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The effect of turning frequency on in-vessel compost processing and quality

Paige E. Boyle[*], *Mary C. Savin*[†], *and Lisa S. Wood*[§]

ABSTRACT

Composting can contribute to the zero waste initiative on the University of Arkansas (UA) campus. In-vessel systems like Earth Tubs™ are purported to provide better control of temperature and moisture during the composting process. Turning materials helps facilitate microbial activity and thermophilic composting. The goal of this research was to determine if turning frequency affects processing or final quality of compost made with pre- and post-consumer food waste feedstock and a wood chip bulking agent. Turning frequencies (treatment) of 3 days/week and 7 days/week were evaluated simultaneously throughout three sequential runs. Temperature, pH, electrical conductivity (EC), and moisture content (MC) were measured weekly during vessel filling. When the vessels reached one-half to two-thirds volumetric capacity, the compost entered a 30-day composting period during which no food waste or wood chips were added to the vessels, but turning continued. Total C, N, C:N ratio, and hot water extractable C (HWEC) and N (HWEN) were also measured at the conclusion of composting. Recommended values for temperature, pH, MC, and total C:N ratio are all possible to reach when composting with Earth Tubs™, but there is little to no effect of 3 days/week versus 7days/week treatment on final quality of compost, and quality is not consistent over time between runs. Further research would need to be done to assess whether Earth Tubs™ are a viable option for large-scale food waste composting at UA, and whether the logistics of having the vessels off-site lend themselves to a sustainable campus-wide composting program.

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MEET THE STUDENT-AUTHOR

Paige Boyle

I grew up in Bentonville, Arkansas and graduated with honors from Bentonville High School in 2011. I graduated from the University of Arkansas in May 2015 with a B.S. in Environmental, Soil and Water Science, and minors in Horticulture and Wildlife Habitat. During my undergraduate time at the University of Arkansas, I served as a student ambassador for the Dale Bumpers College of Agricultural, Food and Life Sciences; president of the Crop, Soil and Environmental Sciences Undergraduate Club; two-time intern for Boston Mountain Solid Waste District; and summer intern for the University of Arkansas Ecosystem Research Experience for Undergraduates. I would like to thank Dr. Mary Savin for all her guidance as my academic and club advisor, research mentor, and professor. I would also like to thank Dr. Lisa Wood for all her assistance with the day-to-day composting operation and her guidance and patience as my instructor and club advisor. I will be pursuing a graduate degree at the University of Arkansas starting in the fall of 2015.

INTRODUCTION

The University of Arkansas (UA) dining halls, run by Chartwell's Food Service, produce approximately 110 metric tons of food waste annually (pers. comm., Kim Johnson, Chartwell's Food Service). With an estimated cost to landfill at $132.30 per metric ton (pers. comm., Gary Enzor, UA Facilities Management), this amounts to $14,553 to landfill campus dining hall food waste each year.

In 2007, UA signed the American College and University Presidents' Climate Commitment Plan, which launched the university's zero-waste initiative (pers. comm., Carlos Ochoa, UA Office for Sustainability). The UA now has a goal of being zero waste by 2021, which entails 90% diversion (UAOSAP, 2014). This is achieved by keeping 90% of campus-produced waste out of the landfill through preventative planning, recycling, and composting (UAOSAP, 2014). The UA Office for Sustainability claims to be at 16% diversion as of December, 2014 (UAOSAP, 2014). In August, 2013, the UA Crop, Soil and Environmental Sciences Club (CSES) Club, in collaboration with the Office for Sustainability, began composting food waste provided by Chartwell's Food Service as a method of diverting food waste from Fulbright Dining center on campus. Composting food waste is one method of increasing the UA diversion rate and reducing waste on campus.

Composting refers to the decomposition of piled, moist organic material under aerobic conditions (Brady and Weil, 2002). For composting to occur, temperatures must progress through a mesophilic range, to a thermophilic stage, followed by a mesophilic curing stage where temperatures reduce to ambient levels (Pepper et al., 2006). Mesophilic temperatures are considered moderate, ranging from 15 °C to 40 °C (Brady and Weil, 2002). Thermophilic temperatures range from 45 °C to 90°C (Brady and Weil, 2002).

Nutrient cycling processes are impacted by aeration. To ensure decomposition of the organic material in compost, proper nutrient ratios, suggested to be between 20:1 and 40:1 for C:N (Kumar et al., 2010; Monson and Murugappan, 2009; Chang and Chen, 2010), are required for input materials (feedstock and bulking agents). Activity of the microbial community is affected by moisture and proper aeration, which are necessary to ensure optimal temperatures are reached during the composting process. Too little aeration can result in non-uniform moisture and temperature, anaerobic conditions, buildup of harmful gases, odor, and limited decomposition. Excessive aeration can lead to loss of heat needed for thermophilic stage microorganisms and moisture reduction, which in turn, increases composting time (Brady and Weil, 2002; Xu et al., 2012; Guo et al., 2012).

Closed, in-vessel systems such as Earth Tubs™ are purported to provide greater degree of control of the composting atmosphere, reducing composting time to only three weeks (Kalamdhad and Kazmi, 2009 a,b; Monson and Murugappan, 2009). Through a 2008 pilot study, UA received two Earth Tub™ composting vessels (Teague, 2011), and in 2013, the composting operation was taken over by the CSES Club. As composting relied on volunteers, determining if reduced effort in turning (aerating) materials in the vessel could achieve compost of similar quality in the same time frame as daily turning became an important objective. Thus, the objective of this study was to determine if turning (aeration) frequency (3 days/week versus 7 days/week) for an in-vessel composting system impacts compost processing or final quality of compost to be used for food production.

MATERIALS AND METHODS

The in-vessel composting was completed in two Earth Tubs™ (Green Mountain Technologies, Bainbridge Island, Wash.), located at the Division of Agriculture Agricultural Research and Extension Center, Fayetteville, Ark. Each Earth Tub™ was capable of holding up to 2.3 m^3 of waste and contains a 30-cm diameter stainless steel mechanized auger, which can move the radius of the vessel. Each Earth Tub™ lid is equipped with handles, which were used to manually turn the rotating auger around the vessel to mix and aerate the composting materials within the stationary vessel.

The food waste feedstock was provided primarily by Chartwell's Dining Services and delivered by Facilities Management. Additional food waste was provided by the School of Human and Environmental Sciences and the Jean Tyson Child Development Center to supplement the dining hall food waste to help fill the vessels during the first run. Food waste was split by volume between the two vessels. Wood chips, supplied by the Division of Agriculture, were added at a 1:1 (vol:vol) ratio to food waste as the bulking agent to increase the C:N ratio and reduce the high moisture content (MC) of the food waste. Wood chips were heterogeneous in size and of unknown source.

Treatments of rotation 3 days/week (MWF) or 7 days/week were randomly assigned to a vessel and replicated over time in three separate, consecutive composting runs from January 2014–April 2015. Each run consisted of a period of vessel-filling until the vessels were approximately one-half to two-thirds full, followed by a 30-day composting period, the solids retention time used by Kim et al. (2008).

Temperatures were measured on a weekly schedule during both the filling and maturation stages, and at the time of final compost sampling. Weekly samples of compost were collected throughout the composting process until vessels were emptied to measure pH, electrical conductivity (EC), and MC, as indicators of compost maturation. Samples were collected with a 6.4-cm diameter soil auger. Five auger samples were composited per sample, and two samples were collected per vessel per week. The pH and EC were measured for each sample at a 1:2 compost:water (wt:vol) ratio (10 g compost:20 mL deionized water) by pH and EC electrodes and meter. Gravimetric moisture content was calculated on a wet weight basis after oven-drying compost at 55 °C for 5 days.

Once the vessels reached approximately one-half to two-thirds volumetric capacity, the compost was allowed to stabilize for 30 days. Aeration through turning continued during this stage, but no food waste or wood chips were added. Vessels were emptied at the end of the 30-day period. Two composite samples per vessel per run were collected at emptying and split into three subsamples each per vessel to measure hot water extractable carbon (HWEC) and nitrogen (HWEN), total C and N, and associated C:N ratios to assess final compost quality. The total C and N in wood chips (n = 6) and final compost was measured by combustion at 950 °C (Leco Corp., St. Joseph, Mich.). Hot water extractable C and N were measured in 1:10 (wt:vol) extracts after 16 h incubation at 80 °C using a procedure modified from Ghani et al. (2003). Carbon and N in diluted extracts were measured on a Shimadzu TOC-V PC-controlled total organic C with attached total-N analyzer (Shimadzu, Columbia, Md.).

Temporal changes in compost were observed separately for the first run due to the time difference between run 1 and runs 2 and 3. Temporal trends for temperature, moisture, pH and EC were assessed qualitatively for the final two runs. The C and N concentrations were evaluated by analysis of variance (ANOVA) in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) as a randomized complete block (RCB) with subsampling, with run as the block and vessel as the treatment. Contribution of both the block-by-treatment and subsample variance to the total error was assessed. Least square means were compared using a protected least significant difference procedure where appropriate ($P < 0.10$).

RESULTS AND DISCUSSION

Compost Processing

Run 1 ran from 18 January 2014 to 30 August 2014, lasting 32 weeks, due to lack of food waste delivery. Run 2 lasted 12 weeks from 31 August 2014 to 21 November 2014; and run 3 lasted 10 weeks and ran from 28 January 2015 to 6 April 2015.

Run 1 temperatures followed the normal composting stages outlined by Brady and Weil (2002) during vessel filling. Temperatures began below mesophilic ranges, but warmed to mesophilic ranges by 19 February (week 4). Mesophilic range temperatures were maintained until temperatures increased to a thermophilic range in early May (week 15). Temperatures dropped back down to mesophilic temperatures in mid-June (week 20; Fig. 1). Between 5 May and 7 May 2014, 55 °C was reached and maintained in both treatments. There was very little overall difference in temperatures between treatments; and during the final 30-day composting period, the temperatures in the 3 days/week and 7 days/week treatments were essentially the same. The point of temperature increase to thermophilic ranges coincides with the increase in EC (Fig. 2) and decrease in MC (Fig. 3) that occurred between week 14 and 15. The increased EC and decreased MC occurred about the time of the switch to post-consumer food waste. Run 1 confirmed that thermophilic temperatures were possible to reach within the Earth Tub™ vessels.

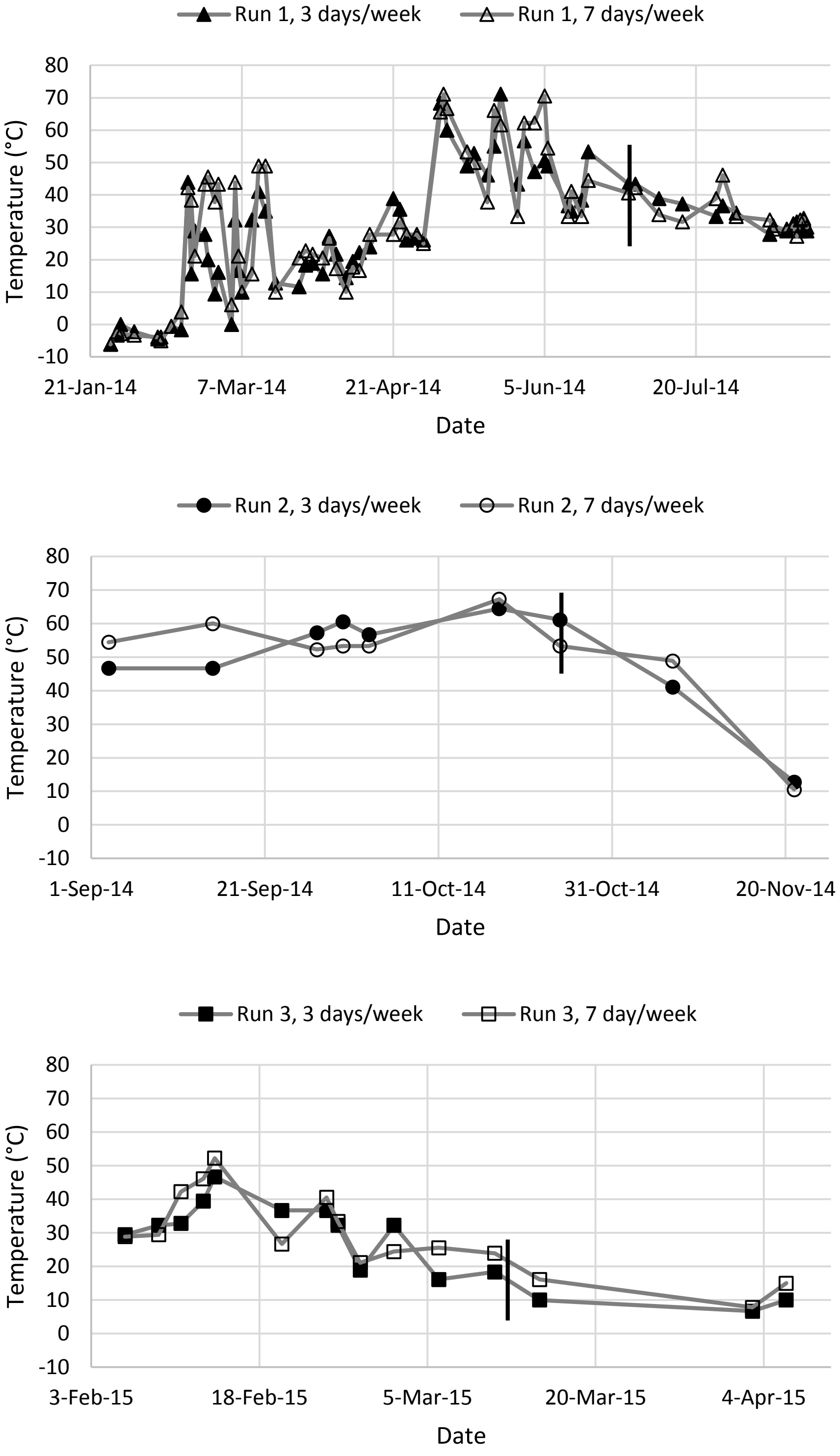

Fig. 1. Temperatures for runs 1, 2, and 3. Solid lines indicate the beginning of the 30-day composting period for each run.

Both treatments in run 2 reached and maintained temperatures in the thermophilic range during vessel filling (Fig. 1). The 3 days/week treatment reached and exceeded the 55 °C between 27 September and 25 October 2014 (weeks 4–8). The 7 days/week treatment reached a maximum temperature of 67 °C on 18 October, but did not maintain above 55 °C for three days. In contrast, both treatments in run 3 remained within the mesophilic range with the exception of one sampling point in the 3 days/week treatment and two sampling points in the 7 days/week treatment, all in mid-February (week 3; Fig. 1). Neither treatment reached 55 °C.

Measurements for run 1 MC, pH, and EC began in week 8. Moisture content for both treatments in run 1 began and was maintained in the 50-70% range recommended by Chang and Chen (2010), Guo et al. (2012), and Monson and Murugappan (2009) until week 14 when moisture content declined in both treatments (Fig. 4). Moisture content remained variable between treatments, with the 3 days/week treatment having overall lower moisture content (Fig. 3). At week 24, moisture content in the 7 days/week treatment returned to the 50-70% range, and remained in this range through the 30-day composting period (Fig. 3). Moisture content for the 3 days/week treatment only reached the recommended range at weeks 7 and 30, but final moisture content at 43.8% was below the recommended range (Fig. 3).

Moisture content for both treatments in run 2 generally decreased throughout vessel filling. Both treatment values were similar except at week 4, when there was a 16% difference between treatments (Fig. 3). Moisture content for both treatments in run 2 was initially within the 50-70%, but by the end of the composting period, MC had decreased below the recommended range (Fig. 3). There was a final difference of 2% in MC between the two treatments in run 2 (Fig. 3). Moisture content for run 3 remained within the 50-70% range recommended throughout the filling and final 30-day composting periods (Fig. 3). Moisture was also similar between treatments throughout the process, with the largest difference of 3% at week 5 (Fig. 3).

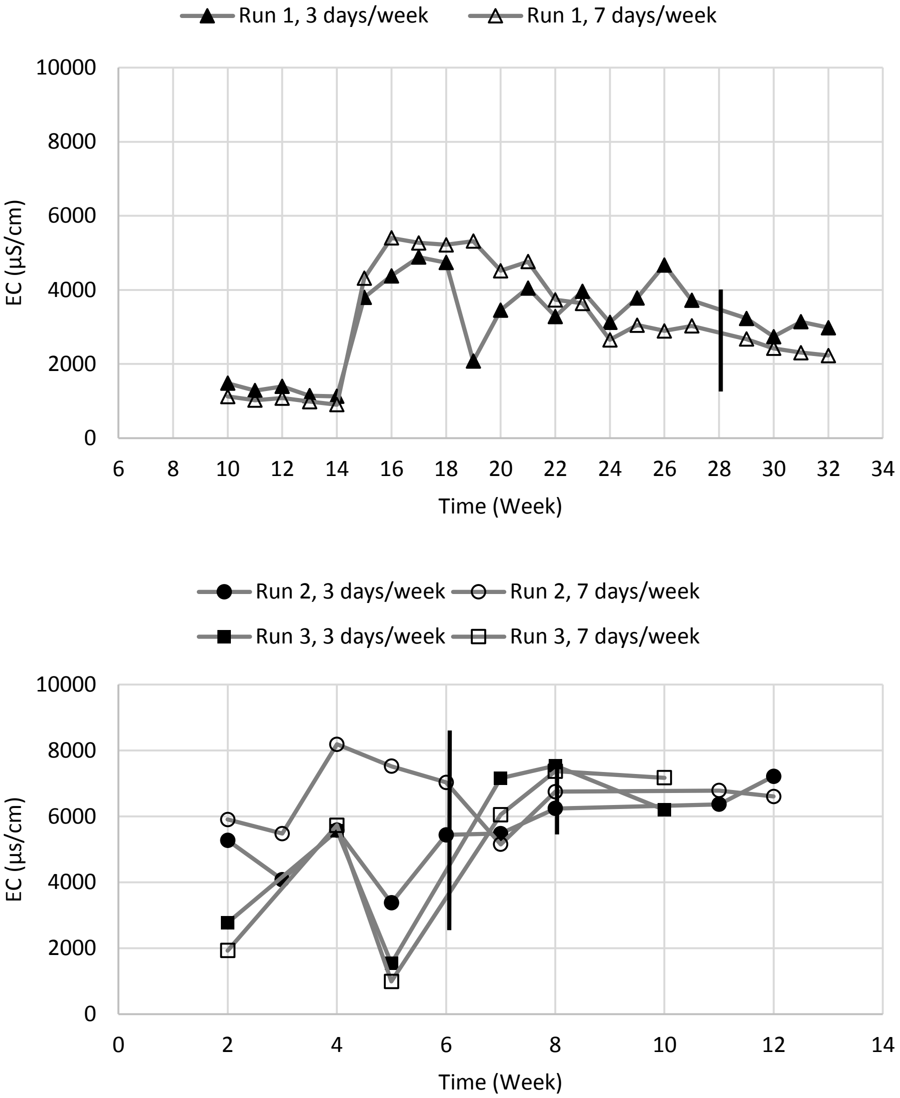

Fig. 2. Average electrical conductivity for runs 1, 2, and 3. Solid lines at weeks 28, 8, and 6 indicate the beginning of the 30-day composting period for runs 1, 2, and 3, respectively.

Average pH for run 1 was similar between treatments with values of 7.2–8.8, until week 19 when the 3 days/week treatment decreased to a low of 6.1 by week 25 (Fig. 4). The pH for the 7 days/week treatment remained within the recommended values of 7–8 (Kalamdhad and Kazmi, 2009b; Antil and Raj, 2012), with the exception of week 29, when the pH rose to 8.1 (Fig. 4). Both treatments followed the expected initial increase followed by a decrease in pH as organic material was broken down, resulting in the production of organic acids, as discussed by Wu et al. (2000). Final pH for the 3 days/week and 7 days/week treatments remained steady between 6.1–6.3 and 7.6–8.1, respectively, indicating that 7 days/week aeration results in a higher pH that better fit the recommended 7–8 range of values, while 3 days/week aeration results in lower pH.

The pH for runs 2 and 3 was highly variable throughout time in both treatments, although it differed between runs (Fig. 4). The pH in run 2 for both treatments generally increased from around pH 6 and stabilized after week 8 to around pH 8 during the final 30-day composting period (Fig. 4). Run 3 had variable pH throughout the vessel filling, but stabilized at around pH 5 at week 7 which was during the final 30-day composting period (Fig. 4). The decrease in pH at the 7 week mark for run 3 coincided with the observed presence of standing water in both Earth Tub™ vessels (affecting both treatments), which suggests that the drop in pH was potentially the result of the shift to pockets of anaerobic activity, during which decomposition would be expected to slow down and acids would be produced (Brady and Weil, 2002).

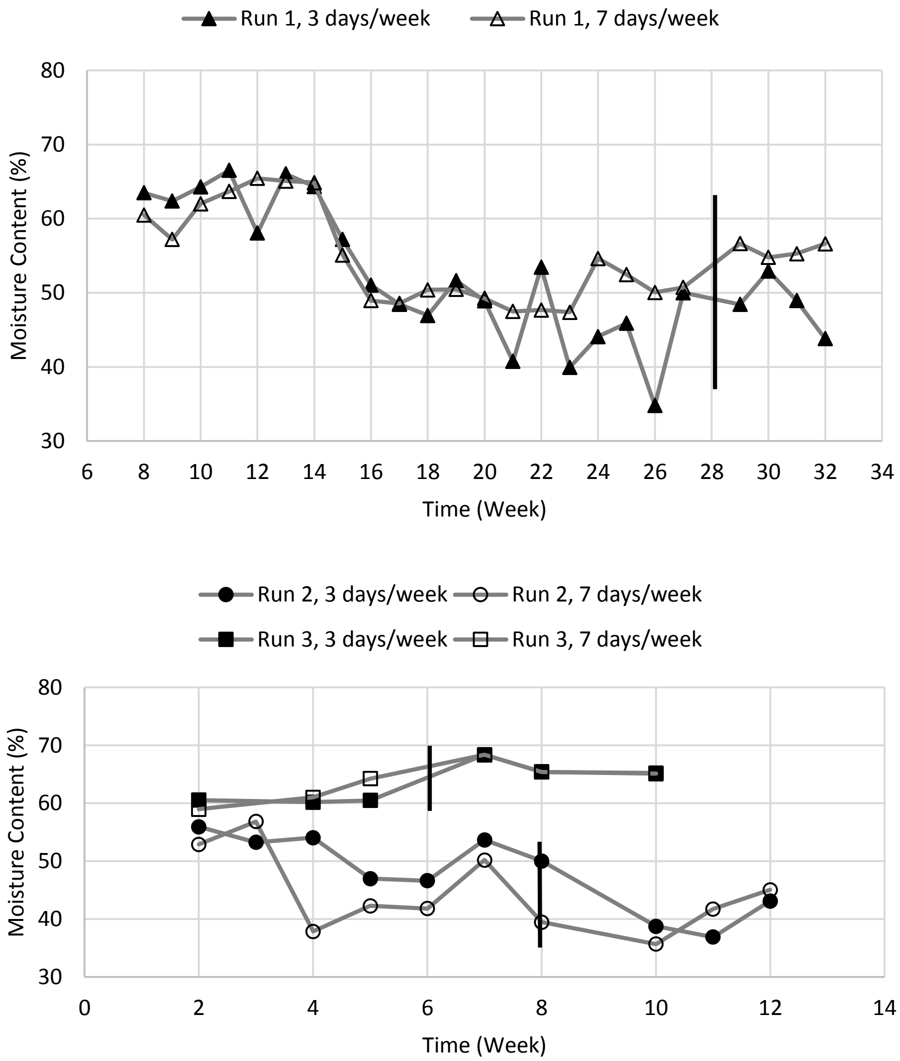

Fig. 3. Average gravimetric moisture content for runs 1, 2, and 3. Solid lines at weeks 28, 8, and 6 indicate the beginning of the 30-day composting period for runs 1, 2, and 3, respectively.

Electrical conductivity in run 1 started relatively low, compared to runs 2 and 3 (Fig. 2). This is potentially related to the food waste feedstock type. Initially, feedstock consisted of pre-consumer food waste, to include coffee grounds, egg shells, and vegetable scraps. At week 15, there was a noticeable increase of EC that coincided with the switch to include post-consumer food waste in the feedstock. This change was made to increase the amount of food waste received in an effort to fill the vessels more quickly. Post-consumer food waste included processed foods, sauces, occasional meats, and other cooked foods. The change in food waste composition resulted in increased EC throughout the rest of the project. Weeks 19 and 26 show noticeable differences in EC between treatments; but overall, EC during vessel filling remained fairly similar (Fig. 2).

Electrical conductivity was variable throughout both treatments for both runs 2 and 3 (Fig. 2). In run 2, EC varied by as much as 1400 and 2600 µS/cm between treatments at weeks 4 and 5, respectively. However at week 6 (the beginning of the final 30-day composting period), the difference diminished, and at the end of the composting period, the two treatment values varied by about 600 µS/cm (Fig. 2). The EC in run 3 was initially lower than that of run 2 (Fig. 2). There was a noticeable peak at week 4 before the EC decreased to the lowest point at week 5; however, values rose again and remained similar to run 2 values, regardless of treatment, for the remainder of the composting period (Fig. 2).

Final Compost Quality

Compost quality can be determined by measuring various parameters. Temperature indicates whether compost reached the U.S. Environmental Protection Agency (USEPA) standard of 55 °C maintained for 3 days, which is necessary to kill weed seed and pathogens (USEPA, 2002; Kalamdhad and Kazmi, 2009a; Monson and Murugappan, 2009), and whether the compost has progressed through the mesophilic, thermophilic, and curing stages (Brady and Weil, 2002; Pepper et al., 2006). Temperature in all three runs reached thermophilic stages, then decreased to temperatures at or below mesophilic ranges by the end of the 30-day composting period (Fig. 1). This suggests that the vessels are able to process the temperature stages of compost. Final temperature never varied between treatments more than 5 °C (run 3), which suggests there is little or no effect of turning frequency in final temperature of compost.

Neither the 7 days/week treatment in run 2 nor either treatment in run 3 reached the 55 °C threshold, and as such, would have restricted use due to the risk of weed seed germination and potential pathogenic effects if used for food crop production. Both treatments in run 1, as well as the 3 days/week treatment in run 2 were able to reach the 55 °C threshold to kill pathogens and weed seed.

Moisture must be maintained between 50-70% gravimetric moisture content (MC) on a wet-weight basis (Chang and Chen, 2010; Guo et al., 2012; Monson and Murugappan, 2009) to facilitate transport of dissolved nutrients and waste removal without development of anaerobic conditions (Kumar et al., 2010; Guo et al., 2012). Moisture content for all treatments and runs was maintained at or below the recommended moisture content. This could be amended by altering the bulking agent content or ratio, to better control moisture throughout the process. Standing water was observed during the final 30-day composting period in both treatments of run 3. This resulted in moisture contents higher than those in runs 1 and 2 but did not result in moisture content percentages outside of the recommended values. Though end MC was different between runs 2 and 3, the final MC in each run was similar between treatments (Fig. 4). The results suggest that there was no effect of aeration treatment on final MC of compost produced in Earth Tub™ vessels.

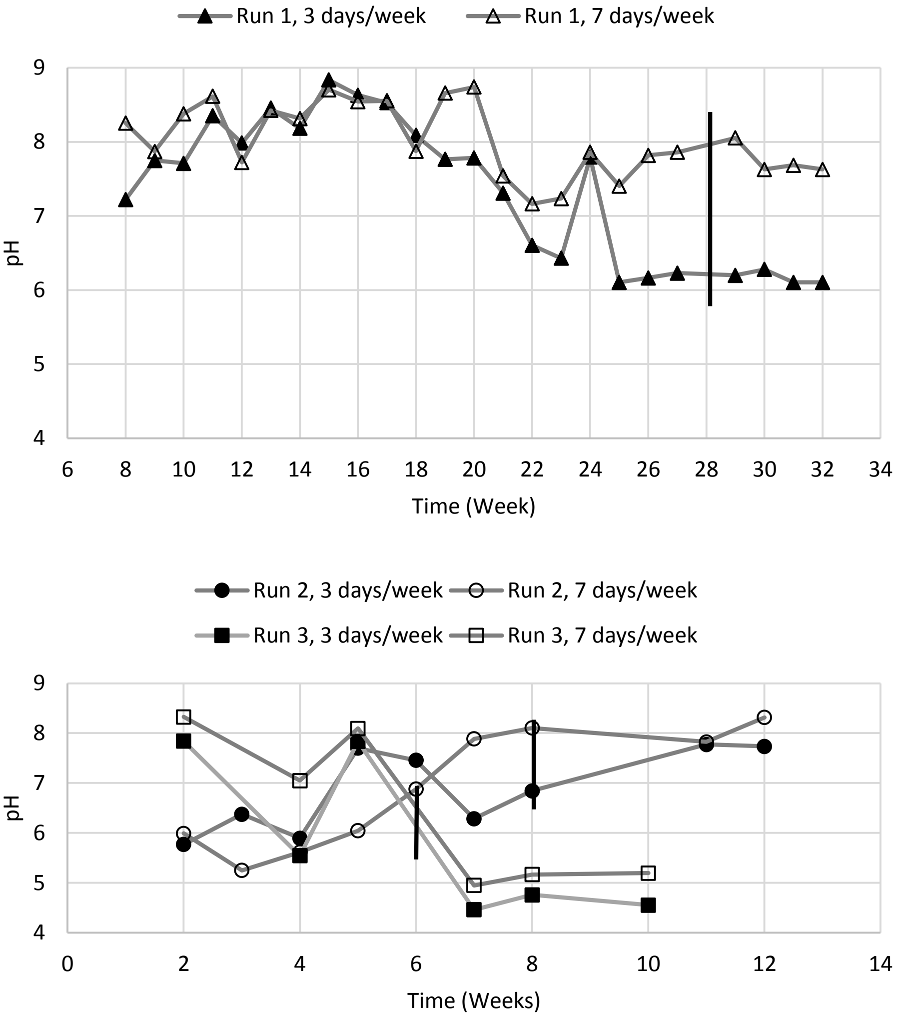

Fig. 4. Average pH for runs 1, 2, and 3. Solid lines at weeks 28, 8, and 6 indicate the beginning of the 30-day composting period for runs 1, 2, and 3, respectively.

Other parameters, including pH and electrical conductivity (EC), affect microbial development and activity (Kim et al., 2008). The pH value can be used as an indicator of maturation of compost, with an ideal pH around 7–8 (Kalamdhad and Kazmi, 2009b; Antil and Raj, 2012). End pH was different between runs, but the final pH values in each run were similar between treatments (Fig. 2). The results suggest that there was no effect of turning frequency on final pH of compost, though there was a noticeable difference in pH values between runs. The 7 days/week treatment of run 1 and both treatments in run 2 resulted in pH between 7 and 8, as recommended by Kalamdhad and Kazmi (2009b) and Antil and Raj (2012). This suggests that the in-vessel systems are capable of producing compost with a desirable final pH, but results were not consistent through time. This inconsistency could be related to possible pockets of anaerobic activity that would be expected to result in the production of strong acids, as may have been the case in run 3.

Final EC was highest in the 3 days/week treatment for all 3 runs, with the largest treatment difference of 920 μS/cm in run 3 (Fig. 2). This suggests that aeration potentially could have an effect on the final EC of compost produced in an in-vessel system, as turning helps distribute nutrients and thus helps facilitate breakdown of material by microbes in the compost. Final EC of run 1 ranged from 2230–2980 μS/cm, which is lower than the final

Table 1. Final mean total C, total N, and hot water extractable C after composting food waste and wood chips in Earth Tub™ vessels during three separate consecutive runs.

Run #	Total C (%)	Total N (%)	Hot Water Extractable C (mg/g)
1	40.97a[†]	3.29a	15.01b
2	26.73c	2.19c	24.24a
3	35.08b	2.81b	28.64a
P value	0.0299	0.0099	0.0935

[†] Means followed by a similar letter are not significantly different.

EC value of 4840 µS/cm found for food waste compost by Kalamdhad and Kazmi (2009b). Final EC for runs 2 and 3 ranged from 6195–7215 µS/cm (Fig. 2), which was higher than that found by Kalamdhad and Kazmi (2009b). These differences could be due to differences in food waste composition. All final EC values were above the 1500 µS/cm value recommended by the University of Missouri Extension (2015); however, this recommendation is based on compost used as a growing medium, and does not factor in the dilution effect that occurs when compost is mixed with other media, such as soil.

Total C differed significantly (P = 0.0299) by run but not treatment (P = 0.2859; Table 1). The lack of significant difference in mean total C between treatments suggests that there is no consistent effect of turning frequency on total C of compost produced in an in-vessel system. Differences among runs may be due to differences in feedstock composition, differences in initial wood chip C content, and the possible anaerobic pockets which would prevent C breakdown by microbes. Final total C for run 1 is higher than those found by Kim et al. (2008) and Kalamdhad and Kazmi (2009b), where final total organic C of compost made with food waste feedstock was 34% and 24.82%, respectively. Total C could be reduced by adjusting the amount of wood chip bulking agent added in with the feedstock. It would be beneficial to measure initial total C of inputs and total C throughout composting, so adjustments could be made as necessary to ensure conditions suitable for microbial metabolism.

Total N consists of inorganic and organic forms of N. Total N differed by the run (P = 0.0099) but not treatment (P = 0.1599; Table 1). Mean total N for all three runs were higher than the 1.2–1.7% final N reported by Antil and Raj (2012). Differences in total N could be related to differences in the feedstock used as Antil and Raj (2012) composted farm and agro-industrial wastes of different compositions.

Total C:N ratio is an indicator of compost maturity, with an ideal initial C:N ratio of 20:1 and 40:1 for C:N (Kumar et al., 2010; Monson and Murugappan, 2009; Chang and Chen, 2010) and an ideal final C:N ratio under 15–20 (Antil and Raj, 2012; Kim et al., 2008). The average initial C:N ratio of the wood chips was 24:1, which was within the recommended range. Total final C:N was 12.4:1, and was not significantly affected by run (P = 0.6382) or treatment (P = 0.6021). This ratio complies with the recommendations of Antil and Raj (2012) and Kim et al. (2008) of 15 or less for mature compost, and is an indication that the compost was mature; however, Antil and Raj (2012) do state that C:N ratio cannot be used exclusively to determine maturity of compost. Subsamples accounted for 42%, 89%, and 95% of total variance for total C, N, and C:N, respectively (data not shown). The high variability in amount of C and N in the material within a vessel may indicate that the composting process was incomplete.

Dissolved C represents the easily accessed and biodegradable sugars and acids in the composting material (Antil and Raj, 2012). The recommended level of dissolved C is <10 mg C/g on a water extractable basis (Antil and Raj, 2012). There was a significant effect of HWEC on run (P = 0.0935; Table 1) but not treatment (P = 0.7943; data not shown). All HWEC values were above the recommended 10 mg C/g, likely due to the fact that the dissolved C of a hot water extractable sample would naturally be higher than that of a water soluble test due to the heat involved. This measure of dissolved C also suggests that there was still easily biodegradable C within the compost, and that the compost was not yet mature.

Neither run nor treatment was significant for HWEN (P = 0.8241 and 0.5213, respectively) or the HWEC:HWEN ratio (P = 0.1051 and 0.3466, respectively; data not shown). Subsamples accounted for 44%, 44%, and 47% of total variance for HWEC, HWEN, and HWEC:HWEN, respectively (data not shown). The large contribution to the total variability for hot water extractable C and N in the material within a vessel may also be indicating that the composting process was incomplete.

Lesson Learned and Recommendations for UA Earth Tub™ Composting

Use of in-vessel composting can come with multiple challenges in a university campus setting, including establishing coordination and cooperation among multiple groups of participants (dining hall, food waste transportation, compost volunteers, maintenance workers, etc.). Utilization of the vessels is labor intensive, as they need manual rotation of the vessel lid to aerate and turnover the food waste, and the vessels are subject to mechanical break down and failures when housed outside. It was difficult to maintain volunteer interest over the course of a year time period.

The location of the vessels was established prior to this study, as they had been installed during a previous pilot study (Teague, 2011). This caused logistical problems, as the food waste had to be transported from the UA campus to the UA farm. I would suggest that the Earth Tub™ vessels only be used on-site, so as to avoid transportation issues.

CONCLUSIONS

Turning (aeration) frequency (3 days/week versus 7 days/week) for an in-vessel composting system was investigated using two Earth Tubs™ located at the UA Agricultural Research and Extension Center, Fayetteville, Ark. during three separate, consecutive composting runs from January 2014–April, 2015. Overall, there was little to no effect of turning frequency on compost processing or quality, and the Earth Tub™ vessels produced compost with inconsistent quality. Additionally, the in-vessel systems were not equipped to compost food waste in as short a time as 2–3 weeks, as projected by Kalamdhad and Kazmi (2009a, 2009b) and Monson and Murugappan (2009). It should also be noted that this project only utilized food waste from one of the three dining halls on campus. If the UA were to expand the composting operation to include all dining halls and other food service providers, as would be necessary to achieve its zero waste initiative, there would need to be further research conducted to assess if the Earth Tubs™ were a viable option for handling an increased food-waste stream. Location and logistics would also need to be reassessed, and the potential for either on-site composting or a change in transportation and labor would need to be made to make UA composting sustainable.

ACKNOWLEDGMENTS

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