fortnight basis to ensure proper aeration and decomposition of the materials.

Composting materials were randomly picked on a fortnight basis from each of the composting units and taken to the laboratory for analysis of pH, mineral nitrogen (ammonium and nitrate nitrogen), water–soluble carbon (WSC), Carbon–dioxide evolution rate, total organic carbon (TOC), nitrogen (TN), phosphorus (P), and potassium (K). Organic nitrogen (OrN) was calculated by subtracting inorganic (mineral nitrogen) from the total nitrogen.

The experiment was run for 24 weeks.

LABORATORY ANALYSIS OF COMPOST SAMPLES

Measurement of pH and Water–soluble organic carbon (WSC)

The pH of each of the compost sample was determined from a compost water solution ratio of 1:10 (w/v) by inserting the pH meter electrode in the supernatant of a settled suspension. After determining pH, contents were further extracted by shaking on a reciprocal shaker for a day (24 hours). The extracts were centrifuged at 10 K rpm for 20 minutes and filtered through No. 42 Whatman paper and analysed for organic carbon as stipulated by okalebo *et al*. (2002)

Mineral nitrogen (NH_4^+N and NO_3^-N)

Ammonium and nitrate nitrogen were determined using the colourimetric method after extraction with potassium sulphate solution. NH_4^+N and NO_3^-N were determined using procedures described by Okalebo *et al*. (2002). In the case of ammonium nitrogen 0, 5, 10, 15, 20 and 25 ml of standard solution (0.1mgNH_4^+N/ml) while for nitrate–nitrogen 0, 2, 4, 6, 8 and 10 ml of the standard solution (0.05mgNO_3^-N/ml) were pipetted into a clean set of 100 ml volumetric flasks and made up to the mark with 0.5 M potassium sulphate. The absorbances were measured at 655 nm and 419 nm for NH_4^+N and NO_3^-N respectively. Calibration curves were plotted in each case, and the concentrations of both ammonium and nitrate were calculated after obtaining the moisture correction factor.

Carbon–dioxide (CO_2) Evolution/Respiration

CO_2 evolution as a result of respiration of compost microbes was measured using static measurement method (Soda lime trap method) as described by Knoepp and Vose (2002). 10 g of each compost sample was sealed in a 0.5 L vessel along with a beaker containing a known weight of oven dried (105°C) soda lime (2.0 mesh). The samples were incubated at room temperature. Blanks necessary for carbon–dioxide flux calculation were set up as in the case of compost samples but without putting any sample in a vessel. Soda lime traps were removed after 24 hrs, oven dried and reweighed to determine CO_2 absorbed.

Nitrogen (N), Phosphorus (P) and Potassium (K)

Nitrogen, phosphorus and potassium concentrations were analysed after digestion of compost samples. The samples for N and P were digested at 110°c for 1 hour and then after hydrogen peroxide additions at 330°C until the solution turned colourless while those for K were digested at 360°C for 2 hours. Both nitrogen and phosphorus concentrations were determined following the colourimetric procedures outlined by Okalebo *et al*. (2002). Total nitrogen was determined after the dilution of the digests and the blanks with distilled water. Total phosphorus was determined after pH adjustment of the digest. Potassium concentration was determined by spectrometric analysis after digestion of samples following Kjeldahl procedures as described by Okalebo *et al*. (2002). The analysis followed a 2–hour digestion at 360°C after the addition of 4.4 ml of the digestion mixture to the oven dried compost samples and reagent blanks.

Total organic carbon (TOC)

The total organic carbon was determined by the wet oxidation method described by Okalebo *et al*. (2002).

Statistical Analysis

The obtained data were analysed for variance using genstat. pH data was normalised log10 transformation.

RESULTS AND DISCUSSIONS

pH variations

The observed general trend of increasing pH in the first weeks of the experiment can be ascribed the to the accumulation of ammonium ions (NH_4^+) released as a result of rapid biodegradation of substrates as indicated by Wichuk and McCartney, 2008. They additionally showed that NH_4^+ is nitrified to nitrates as the compost matures which causes decreases in the pH observed in the later weeks of the experiment. Consequently, high pH values may be indicative of high NH_4^+ concentration and thus compost immaturity (ASCP 2001). Several studies have studied pH as a potential indicator of compost maturity and stability coming up with different values for a mature and stable compost. For example, studies by Avnimelech *et al.* (1996), and Brewer and Sullivan (2001a, 2003) found that pH values of mature and stable composts approach neutrality, i.e. 6.5 to 7.0. Basing on this value, S.P.B composting materials matured and stabilised in the 24th week while the rest were still immature at the end of the experiment. Other studies, however, for example by Grebus *et al.* (1994) indicated that the pH of grass clippings compost remained slightly basic (7.5 to 8.1) even in a stable and mature state. This value means that S.P.B compost matured in the 20th week while S.P and S.B matured in the 22nd week. The control, on the other hand, didn't mature.

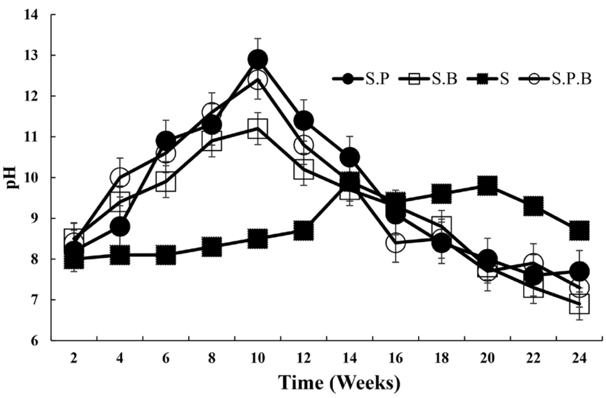

Fig. 1. Changes in pH during composting.

Changes in WSC and WSC: OrN ratio during Composting

WSC concentrations gradually increased in the first six or eight weeks and then decreased after that until the end of the composting process. This observation was in agreement with what Wichuk and McCartney (2008) said that stable and mature composts usually have lower concentrations of water–soluble organic carbon than immature and unstable organic materials because soluble and readily bioavailable compounds get used up as compost matures. Therefore, an evaluation of the WSC or dissolved organic carbon (DOC) as is sometimes called can be useful in the determination of compost stability and maturity while Raj and Antil (2012) proposed the usage of WSC: OrN as a stability index.

Hue and Liu (1995) found that compost stabilised at WSC levels below 4 g kg^{-1}, however, they suggested that any compost with WSC less than 10 g kg^{-1} dry weight could be considered stable and mature. This suggestion was later vindicated by Avnimelech *et al.* (1996) who found that WSC levels stabilised below 10 g kg^{-1} and going by this value, S.P.B compost matured in the 12th week, S.B in the 16th week, S.P in the 20th week while S composting materials didn't mature. Bernal *et al.* (1998) established a WSC value of less than 1.7% as an index of stable and mature compost and accordingly, S.P.B matured and stabilised in the 10th week, S.B in the 14th week, S.P in the 18th week and S in the 22nd. Zmora–Nahum *et al.* (2005) observed that all composts they studied about had WSC concentrations below 2 g kg^{-1} at maturity, regardless of the starting materials and initial WSC concentrations. They proffered that a stable and mature compost should have WSC levels below 4 g kg^{-1}. Basing on this limit, S.P.B matured and stabilised in the 20th week, S.B in the 22nd week, S.P in the 24th week whereas the control was immature at the end of the experiment. Shao *et al.* (2009) also noted that the WSC concentration of a municipal solid waste compost stabilised around 4 g kg^{-1}. As indicated by Wichuk and McCartney (2008), the WSC: OrN ratios in the current study also decreased throughout the composting periods as shown in table 1 above. Hue and Liu (1995) proposed a WSC: OrN ratio of less than 0.70 as an index for a mature compost. Hence, S.P.B matured and stabilised in the 10th week, S.B in the 18th week, S.P in the 22nd week while S was immature at the end of the experiment. Bernal *et al.* (1998) proposed the WSC: OrN of less than 0.55 to represent a well–mature and stabilised compost. With inference to this index, S.P.B, S.B and S.P matured and stabilised in the 12th, 20th and 22nd weeks respectively while S was still immature.

Table 1. Some chemical properties of the maize stovers and poultry litter

Parameter	Maize Stovers	Poultry Litter
Total Organic Carbon (TOC) (%)	44.90	16.00
Total Nitrogen (%)	0.97	1.96
Phosphorus (%)	0.30	1.30
Potassium (%)	0.49	0.88
C: N ratio	46.29	8.16

Changes in CER during Composting

Microbial activity results in CO_2 production (Wichuk and McCartney, 2008) – which accounts for high rates of CO_2 evolved in the first weeks of the experiment. The above stated anthors also indicated that the CO_2 evolution rates decrease as compost stabilises due to microbial activity decline something that concurred with our observations. Several studies have confirmed that CO_2 evolution is a good indicator of compost stability. Brewer and Sullivan (2001a) proposed a limit of 6 mg CO_2 g^{-1} carbon (C) day^{-1} or less which means that S.P.B and S.B matured and stabilised in the 18th week, S.P in the 22nd week while S didn't mature by the end of the experiment. Additionally, Goyal *et al*. (2005) proposed a threshold value of 500 mg CO_2 100 g^{-1} total organic carbon for a stable compost. Basing on this limit, S.P.B and S.B matured and stabilised in the 20th week, S.P in the 22nd week whereas the control was still immature.

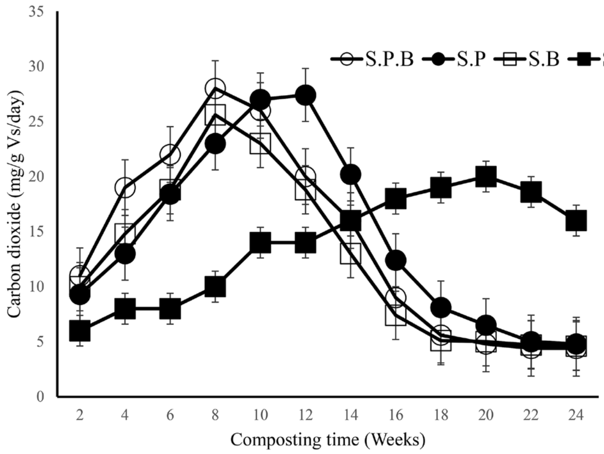

Fig. 2. Changes in carbon–dioxide evolution rate (CER) during composting.

Variations in NH_4^+–N: NO_3^-–N during Composting

As previously mentioned, the decomposition of proteins during active composting results in the release of relatively high levels of ammonium ions (NH_4^+) which undergo nitrification to produce nitrate (NO_3^-) as the composting process progress. This decrease in NH_4^+ and increase in NO_3^- causes an increase in the NO_3^-: NH_4^+ ratio as compost matures (Brinton 2000; ASCP 2001; Sullivan and Miller 2001) which accounts for the observed NO_3^-: NH_4^+ decreases as the experiment progressed. Bernal *et al*. (1998) recommended an NH_4^+: NO_3^- ratio of 0.16 or less as an appropriate representation of mature composts and thus, S.P.B matured in the 16th week, S.P and S.B in the 18th week while S was immature at the end of the experiment. ASCP (2001) indicated that the NO_3^-: NH_4^+ ratio is a handy parameter in evaluating compost quality, with a value below 2:1 indicating an immature compost product. If we refer to this threshold value, therefore, S.P.B, S.B and S.P matured in the 12th week while S did so in the 18th week. On the other hand, Ko *et al*. (2008) proposed a threshold of 1:1 for the NH_4^+: NO_3^- ratio and indicated that this ratio is more useful than the C: N ratio in assessing compost for maturity and stability. However, this threshold value couldn't be applied in our current study because it was obtained so early when all the composting materials were still immature.

Changes in Carbon to Nitrogen ratios

The observed trend of decreasing C: N ratios in the current study conforms to observations made by Khan *et al*. (2009), Raj and Antil (2012) and others. This is because as organic materials decompose CO_2 is released, consequently decreasing carbon concentrations (Bio–Logic 2001; Khan *et al*., 2009). Different studies have established different threshold C: N ratios for mature composts with ranges from less than 20:1 to <10:1 (Mathur *et al*., 1993; Chefetz *et al*., 1996; Goyal *et al*., 2005). However, Sullivan and Miller (2001) suggested that the C: N ratio limit for mature and stable compost should be based upon that of the stable soil organic matter, which is generally between 10:1 and 15:1.

Cayuela *et al*. (2008), reported a decline in C: N from 25:1 to 15:1 over 34 or 40 weeks of composting of olive mill wastes. Raj and Antil (2012) also indicated that farm waste compost stabilised at a C: N ratio of less than 15. Considering a C: N ratio of 15:1 as a limit for a mature compost implies that S.B matured in the 12th week, S.P.B and S.P in the 14th week while S was immature at the end of the experiment. Additionally, if 10:1is taken as the threshold C: N ratio of the mature compost,

Table 2. Variations WSC (%) and WSC: OrN with composting time

Time	S.B		S.P		S.P.B		S	
(Weeks)	WSC	W: OrN	WSC	W: OrN	WSC	W: OrN	WSC	W: OrN
2	4.96±0.91	3.93±0.89	5.13±1.51	3.67±0.77	3.48±1.07	2.82±0.17	5.88±0.97	7.15±1.54
4	5.33±1.02	3.57±0.84	5.98±2.01	3.54±0.35	4.02±0.64	2.60±0.11	4.17±1.11	4.88±1.07
6	5.95±1.10	3.28±0.68	6.30±1.99	3.18±0.79	3.80±0.77	2.08±0.27	4.90±1.70	4.62±1.02
8	4.15±1.01	3.57±0.76	6.14±2.45	2.73±0.88	2.53±0.43	1.41±0.15	4.00±1.05	4.97±1.23
10	3.70±0.78	3.30±0.71	4.64±1.11	2.60±0.91	1.05±0.21	0.59±0.08	3.65±1.99	4.60±1.12
12	2.81±0.63	2.67±0.65	4.08±1.40	1.99±0.66	0.84±0.14	0.49±0.01	3.38±0.99	4.61±0.87
14	1.02±0.17	1.04±0.34	3.09±1.12	2.06±0.55	0.88±0.07	0.53±0.13	3.08±1.07	4.32±1.08
16	0.99±0.09	1.07±0.39	2.75±1.08	1.85±0.90	0.61±0.06	0.50±0.10	3.46±1.02	4.62±1.14
18	0.53±0.02	0.62±0.11	1.14±0.55	1.50±0.62	0.43±0.09	0.55±0.17	3.00±0.15	3.21±0.93
20	0.49±0.05	0.46±0.14	0.91±0.22	1.06±0.35	0.34±0.03	0.63±0.29	1.89±0.02	1.81±0.09
22	0.39±0.04	0.56±0.10	0.44±0.15	0.54±0.16	0.28±0.00	0.50±0.03	1.53±0.06	1.36±0.00
24	0.27±0.05	0.50±0.21	0.36±0.18	0.53±0.19	0.19±0.02	0.32±0.07	1.32±0.06	1.26±0.00

WSC: Water Soluble Carbon, W: OrN: Water Soluble Carbon to Organic Nitrogen ratio.

then S.B, S.P and S.P.B matured in the 24th week whereas S was still immature by the end of the experiment.

Variations in N, P and K during composting

Both N and K decreased throughout the composting process while phosphorus content increased. For all the three nutrient elements, staw mixed with poultry litter had the highest concentrations at the end of the experiment which can be explained by the higher contents of these nutrients in animal excreta. Although these parameters can't be used for judging the maturity and stability of compost, they are important in the agronomic aspect, i.e. good indicator of compost's ability to support proper plant growth and development.

CONCLUSIONS

The time difference between when the microbial inoculant treated dry straw and poultry litter amended ones matured and stabilised is so short to justify any added cost of buying a commercial inoculant. Additionally, compost produced with poultry litter had a higher agronomic value than the one produced with a commercial microbial inoculant. We can conclude therefore that, in cases where animal manures like poultry litter can be readily or cheaply accessed, purchasing commercial inoculants is not necessary, but in cases where animal manures are not readily available, the microbial inoculants are a viable option.

AUTHOR CONTRIBUTIONS

D. Luyima, B. BALIKUDDEMBE, and J. B. TUMUHAIRWE wrote the paper and designed the study. J. H. LEE and S. H. KIM analyzed the data. Y. SHINOGI commented on the manuscript. K. S. Lee and T. K. OH supervised the work. All authors assisted in editing the manuscript and approved the final version.

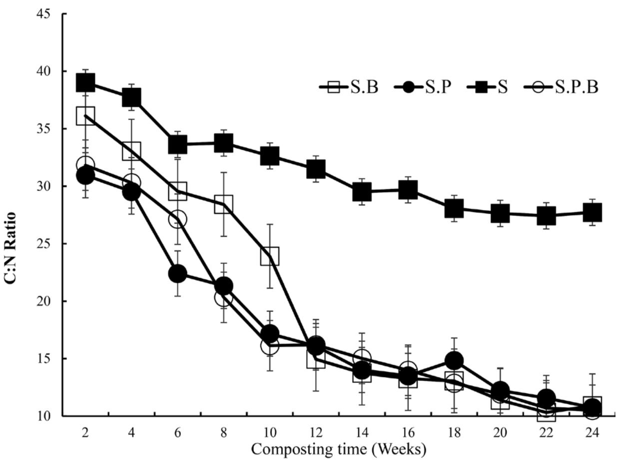

Fig. 3. Changes in C: N ratios.

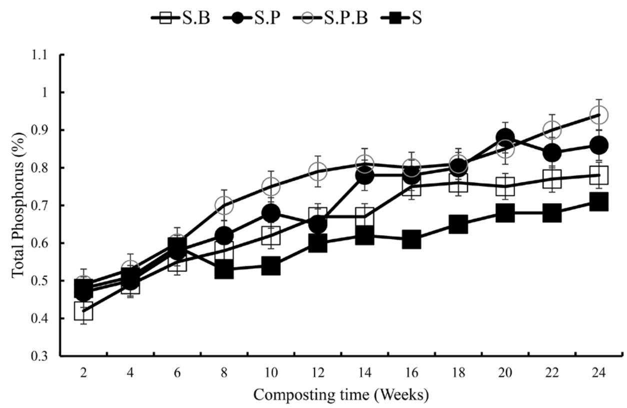

Fig. 5. Changes in P concentration.

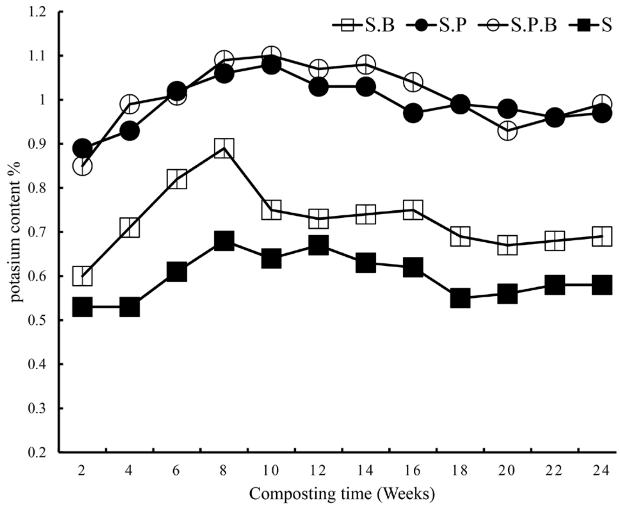

Fig. 4. Changes in K content during composting.

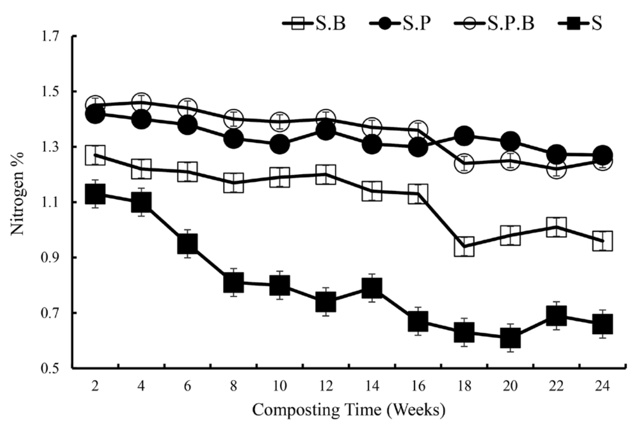

Fig. 6. Variations in nitrogen content during composting.

Table 3. Variations in NH_4^+: NO_3^- during composting

Time (Weeks)	S.B	S.P	S.P.B	S
2	2.20±0.42	1.89±0.32	2.27±0.50	3.73±0.63
4	2.09±0.48	1.46±0.28	1.48±0.51	2.24±0.49
6	1.56±0.23	1.10±0.12	0.81±0.30	1.74±0.28
8	0.71±0.13	0.92±0.17	0.63±0.12	1.16±0.19
10	0.54±0.03	0.53±0.12	0.67±0.18	0.79±0.10
12	0.40±0.10	0.37±0.09	0.35±0.08	0.71±0.14
14	0.34±0.06	0.30±0.05	0.19±0.01	0.58±0.17
16	0.20±0.03	0.21±0.06	0.15±0.01	0.51±0.10
18	0.16±0.09	0.15±0.10	0.11±0.00	0.49±0.11
20	0.14±0.06	0.11±0.07	0.08±0.00	0.47±0.11
22	0.13±0.04	0.08±0.00	0.07±0.00	0.40±0.07
24	0.12±0.01	0.06±0.00	0.07±0.00	0.34±0.10

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