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Research paper

In-Vessel Poultry Litter Composting to Facilitate Pathogen Reduction and Biofertilizer Production

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Abstract

Poultry litter-based organic fertilizers are usually incorporated into soil to improve its structure and fertility to increase crop production, however, poultry litter may also contain a variety of microorganisms which can compromise the safety of fresh produce when applied on agriculture lands. Composting can be a strategy to inactivate these microorganisms while creating a soil amendment beneficial for application to arable agricultural land. The objective of this study was to design and test the effect of moisture and temperature in a mechanically aerated in-vessel composting system for the purpose of reducing bacteria concentration in poultry litter while producing bio fertilizer. The actual composting occurred in four digesters which measured 1.2m x 1.2m x 1.2m. Four treatments were utilized with four different levels of moisture content in each vessel (treatment 1=65%, treatment 2=55% treatment 3=60% treatment 4=50%).Moisture gradually decreased and reached 55%, 44% and 48%, and 38.9% for treatment 1,2,3 and 4, respectively in the final compost product. The maximum average temperatures recorded for test 1, 2, 3 and, 4 were 50.54°C, 50.9 °C, 60.7 and 71.5°C respectively compared to outside temperature (15.4°C), and these temperatures were able to significantly reduce the concentration of total aerobic bacteria, fecal coliform and enterococcus listeria. The initial concentration of the compost piles was approximately 6.57, 6.04 and 3.72 log10 CFU/g of total aerobic bacteria, fecal coliform and enterococcus respectively. After analyzes, all target microorganisms were significantly eliminated. The significant levels of total aerobic bacteria, fecal coliform and enterococcus were p=0.0303, P=0.0258, p=0.0233 respectively. The presence of Salmonella spp. and Listeria spp. were not detected in all sampling period. Results of in-vessel compost analyses revealed a 16.9% N reduction; 10.1% P increase and 33.7% K increase. Moisture content decreased by 52.2% and elevated C/N ratio and pH by 27.7 % and 3.30% respectively. The leachates generated from the in-vessel composting for the first 21 days were analyzed, and the average results for week 1, 2, and 3, were observed to be 1043.7 mg/L, 1335.23mg/L, and 1029.9mg/L.

Keywords: *Poultry; Organic Fertilizers; Poultry Litter.*

1. Introduction

Compost is used as soil amendment to improve its fertility, structure, and water holding capacity Composting is one of the essential and most cost-effective methods of recycling organic waste material. Composting have some benefits, it improves agriculture lands, manure handling, possible saleable product such as leachate, weed seed and pathogen control, and reduced risk of different pollution issues. Composting is a process in which biological breakdown of organic waste under different controlled conditions takes place (Shahid R, and Jalil A, 2016). Poultry manure has been defined as a mixture of feces, wasted feeds, bedding materials, and feathers (Wilkinson et al, 2011). It is commonly obtained from many poultry operations and recycled as an organic fertilizer (Caulicle et al., 2004; Rankins et al., 2002; Harappas et al., 2003). In the United States, over 14 million tons of poultry manure is produced annually, most of which are primary used on agriculture lands for crop production as a source of low cost biofertilizer (More, et al, 1997; Enticknap, et al, 2006). Poultry manure contains high amounts of nitrogen due to protein and amino acids present in them. Poultry has been considered to be one of the most valuable animal wastes as bio fertilizer (Wilkinson, 1979), however poultry manure can be a source of human pathogens, such as Campylobacter jejuni, Salmonella, and Listeria monocytogenes, that can potentially contaminate fresh produce associated with foodborne outbreaks (Wilkinson et al, 2010; Chinivasagam et al., 2010). Studies have showed that poultry litter contains a large and diverse population of microorganisms. Microbial concentrations in poultry litter can reach up to 1010 CFU/g, and Gram-positive bacteria, such as Clostridia/Eubacteria, Actinomycetes, and Bacilli/Lactobacilli, account for nearly 90% of the microbial diversity (Bolan et al., 2010). Li, X., 2007 reported that fecal samples of 18-week-old layer birds had the highest prevalence of Salmonella (55.6%), followed by the 25- to 28-wk birds (41.7%), 75- to 78-wk birds (16.7%) and 66- to 74-wk birds (5.5%). Chinivasagam et al., 2010, indicated that Salmonella is more frequently isolated from poultry litter samples when compared to other pathogens. According to their report population of Salmonella in poultry litter can range from 4 to 1.1 × 105 MPN/g litter with prevalence rate from 0 to 100%. Studies conducted by Martin et al., (1998) and Shepherd et al, (2007) found out that E. coli was present in poultry litter with the prevalence rate as high as 100%; however, E. coli O157:H7 was not detected in poultry litter samples. The incidence of Campylobacter in poultry litter can range from 0 to 100% and its average population level was reported to be 10^5 CFU/g in fecal samples collected from broiler chicken flocks (Stern, et al., 2003). Pathogens can be transmitted to humans directly through contact with poultry litter or indirectly through contaminated poultry by-products. Water may also become contaminated by runoff either from poultry facilities or from excessive land application of poultry waste (Berry et al., 2007). Several studies have demonstrated that composting can be an effective way of lowering the level of foodborne pathogens in chicken litter. In some cases, moreover, common foodborne pathogens can be eliminated during the composting process. Martin et al., (1998) reported that no E. coli O157:H7 and Salmonella spp. was detected in 64 composted poultry litter samples. Livshutz (1964) also observed the complete elimination of Salmonella, C. jejuni, and L. monocytogenes from poultry compost when temperature exceeded 55°C Composting is commonly adopted as a pathogen control method to recycle animal wastes back into the soil to improve its fertility (Singh, 2011). Heat treatment after composting or without composting is also recommended to reduce or eliminate potential bacterial pathogens in animal wastes (Chen & Jiang, 2014). Composting is a controlled process of mixing organic wastes with other ingredients in an appropriate ratio to optimize microbial growth. One objective of composting is to manage temperatures actively so that all parts of the pile are sanitized by exposure to high temperatures (Epstein, 1997). Besides high temperature, other mechanisms are also known to be involved in the inactivation of foodborne pathogens during composting, including microbial antagonism, production of organic acids, pH change, desiccation and starvation stresses, exposure to ammonia emission, and competition for nutrients (Wilkinson et al, 2011).

Composting has been proven to be an effective method to produce organic fertilizers in order to treat the ever-increasing volume of poultry wastes (Sims et al., 1993) which convert the soluble nutrients to more stable organic forms, thus increasing their bioavailability while reducing their susceptibility to loss, when applied to agricultural land. The use of in-vessel composting system has increased because of faster odor control, lower labor cost, and smaller area requirements. The detention time in vessel varies from 1 to 2 weeks, but virtually every system employs a 4- to 12- week curing period after the active composting period (Tchobanoglous et al, 1993). In-vessel composting technology is more suitable than other composting technologies in urban and suburban settings because the system allows for suppression and treatment of air to remove odors before release into the environment (EPA, 2000). An in-vessel composting system is defined as a confined process in which composting is accomplished inside an enclosed container (Izrail, 2006). In-vessel composting produces a more stable and, consistent product in less process time, because of its ability to control environmental conditions, such as airflow, temperature, and oxygen concentration. The most important design feature of an in-vessel composting system is the ability to maintain uniform aerobic conditions during the composting process. The air circulation system may be controlled by cycle timers and/or temperature feedback control (EPA, 2000). In-vessel systems are less pliable and flexible compared with windrow and aerated static pile systems. However, in-vessel composting requires a smaller area (EPA, 2002), also the vessel is completely enclosed, and the potential for odors are increased (EPA, 2002). Selection of in-vessel composting systems depends on cost, facility, configurations, and equipment. The specific temperatures that must be achieved and maintained for successful composting vary based on the method and use of the product (EPA, 2000; EPA, 2002.

2. Materials and Methods

2.1. System Design and Description

2.1.1. Experimental setup with four in- vessel compost systems

A total of four CM-Pro Composting System which is an in-vessel, containerized and modular composting system were used. Four treatments were utilized with four different levels of moisture content in each vessel (treatment 1=65%, treatment 2=55% treatment 3=60% treatment 4=50%). The system was designed to convert raw organic materials into a more stable and usable compost product. The actual composting occurred within Composting digesters. Digester sizes measured 1.2m x 1.2m x 1.2m configured for top loading with a gasketed lid. The digesters were made from a high-density polyurethane plastic with insulation. Digesters had a removable PVC perforated manifold that allows air to permeate through the composting mass. There was a lid with a water-tight gasket that opened for discharging compost material. A leachate liquid removal port was provided with a drain to a 19.1mm flexible hose. (Figure 1).

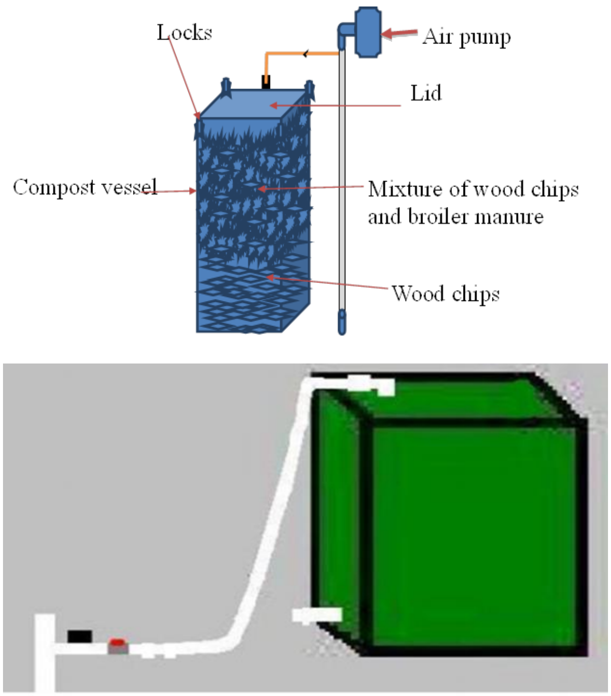

Fig. 1: (A) Diagram of in-Vessel Composting Digester, (B) Diagram of Compost Digester Showing Leachates Drainage Port.

2.2. Leachate characterization

Each digester (Figure 1a) generates leachate. This liquid was disposed through a drain, sent to a sump and collected in a pan and used on crop field as bioifertilizer. To collect the leachate, a 2.54cm hoses were provided and connected to each digester and leachate was collected into a holding container. The pH of each leachate sample was measured immediately following collection using VWR SympHony Meter, SB90M5. NH_4^+, samples were filtered through 0.45µm filter and the supernatant diluted and analyzed for NH_4^+ by flow injection using Lachat QuickChem® method 10-107-06-2-A (Lachet Instruments, Milwaukee, WI).
Compost Material and Characterization
Compost material was characterized for pH, electrical conductivity, various nutrients, and C/N ratio. Triplicate samples of the composts were sent to Waypoint Analytical using protocols of the SW USEPA, SW-846, Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods, 3rd Ed.

2.3. Process control system

The CM-Pro Composting System utilized a 24V Weathermatic Smartline zone controller typically used in irrigation systems. This controller served as a programmable timer to open and close Belimo LF24 actuators. Interfaced between the controller and the composting containers were four Johnson Controls A419 NEMA-1 programmable temperature switches, one for each of the composting containers. On these switches there was an LCD read-out for displaying temperatures. The temperature switch was set at 60°C at which point the damper is opened continuously to assist in heat removal from the composting system.

2.3. Composting temperature management

Compost temperatures were maintained at 55ºC for the three-day minimum to meet Processes to Further Reduce Pathogens (PFRP) standards and were maintained at 40°C for 14 days to meet vector attraction reduction requirements. Regardless of reaction performance in the vessel, compost always heated properly without undue management procedures. As temperature increases, increased airflow rates ensured that the temperature stayed in the designed operating range.

2.4. Composting material preparation

Compost vessels material consisted of three parts of poultry manure obtained from the University of Maryland Eastern Shore poultry research experimental station and one part of wood chips thoroughly mixed together to a different moisture content levels and loaded into vessels.

2.5. Moisture content

The moisture content of the compost was determined by weighing composite samples of about 100g and drying each sample in an oven for 72 hours at 70ºC. Samples were allowed to cool down in desiccators and dry weight recorded. The moisture content was calculated by subtracting the dry weight of the sample from the wet weight. Percent moisture was calculated by dividing the moisture content by the wet weight which was then multiplied by 100 to obtain the moisture percentage (AOAC, 1990), using the following equation:

%W =A- B ×100
B
Where:
%W = Percentage of moisture in the sample,
A = Weight of wet sample (grams), and
B = Weight of dry sample (grams)

2.6. Temperature data logging

The temperature was sampled from the thermistor input and the results sent manually to a data file and utilized in spreadsheet and converted into graphs and charts showing the history of the process. Temperature was also manually taken using an external thermometer.

2.7. Salmonella SPP. and Listeria SPP

Six (6) g of PL were mixed with 24 ml of TSB per sample, with three replicates/sample. Samples were incubated at 37ºC for 24-48 hours. Six 10 µl aliquots of enrichment were spotted equidistantly onto MSRV (Rapport-Vassiliadis medium) and incubated at 42ºC for 18-24 hours then examined for possible Salmonella isolates. Samples determined as positive on MSRV, were transferred onto Xylose-Lysine-Tergitol 4 agar (XLT4). Colonies presumptively positive for Salmonella on XLT4, (colonies yellow-red with black centers), were tested further on TSI (Triple Sugar Iron agar), LIA (Lysine Iron Agar), and in Urea Broth, to confirm them as Salmonella spp. for Listeria ssp., 6g portions of litter samples were mixed in Whirl-pak® bag with 24 ml Listeria Enrichment Broth and hand massaged thoroughly to mix the contents. Sample bags were Incubated at 30 ºC for 48 h. and streaked on Listeria Chrome Agar and incubate at 37 ºC for 24h. Blue, colorless, other color, inhibited, diameter less than 3mm, regular and white halo were considered positive and subjected further examination.

3. Data analyses

Statistical analysis was performed using the three replicates from each treatment. Analysis was performed using Stata v.15 Statistical Software. Pearson's correlation analysis used to determine if concentration ($\log_{10}$MPN/g) of microorganisms were correlated with moisture and temperature in the vessel pile. Using means procedure, standard error of mean to compare temperature difference. A paired t-test was used to determine the significant mean difference between variables. The level of significance at $p \le 0.05$ was considered statistically significant.

4. Results and discussion

4.1. In-vessel compost temperature and moisture content achieved

In-vessel composting occurs within a contained vessel, allowing the operator to maintain and regulate the process in comparison with other composting methods (EPA, 2000). Also, temperature has been widely recognized as one of the most important parameters in the composting process, and the variation of temperature has been reported to correlate with microbial activities (Tiquila & Tam, 2002).

In this study, the purpose was to monitor moisture and temperature differences in the CMpro composting system and its impact on bacteria reduction and biofertilizer production. Table 1 shows final moisture and temperature achieved using the in-vessel composting process. Moisture content gradually decreased and reached 55%, 44% and 48%, and 38.9% for treatment 1, 2, 3 and 4, respectively in the final compost product (Table 1). The maximum average temperatures for treatment 1, 2, 3 and, 4 were 51 ºC, 49 ºC, 55 ºC and 59 ºC respectively (Table 1). This finding agrees with a study conducted by Makan et al., (2012) who investigated the effect of initial moisture content on in-vessel composting under air pressure of organic fraction of municipal solid waste. They reported a maximum value of 43°C, 47°C, 52°C, 40°C and 33°C in first, second, third, fourth and fifth experiment respectively after 5, 3, 2, 3 and 5 days. Temperature shows whether compost has reached the US Environmental Protection Agency standard of 55°C maintained for a period of three days, which is necessary to kill pathogens and weed seeds (EPA, 2002).

Table 1: Descriptive Statistics of Temperatures (°C) Observed in In-Vessel Composting and Outside Temperature.

Treatment	Average Moisture content (%)	Temperature (ºC)
1	55.0± .058	50.85 ±13.95
2	44.0.1±.084	48.09 ±13.50
3	48.4.5±.09.4	55.24 ±9.198
4	38.9±.084	58.86 ±9.32

N=164. Values are means from 4 replicates. Values represent mean ± standard deviation (n = 8)

4.2. Effect of compost process time on bacterial populations in compost material

Fecal indicator organisms are non-pathogen bacteria which are usually used as indicators for feces contamination from animal gut (EPA, 2012). They are used to measure the microbial quality of food and water. Fecal bacteria that are commonly tested as indicators are total aerobic bacteria, fecal coliform, E.coli, and Enterococci (EPA, 2012). Shepherd et al., (2007) found out that organisms such as E.coli can be eliminated from compost pile between 2 and 5 days. Total aerobic bacteria, fecal coliform and enterococcus. This study achieved a maximum temperature of ~ 71°C with an average of ~55°C and that was able to significantly reduce the concentration of total aerobic bacteria, fecal coliform and enterococcus listeria. The initial concentrations of the compost pile were approximately 6.57, 6.04 and 3.72 log10CFU/g for of total aerobic bacteria, fecal coliform and enterococcus respectively. After analyzing the data obtained from the experiment, it was observed that concentrations of all target microorganisms were significantly eliminated (Figure 2). The presence of Salmonella spp. and Listeria spp. were not detected in all sampling period. Several studies reported that factors such as initial cell numbers of pathogens, microbe strain variations, season of the year, and geographical location can affect the potential for pathogen inactivation within a manure heap (Shepherd et al., 2007). Also, Nicholson et al., (2005) suggested that ammonia release may have a hazardous effect on the survival of pathogens.

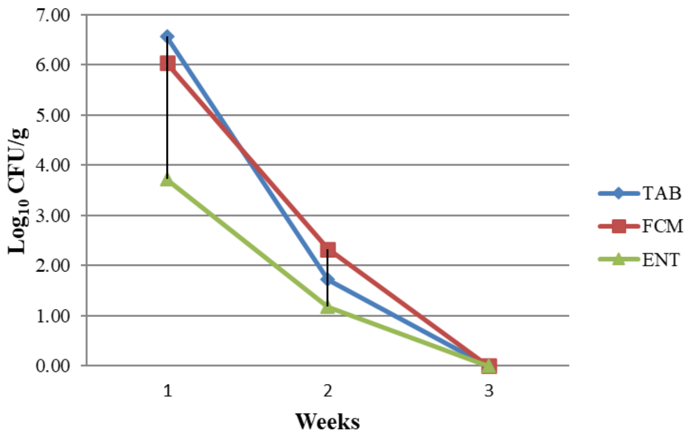

Fig. 2: Vessel Temperature as A Factor Affecting Microorganism Survival.

Several studies have reported that high temperatures are major factor for reducing pathogenic microorganisms in compost pile (Shepherd et al., 2007; Erickson et al., 2009). For this study, at the start of the composting process, the average temperature was approximately 24.2ºC with an ending temperature of ~ 71.25 ºC during four weeks of composting. Despite the fact that other factors such as pH, moisture content, ammonia generation, and microbial competition with other microorganisms played a role in the successful inactivation of pathogens during composting, the temperature profile was observed to be the most important factor and thus makes it essential that the composting process be managed in a way that includes an effective time and temperature regime

4.3. Bacteria persistence as influenced by moisture content

A paired t-test analysis was conducted to determine the effect of compost moisture content on microbial persistence and survival. For all microbes tested, moisture content had a significant effect on the concentrations (log10MPN/g) of total aerobic bacteria, fecal coliform, and enterococcus. Significant levels of total aerobic bacteria, fecal coliform, and enterococcus were p=0.0013, p=0.0014, p=0.0012 respectively. Studies have shown that microorganisms need sufficient moisture content for growth and survival (Elkader et al., 2007). During the experiment, moisture content in the compost pile ranged from 32-67%, with an average of 47.5%. According to Elkader et al., (2007), the optimum moisture content for microorganism activity is 50% to 70%. Over time, the compost material continued to dry out, resulting in a depletion of available moisture for these indicator bacteria. When observing the population of these bacteria within the compost vessel, it becomes clear that temperature alone cannot account for microbial inactivation. This finding indicates that moisture depletion, along with other factors may have contributed to the decline of the microorganisms.

4.4. Bacteria persistence as influenced by pH

Old poultry litter has an average pH of 8.0-9.0 and new poultry litter a pH of 6.0-7.0 (Hamilton, 2014). Manipulating the pH of the litter can affect most bacterial growth, dropping the pH of the litter to below 4.0 will convert the litter into a medium hostile to the growth and survival of pathogenic bacteria (Hamilton, 2014) during this experiment the, average compost pH was 8.3). For all microbes tested, pH had a significant effect on the concentrations (log10MPN/g) of fecal coliform, and enterococcus. Significant levels for fecal coliform, and enterococcus were p=0.0041 p=0.0001 respectively. pH had no effect on total aerobic bacteria (Table 2).Erickson et al., (2009) found out that factors such as pH and initial carbon: nitrogen ratio of compost significantly affects the inactivation of pathogens such as E. coli O157:H7.

Table 2: Paired T-Test Analysis of the Effect of Moisture Content, Ph, and Vessels Temperature on Bacteria Persistence in Compost.

Variable	Total Aerobic Bacteria		Fecal coliform		Enterococcus	
	t-stats	p-value	t-stats	p-value	t-stats	p-value
Moisture Content	11.7603	0.0013	11.5287	0.0014	12.2144	0.0012
pH	1.6495	0.1976	7.9683	0.0041	33.550	0.0001
Vessel Temperature	3.8789	0.0303	4.1247	0.0258	4.2892	0.0233

Note: Means difference was established using t-test analysis at 5% probability. N=164.

4.5. Nitrogen recovery from poultry litter using in-vessel composting

Poultry litter management has become an increasing concern for most crop farmers due to increasing fertilizer costs (Sharpley et al., 2000). Between 2004 and 2008, the nutrient value (N, P and K) of poultry litter increased from $36 to $107/ton (USDA National Agricultural Statistics Service, 2008). Poultry litter can serve as a significant and important supply of nutrients for crop production. Studies have shown that the nutrient concentration of litter varies, depending on several factors (VanDevender et al., 2000). Poultry litter can serve as an important complement to synthetic (N) fertilizers. The level of Phosphorus in poultry litter is usually high, and application rates should be based on P levels to avoid surface water contamination (Ruiz et al., 2013). This study aimed to develop, design, and test temperature of a periodic, mechanically aerated in-vessel composting system in reducing bacteria populations in poultry litter while increasing nitrogen stabilization through in-vessel composting of poultry litter for crop production. Results of in-vessel compost analyses revealed a 16.9% N reduction: 10.1% P increase and 33.7% K increase. Moisture content decreased by 52.2% and elevated C/N ratio and pH by 27.7 % and 3.30% respectively (Table 3). Studies have shown that nitrogen mineralization rates of poultry litter vary widely from 21% to approximately 100%, with different sources of fresh litter (Bitzer & Sims 1988). According to Hartz et al., (2000), N mineralization ranged from 20% (dried chicken manure) to 2% (plant residue compost). This finding agrees with previous study that reported that fresh litter had higher N mineralization rates than composted litter (Hadas & Portnoy, 1994; Paul & Beauchamp, 1994; Hartz et al., 2000). Preusch et al., (2000), reported that C to N ratio was lower in fresh poultry litter (8:1) than composted poultry litter (15:1), suggesting a higher N mineralization rates in fresh poultry litter. A study conducted by Preusch et al., (2000) found out that composting did not have significant effect on P. Asija (1984) investigated the effect of methods of preparation and enrichment on the quality of manure. He found out Phosphorous and potassium content gradually increased during the composting process.

For both initial and after nutrient analyses, moisture content, pH, vessel temperature, EC, did not have any significant effect on nutrient variability, however a perfect negative correlation was observed between outside temperature and after compost analysis (r=-0.99, p=0.0324). This finding agrees with a statement by Ruiz, (2013). He stated that moisture content and nutrient concentration in poultry litter can be highly variable and depends mainly upon production conditions, storage, and handling methods.

Table 3: Selected Chemical Characteristics of Composting Material.

Parameters	Initial	Final	% change
Total Nitrogen, g/kg	34.3	28.5	16.9 ↓
Phosphorus, g/kg	14.9	16.4	10.1 ↑
Potassium, g/kg	28.5	38.1	33.7 ↑
Calcium, g/kg	29.9	33.7	12.7 ↑
Moisture %	67.0	32.0	52.2 ↓
Total Volatile Solids, %	72.06	70.04	2.8 ↓
C/N Ratio	12.33	15.75	27.7 ↑
pH	7.85	8.11	3.30 ↑

Note: Test was completed using USEPA, SW-846, Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods, 3rd Ed.

4.6. Compost leachate NH4+ recovered from in-vessel composting process

Rynk (1992), defined leachate as “the liquid that results when water comes in contact with a solid and extracts material, either dissolved or suspended, from the solid” The leachate produced in in-vessel, channel, or containerized systems can often be collected easily using a built-in system. This leachate can be stored in a holding tank and treated or used directly (Rynk 1992). Leachate can be a significant source of soluble plant nutrients and organic matter, and therefore may be valuable in a variety of applications. However, the content of soluble or suspended material in the leachate at a specific composting site is wholly dependent on the composition of the composting material being processes (The Composting Council of Canada, 2017). The leachates generated from the in-vessel composting for the first 21 days were analyzed, and the average results for week 1, 2, and 3, were observed to be 1043.7 mg/L, 1335.23mg/L, and 1029.9mg/L (Figure 3). The major amount of NH_4^+ recovered (1335.2 mg/L) during the composting process occurred during the second week than during other periods. A Pearson’s correlation revealed a positive relationship (r=0.7146, p=0.0712) between week one and week two, however an inverse correlation was observed between week one and three (r=-0.8925, p=0.0069) and week two and three (r=-0.4289, p=0.3370).

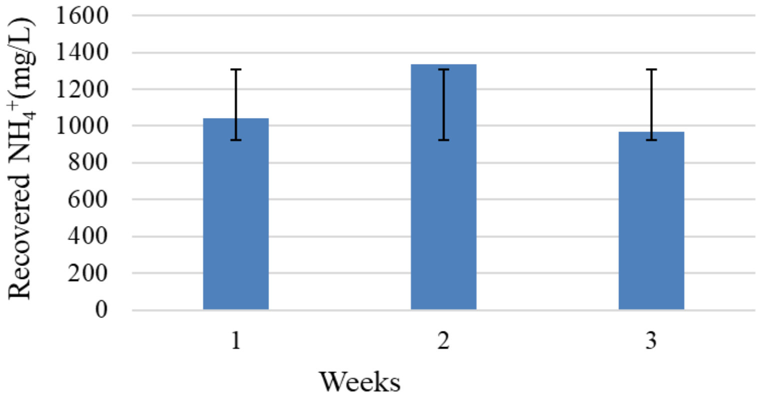

Fig. 3: Weekly Leachate NH_4^+ Recovered from In-Vessel Composting Process. Bars Represent Standard Deviation.

4.7. Factors influencing leachate NH4+ recovery

Table 4 describes the effect of pH, electrical conductivity, and temperature on ammonium recovery in leachate. pH and temperature did not significantly affect NH_4^+ recovery.

Table 4: Effect of Ph, EC, and Temperature on Leachate NH_4^+ Recovery.

Variable	Leachate NH_4^+ Recovered (mg/L)
pH	101.5 (0.43)
Electrical Conductivity	35.70* (2.55)
Vessel Temperature	3.900 (0.67)

Note: t statistics in parentheses; * p<0.05, ** p<0.01, *** p<0.001.

5. Conclusion

The overall objective of this study was to determine the major nutrient (N. P. K) availability from in-vessel. Nitrogen mineralization rates were lower for post-composting poultry litter, than for initial poultry litter. Findings from this study indicated that other factors play a role in microorganism reduction in the compost vessel, but it can be concluded that the major factor that caused the quickest reduction was high temperature. As seen in this study, in-vessel composting process generated high temperatures which suggest the reduction of the microorganisms. It can also be concluded that if time and temperature of in-vessel composting regimen is applied as a manure management technique before manure is applied to agriculture land, a reduction in the threat of fresh produce contamination resulting from manure exposure is expected. Nutrient from manure and leachate produced may serve as a good biofertilizer. Results show that in-vessel composting, as demonstrated with the CMPro composting vessel system, can be a means of reducing pathogen populations during poultry litter composting.

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