ASSESSMENT OF COMPOSTING METHODS FOR USE IN THE GREEN INDUSTRY

Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee. This thesis does not include proprietary or classified information.

William Jeffery Brymer, Jr.

Certificate of Approval:

Mark Dougherty
Assistant Professor
Biosystems Engineering

Jeff L. Sibley, Chair
Alumni Professor
Horticulture

Oladiran Fasina
Associate Professor
Biosytems Engineering

George T. Flowers
Dean
Graduate School

ASSESSMENT OF COMPOSTING METHODS FOR USE IN THE GREEN INDUSTRY

William Jeffery Brymer, Jr.

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
December 19, 2008

ASSESSMENT OF COMPOSTING METHODS FOR USE IN THE GREEN INDUSTRY

William Jeffery Brymer, Jr.

____
Signature of Author

____
Date of Graduation

VITA

William Jeffery Brymer, Jr., son of William (Billy) Jeffery Brymer, Sr. and Rachel Ann Brymer of Pulaski, Tennessee, was born January 23, 1984 in Columbia, Tennessee. He has one older sister, Bonny. He graduated in May 2002 from Giles County High School in Pulaski, Tennessee. He entered Middle Tennessee State University in the Spring Semester of 2003 and transferred to Tennessee Tech University in the Fall of 2004 earning a Bachelor of Science degree in Agriculture in May 2007. Upon graduation, William continued his studies at Auburn University pursuing a Master of Science degree in Horticulture as a Graduate Research Assistant under the direction of Dr. Jeff Sibley. In December 2008, he received his Master of Science degree in Horticulture from Auburn University.

THESIS ABSTRACT

ASSESSMENT OF COMPOSTING METHODS FOR USE IN THE GREEN INDUSTRY

William Jeffery Brymer, Jr.

Master of Science, December 19, 2008
(Bachelor of Science, Tennessee Tech University, 2007)

118 Typed Pages

Directed by Jeff L. Sibley

Composting is a common waste management tool for successful reduction of waste materials. Due to increased consumer awareness for compost products and their value to the green industry research is needed to evaluate different compost methods. Composts can be a suitable media component for container-grown plants based on typical physical and chemical properties. The purpose of this study was to evaluate two composting methods of poultry litter (PL) to determine differences in materials destined for use in the green industry. Windrow composting and In-Vessel Digester composting of PL were compared. Composting for both methods began at the same time and were evaluated using temperature logging, moisture analysis, C:N tracking, and quantification of biological organisms such as *Salmonella*, fecal coliforms, and *Enterococci*. Results indicated that there were noticeable differences between compost methods in regarding temperature, moisture analysis, and C:N ratios. Both methods produced compost with safe levels of bacteria for human use. At the end of the compost process samples were taken from each of the two methods and compared in plant growth trials for two ornamental crops and a weed germination test. In the first study using *Impatiens waleriana* 'Fanfare' substrate leachates, plant growth indices, and plant dry weights were analyzed at the end of the study to determine which method of composting produced the best overall plants. In this study windrow composted PL out performed in-vessel composted PL. There was a noticeable difference in plant dry weight, substrate leachate, and plant growth indices in substrates comprised of windrow composted PL. In the second study *Hemerocallis spp.* 'Pardon Me' plant growth, substrate leachates, and plant dry weights were analyzed after 10 weeks. Results indicated following the *Hemerocallis* study that compost produced by windrow method was more suited for container substrate use than in-vessel compost. Plant dry weights for this study revealed that substrates containing windrow composted PL produced larger plants. A weed germination test was conducted in which twelve pots were filled with each compost material and allowed to sit in a climate controlled greenhouse for a total of 6 weeks. Results revealed that both methods are equally suitable at eradicating potential weed seed that are present during the composting process. Results of these studies indicate that windrow composting produced compost more suitable for green industry use. Data revealed that the electrical conductivity and pH levels for in-vessel derived compost might not be suitable for production without pre-plant leaching of salt and pH sensitive plants.

ACKNOWLEDGEMENTS

The author would like to express his sincerest gratitude for the guidance, insight, and patience extended to him over the past two years by Dr. Jeff Sibley. The author would also like to thank Dr. Mark Dougherty and Dr. Oladiran Fasina for lending support and wisdom while serving on his advisory committee. He would also like to thank Drs. Charles Gilliam and Joe Eakes for their support and help during the completion of this research. The author would also like to thank Drs. Jed Young, Douglas Airhart, and Jim Baier for their help and encouragement to pursue this Masters Degree. Without their direction he most likely would not have entered the Graduate School.

The author would like to thank Daniel Wells, Diana Cochran, Chris Marble, and Matt Wilson for their unique friendship that has developed over the past two years. The author would also like to extend a special thanks to Jeremy Pickens for the extraordinary help he has provided in the field.

To his parents, thank you for being wonderful role models and for providing unconditional love and support. The author wishes to thank his sister Bonny for her friendship, love, and encouragement through the years whether she meant to or not. If he had not seen her devotion to pursuing dreams it would have seemed impossible. Most importantly, the author wishes to thank the Lord Jesus Christ for allowing, an imperfect, undeserving sinner to pursue his dreams of becoming a great man.

Styled after the following journals:

Journal of Environmental Horticulture and HortTechnology

Computer software used:
Microsoft Word 2003, Microsoft Excel 2003, and SAS v. 9.1

TABLE OF CONTENTS

LIST OF TABLES

Chapter II:

Chapter III:

Chapter IV:

LIST OF FIGURES

Chapter II.

Chapter III.

Chapter IV.

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Evaluation of Two Composting Methods for Poultry Litter

Poultry production is a rapidly growing industry in the United States. As a nation the U.S. produces 8.9 billion birds annually with Alabama currently third in production with 11.9% (1.1 billion birds) of U.S. totals (AAS, 2007). Typically, on a commercial broiler farm, litter is used for six or more consecutive grow-outs. Each grow-out generally lasts 6+ weeks; which means that litter is generally being utilized for at least one year (Macklin, 2008). Currently a conservative estimate of 16.6 million tons of poultry litter is produced in the United States each year. In Alabama alone the poultry and egg industry represents approximately $2.7 billion in gross farm receipts and employs approximately 78,000 people. One impact of this industry is that millions of pounds of waste material, particularly ~ 2 million tons of litter are generated by the poultry and egg industry in Alabama annually (Edwards et al., 1995).

In agriculture, poultry litter (PL) or broiler litter is a material used as bedding in poultry operations to render the floor more manageable. Common litter materials in the southeast can consist of wood shavings, sawdust, peanut hulls, straw, and other dry, absorbent, low-cost organic materials. After use, the litter consists primarily of poultry manure, but also contains the original litter material, feathers, and spilled feed (Freeman and Cawthon, 1999). Typical PL has an average wet weight moisture content of 20-40%

and a dry nitrogen content of 1.5-4% (Rynk, 1992). Poultry manure has been used successfully as a fertilizer for the production of maize, small grains, fruits, forage grasses, and vegetables. Poultry manure has been reported to increase nutrient concentration in the soil, to improve nutrient uptake by plants, and to increase crop yields (Mkhabela, 2006). Manure may improve soil structure and subsequently soil permeability, water-holding capacity, aeration, and also supply micronutrients. Thus, structural deterioration of soils can be reversed and soil fertility can be restored by manure (Mkhabela, 2006). PL contains the equivalent of approximately 26- 22- 17 kilograms per metric ton (63-53-41 pounds per U.S. ton) of $N-P_2O_5-K_2O$ on a dry basis, which is equivalent to a bagged, commercial fertilizer analyzing approximately 3-2.5-2 percent of $N-P_2O_5-K_2O$, respectively. Based upon current fertilizer prices, PL would be worth about $30 to $40 per ton as a fertilizer, not including spreading and transportation charges. PL applications of 1.8 to 3.6 metric tons per acre (2-4 U.S. tons) have been effective in promoting grass growth in pasture (http://www.msstate.edu/dept/poultry/pub1998.htm, 1998).

In recent years there has been concern for disposing of agricultural waste in the United States and elsewhere in the world. Some of the resulting issues facing the poultry production industry with regards to waste management include: reduced land area on farms to apply increasing amounts of litter; nutrient management plans that are based on phosphorous indexes; land applying PL to clay soils that already have high phosphorous (P); land application of poultry litter can promote degradation of water quality by promoting increases in groundwater NO_3 content and in cases where N is not limited, leaching may occur when PL is applied to agricultural land at rates in excess of the nitrogen requirement of the crop (Faucette, 2001; Kaplan et al., 2004; Mitchell et al., 1989). Poultry litter is typically land applied according to the amount of nitrogen it can supply. Although P tends not to move in soils, repeated applications of PL can lead to P build-up, which can result in P runoff and affect surface water. Also, P is a limiting element in many processes in plant and microbe development. Increases in P can cause proliferation in plant and microbe growth in lakes and streams, a process known as eutrophication.

Poultry litter can be used by many industries. Studies evaluating PL as a fuel source (Fasina et al., 2005); cattle feed, container media in nurseries, erosion control, and as a fertilizer (Atkinson et al., 1996; Guertal et al., 1997; Lopez et al., 1998; Tyler et al., 1993) have been conducted. Nursery crop growers are looking for substrates that are consistent, available, easy to handle and mix, cost effective, and have the appropriate physical and chemical properties for the crop they are growing (Klock-Moore et al., 2000). Composts meet many of these requirements and therefore can be considered a suitable component of the potting media (Freeman and Cawthon, 1999). Fritsch and Collins (1993) define compost as the biological stabilization of organic wastes under controlled conditions of oxygen, moisture, and temperature. The end result is a stable organic product which improves soil fertility by providing nutrients, reducing bulk density, increasing cation exchange capacity, and enhancing populations of soil microorganisms. Scientists and industry have an increased awareness of composts; in particular PL compost due to the increasing amounts of litter produced each year and the resulting environmental challenges that are associated with PL.

The environmental issues associated with raw manure application could be mitigated by chemically or biologically stabilizing soluble nutrients. Composting of PL converts soluble nutrients to more stable organic forms, thereby reducing their bioavailability and susceptibility to loss when applied to crop fields (Buchanan and Gliessman 1991; Cooperband and Middleton, 1996; Tyson and Cabrera, 1993). Processing of PL wastes by composting therefore provides an opportunity to reduce volume and odor, while increasing the nutritive values of the material (FAO, 1987; Gray and Briddlestone, 1981; Parr et al., 1986).

Currently there are numerous ways to produce compost products, including: open pile, aerated static pile, windrow, and in-vessel composter. Open-pile composting is suitable for small to moderate- sized farms operating under a low level of management. This method involves forming piles of organic materials and leaving them undisturbed until the materials have decomposed into a stabilized product. Small piles are designed to take advantage of natural air movement. In general, larger piles are more difficult to aerate effectively because of pile compaction. Under proper feedstock and moisture conditions, however, pile temperatures increase, contributing to production of good compost. The costs of the labor and equipment used to form and mix the initial piles are the largest operational expenses. Farm loaders and manure spreaders can typically be diverted from other farm uses to form and mix piles (Dougherty, 1999).

The *aerated* static pile system is different in that the compost materials are placed into rows, but the windrows are built on top of an air distribution system composed of flexible perforated pipes embedded in woodchips. Fans are used to provide forced aeration into the pile or induced draft aeration from the pile. The aerated static pile system has been successful in providing high levels of aeration and is used throughout the world to make compost from excessively moist, hard to aerate materials such as municipal and industrial sludges (Dougherty, 1999; Fitzpatrick, 2005).

Windrow composting is an example of an open composting system that uses active tuning with relatively low-level technology. Compost materials are placed in rows and turned periodically using mechanical equipment. Windrow systems are popular because they do not necessarily require dedicated specialized equipment (Fitzpatrick et al., 2005). Windrow composting consists of piles usually ranging from 94 cm in height to heights of 3.7 meters (3ft by 12 ft) with the widths depending on the equipment used to turn the rows. Between turning, windrows aerate by natural or passive air movement (Misra and Roy, 2002). The frequency of turning depends on the rate of decomposition (indicated by temperature rise), the moisture content and porosity of the materials, and the desired composting time (Misra and Roy, 2002). The required frequency of turning windrows usually decreases over time due to the aging of the materials (Misra and Roy, 2002). In a windrow situation, eight weeks is a common period for manure composting operation (Misra and Roy, 2002).

In-vessel composting involves confining actively composting materials within a building, container, or vessel. Many in-vessel systems use a rotating drum. The first of which was developed in the U.S. by Eric Eweson in the 1940s. Eweson designed a system in which compost material anaerobically ferments in a large rotary drum for a period of 3-6 days. Unlike many of the early mechanical composting systems, the rotary drum system has been successful and there are many such systems operating throughout the world at the present time (Fitzpatrick et al., 2005). In-vessel systems are the most aggressively managed and generally the most capital intensive of the composting technologies (Dougherty, 1999). The in-vessel process of composting is an aerobic process by which the materials are constantly tumbled upon each other forcing oxygen inside the mix. Most drum systems include blowers to maintain aerobic conditions and minimize excessive temperatures, with one technology injecting oxygen (Spencer, 2007). Rotating drums are the most common in-vessel method in part because the combination of pulping action and biological degradation in the drum breaks down organic materials in just a few days to a rough, though unfinished compost (Spencer, 2007). The in-vessel system can create an adequate aerobic composting environment allowing compost to reach thermophillic temperatures within 24 hours (Freeman and Cawthon, 1999). The residence time within the in-vessel system depends upon the level of composting desired. Additional curing time outside the in-vessel composter can be used to finish the composting process (Dougherty, Personal Communication). Composting drums are available in sizes from one meter in diameter and 3.6 meters long to 5 meters in diameter and up to 70 meters long (3 feet in diameter and 12 feet long to 16 feet in diameter and 230 feet long).

Composting begins as soon as appropriate biologically active materials are mixed together. Initial mixing of raw materials introduces enough air to start the microbial process. Almost immediately, microorganisms consume oxygen, and settling materials expel air from pore spaces. Aeration is provided by passive air exchange, by forced aeration, or turning (Dougherty, 1999). Temperatures of composting materials usually increase rapidly to 38-60°C (100-140°F) and remain in this range for up to several weeks (Dougherty, 1999). Mature compost provides a stabilized form of organic matter (humus) and has the potential to enhance nutrient release in the soil more than other organic wastes because plants are not competing with soil micro organisms for nutrients (Adediran et al., 2003). Time to maturity, however, depends on factors such as type of substrate, organic components of the substrate, and the temperature regime during composting (Taiwo, 1997; John et al., 1995). Other essential elements in the composting process are carbon-to-nitrogen ratio of the initial mix which should be in the range of 20:1-40:1 (C:N ratios above 30 will minimize the potential for odors). C:N ratios are influenced by the materials in which the compost pile is composed of such as manure with an added carbon source (sawdust). An initial feedstock moisture content of 40%-60% wet basis is recommended and depends upon the specific materials, pile size, and weather conditions. Moisture content has a direct effect on oxygen levels within the compost. When a pile is too moist, air spaces within the compost pile can become filled by water, causing undesirable anaerobic conditions. Initial particle sizes of 1.3-5.1 cm (0.5-2 inches) will be broken down easier. Pile porosity greater than 40% is critical because it permits air to enter and diffuse into the composting mass. Bulk density of 480-710 kg/m^3 (1400-2000 lbs/yd^3) will meet the basic aeration and moisture needs of composting microbes (Dougherty, 1999). If these guidelines are followed it is possible to create an environment that is suitable for composting.

Although there are numerous ways in which to compost PL, the purpose of this research was to evaluate differences between windrow composting and in-vessel composting of PL. The results of this research demonstrate the suitability of turned windrow or in-vessel composter composting of PL for growth of horticultural crops in the green industry.

Literature Cited

Alabama Agricultural Statistics (AAS). 2007. Bulletin 49. Dept. of Ag. and Industries 39-42.

Adediran, J.A., L.B. Taiwo, and R.A. Sobulo. 2003. Effect of organic wastes and method of composting on compost maturity, nutrient composition of compost and yields of two vegetable crops. J. of Sust. Agri. 22(4): 95-109.

Atkinson, C.F., D.D. Jones, and J.J. Gauther. 1996. Biodegradability and microbial activities during composting of poultry litter. Poultry Science 75:608-617.

Buchanan, M. and S.R. Gliessman. 1991. How compost fertilization affects soil nitrogen and crop yield. BioCycle 32: 72-77.

Cooperband, L.R., and J.H. Middleton. 1996. Changes in chemical, physical and biological properties of passively-aerated co composted poultry litter and municipal solid waste compost. J. Compost Sci. Util. 4(4) 24-34.

Dougherty, M. 1999. Field guide to on-farm composting. NRAES Ithaca, NY. 114.

Edwards, J.H., E.C. Burt, R.L. Raper, and R.H. Walker. 1995. Issues affecting application of noncomposted organic waste to agricultural land. pp. *In Agricultural Utilization and Industrial Byproducts;* Kalen et al. Eds.; Agron. Special Publication No 58, ASA, CSSA, SSSA: Madison, WI. pp. 225-249.

FAO, 1987. Soil management: compost production and use in tropical and subtropical environments. FAO, Food and Agri. Org. of United Nations, Rome, FAO Soil Bulletin 56, 177 p.

Fasina, O.O., D.I. Bransby, J.R. Kessler, C.H. Gilliam, and J.L. Sibley. 2005. Pelleted poultry litter provides viable fuel source for greenhouse heat. SNA research proceedings Vol 50: 362-364.

Faucette, B. 2001. Georgia builds poultry litter composting infrastructure. Biocycle, August 2001:23-26.

Freeman, T.M., and D.L. Cawthon. 1999. Use of composted dairy cattle solid biomass, poultry litter and municipal biosolids as greenhouse growth media. Compost Sci. & Util. 7:66-71.

Fitzpatrick, G.E., E.C. Worden, and W.A. Vendrame. 2005. Historical development of composting technology during the 20th century. HortTechnology 15:48-51.

Fritsch, D.A., and A.R. Collins. 1993. The economic feasibility of poultry litter composting facilities in eastern West Virginia. WVU. Agr. Expt. Sta. Scientific Article. 2351.

Gray, K.R., and A.J. Briddlestone. 1981. The composting of agricultural wastes. In: B. Stonehouse (ed.). Biological Husbandry. Butterworths Publications, London, England. 99-112.

Guertal, E.A., B.K. Behe, and J.M. Kemble. 1997. Composted poultry litter as potting media does not affect transplant nitrogen content of final crop yield. HortTechnology 7:142-145.

John, N.M., G.O. Adeoye, and M.K.C. Shridhar. 1995. Effect of a binding agent and sawdust amendment on the stabilization of compost, soil properties and crop growth. Proceedings of the 23rd all African Soil Science Conference. 383-394.

Kaplan, J.D., R.C. Johansson, and M. Peters. 2004. The manure hits the land: economic and environmental implications when land application of nutrients is constrained. Amer. J. Agr. Econ. 86:688-700.

Klock-Moore, K.A., G.E. Fitzpatrick, and G. Zinati. 2000. Container production of ornamental horticultural crops. Biocycle 41(11):58-60.

Lopez, R., C. Duran, J.M. Murillo, and F. Cabrera. 1998. Geranium's response to compost based substrates. Acta Horticulturae 469:255-262.

Macklin, K. 2008. Litter management. North Carolina broiler supervisor's short course. NCSU.

Misra, R.V., and R.N. Roy. 2002. On-farm composting methods. FAO, Rome.

Mitchell, C.C., J.O. Donald, and J. Martin. 1989. The value and use of poultry waste as fertilizer. Poultry byproduct management-agronomy. Alabama Coop. Ext. Serv.: Auburn University, AL., ANR-244:6.

Mkhabela, T.S. 2006. A review of the use of manure in small-scale crop production systems in South Africa. J. of Plant Nutrition 29: 1157-1185.

Parr, J.F., R.I. Papendick, and D. Colacicco. 1986. Recycling of organic wastes for a sustainable agriculture. Bio. Agri. and Hort. 3: 115-130.

Rynk, R. Editor. 1992. On-farm composting handbook. NRAES. 54.

Spencer, R.L. 2007. In-Vessel composting: rotating drums. BioCycle, June 2007:28-32.

Taiwo, L.B. 1997. Development of organic-based fertilizer form sorted urban wastes. PhD Dissertation. 205pp.

Tyler, H.H., S.L. Warren, T.E. Bilderback, and K.B. Perry. 1993. Composted turkey litter: II. Effect on plant growth. J. Environ. Hort. 11:137-141.

Tyson, S.C. and M.L. Cabrera. 1993. Nitrogen mineralization in soils amended with composted and uncomposted poultry litter. Commun. Soil Sci. Plant Anal. 24: 2361-2374.

http://www.msstate.edu/dept/poultry/pub1998.htm. Broiler litter as a feed or fertilizer in livestock operations. 9/17/2008.

CHAPTER II

COMPARISON OF WINDROW COMPOSTING VERSUS IN-VESSEL COMPOSTING OF POULTRY FOR GREEN INDUSTRY USE

Abstract

Composting is said to be as much an art form as it is a science. The purpose of this study was to determine if there was a difference between windrow composting of poultry litter (PL) and in-vessel composter composting of PL for green industry use. Two composts were produced and compared using particle size distribution analysis, weed germination trials, chemical analysis, C:N monitoring, temperature logging, and length of time to maturity. Particle size distribution showed that there were no differences between treatments for coarse, medium, and fine particles. Finished compost from both compost methods were found to be free of viable weed seed. Chemical analysis revealed that the pH and NH_4 levels of composts produced using in-vessel methods were higher than those produced using windrow techniques. C:N results for both methods were typical in that they decreased over time due to microbial activity within the compost piles. Temperature logging of the two piled composts produced the most critical data in determining the stability of the composts. The temperature data revealed that windrow composting can take a considerably longer amount of time to mature than in-vessel but during that time

the temperatures within windrow are more stable. It was concluded that windrow composting of PL, if done using the methods recommended, is a more stable method for producing PL composts for green industry use.

Introduction

Poultry production is a rapidly growing industry in the United States. As a nation the U.S. produces 8.9 billion birds annually with Alabama currently third in production with 11.9% (1.1 billion birds) of U.S. totals (AAS, 2007). Typically, on a commercial broiler farm, litter is used for six or more consecutive grow-outs. Each grow-out generally lasts 6+ weeks; which means that litter is generally being utilized for at least one year (Macklin, 2008). Currently a conservative estimate of 16.6 million tons of poultry litter is produced in the United States each year. In Alabama alone the poultry and egg industry represents approximately $2.7 billion in gross farm receipts and employs approximately 78,000 people. One impact of this industry is that millions of pounds of waste material, particularly ~ 2 million tons of litter are generated by the poultry and egg industry in Alabama annually (Edwards et al., 1995).

In agriculture, poultry litter (PL) or broiler litter is a material used as bedding in poultry operations to render the floor more manageable. Common litter materials in the southeast can consist of wood shavings, sawdust, peanut hulls, straw, and other dry, absorbent, low-cost organic materials. After use, the litter consists primarily of poultry manure, but also contains the original litter material, feathers, and spilled feed (Freeman and Cawthon, 1999). Typical PL has an average wet weight moisture content of 20-40% and a dry nitrogen content of 1.5-4% (Rynk, 1992). Poultry manure has been used successfully as a fertilizer for the production of maize, small grains, fruits, forage grasses, and vegetables. Poultry manure has been reported to increase nutrient concentration in the soil, to improve nutrient uptake by plants, and to increase crop yields (Mkhabela, 2006). Manure may improve soil structure and subsequently soil permeability, water-holding capacity, aeration, and also supply micronutrients. Thus, structural deterioration of soils can be reversed and soil fertility can be restored by manure (Mkhabela, 2006). PL contains the equivalent of approximately 26- 22- 17 kilograms per metric ton (63-53-41 pounds per U.S. ton) of N-P_2O_5-K_2O on a dry basis, which is equivalent to a bagged, commercial fertilizer analyzing approximately 3-2.5-2 percent of N-P_2O_5-K_2O, respectively. Based upon current fertilizer prices, PL would be worth about $30 to $40 per U.S. ton as a fertilizer, not including spreading and transportation charges. PL applications of 1.8 to 3.6 metric tons per acre (2-4 U.S. tons) have been effective in promoting grass growth in pasture (http://www.msstate.edu/dept/poultry/pub1998.htm, 1998).

In recent years there has been concern for disposing of agricultural waste in the United States and elsewhere in the world. Some of the resulting issues facing the poultry production industry with regards to waste management include: reduced land area on farms to apply increasing amounts of litter; nutrient management plans that are based on phosphorous indexes; land applying PL to clay soils that already have high phosphorous (P); land application of poultry litter can promote degradation of water quality by promoting increases in groundwater NO_3 content and in cases where N is not limited, leaching may occur when PL is applied to agricultural land at rates in excess of the nitrogen requirement of the crop (Faucette, 2001; Kaplan et al., 2004; Mitchell et al., 1989). Poultry litter is typically land applied according to the amount of nitrogen it can supply. Although P tends not to move in soils, repeated applications of PL can lead to P build-up, which can result in P runoff and affect surface water. Also, P is a limiting element in many processes in plant and microbe development. Increases in P can cause proliferation in plant and microbe growth in lakes and streams, a process known as eutrophication.

Poultry litter can be used by many industries. Studies evaluating PL as a fuel source (Fasina et al., 2005); cattle feed, container media in nurseries, erosion control, and as a fertilizer (Atkinson et al., 1996; Guertal et al., 1997; Lopez et al., 1998; Tyler et al., 1993) have been conducted. Nursery crop growers are looking for substrates that are consistent, available, easy to handle and mix, cost effective, and have the appropriate physical and chemical properties for the crop they are growing (Klock-Moore et al., 2000). Composts meet many of these requirements and therefore can be considered a suitable component of the potting media (Freeman and Cawthon, 1999). Fritsch and Collins (1993) define compost as the biological stabilization of organic wastes under controlled conditions of oxygen, moisture, and temperature. The end result is a stable organic product which improves soil fertility by providing nutrients, reducing bulk density, increasing cation exchange capacity, and enhancing populations of soil microorganisms. Scientists and industry have an increased awareness of composts; in particular PL compost due to the increasing amounts of litter produced each year and the resulting environmental challenges that are associated with PL.

The environmental issues associated with raw manure application could be mitigated by chemically or biologically stabilizing soluble nutrients. Composting of PL converts soluble nutrients to more stable organic forms, thereby reducing their bioavailability and susceptibility to loss when applied to crop fields (Buchanan and Gliessman 1991; Cooperband and Middleton, 1996; Tyson and Cabrera, 1993). Processing of PL wastes by composting therefore provides an opportunity to reduce volume and odor, while increasing the nutritive values of the material (FAO, 1987; Gray and Briddlestone, 1981; Parr et al., 1986).

Currently there are numerous ways to produce compost products, including: open pile, aerated static pile, windrow, and in-vessel composter. Open-pile composting is suitable for small to moderate- sized farms operating under a low level of management. This method involves forming piles of organic materials and leaving them undisturbed until the materials have decomposed into a stabilized product. Small piles are designed to take advantage of natural air movement. In general, larger piles are more difficult to aerate effectively because of pile compaction. Under proper feedstock and moisture conditions, however, pile temperatures increase, contributing to production of good quality compost. The costs of the labor and equipment used to form and mix the initial piles are the largest operational expenses. Farm loaders and manure spreaders can typically be diverted from other farm uses to form and mix piles (Dougherty, 1999).

The *aerated* static pile system is different in that the compost materials are placed into rows, but the windrows are built on top of an air distribution system composed of flexible perforated pipes embedded in woodchips. Fans are used to provide forced aeration into the pile or induced draft aeration from the pile. The aerated static pile system has been successful in providing high levels of aeration and is used throughout the world to make compost from excessively moist, hard to aerate materials such as municipal and industrial sludges (Dougherty, 1999; Fitzpatrick, 2005).

Windrow composting is an example of an open composting system that uses active turning with relatively low-level technology. Compost materials are placed in rows and turned periodically using mechanical equipment. Windrow systems are popular because they do not necessarily require dedicated specialized equipment (Fitzpatrick et al., 2005). Windrow composting consists of piles usually ranging from 94 cm in height to heights of 3.7 meters (3 ft by 12 ft) with the widths depending on the equipment used to turn the rows. Between turning, windrows aerate by natural or passive air movement (Misra and Roy, 2002). The frequency of turning depends on the rate of decomposition (indicated by temperature rise), the moisture content and porosity of the materials, and the desired composting time (Misra and Roy, 2002). The required frequency of turning windrows usually decreases over time due to the aging of the materials (Misra and Roy, 2002). In a windrow situation, eight weeks is a common period for manure composting operation (Misra and Roy, 2002).

In-vessel composting involves confining actively composting materials within a building, container, or vessel. Many in-vessel systems use a rotating drum. The first of which was developed in the U.S. by Eric Eweson in the 1940s. Eweson designed a system in which compost material anaerobically ferments in a large rotary drum for a period of 3-6 days. Unlike many of the early mechanical composting systems, the rotary drum system has been successful and there are many such systems operating throughout the world at the present time (Fitzpatrick et al., 2005). In-vessel systems are the most aggressively managed and generally the most capital intensive of the composting technologies (Dougherty, 1999). The in-vessel process of composting is an aerobic process by which the materials are constantly tumbled upon each other forcing oxygen inside the mix. Most drum systems include blowers to maintain aerobic conditions and minimize excessive temperatures, with one technology injecting oxygen (Spencer, 2007). Rotating drums are the most common in-vessel method in part because the combination of pulping action and biological degradation in the drum breaks down organic materials in just a few days to a rough, though unfinished compost (Spencer, 2007). The in-vessel system can create an adequate aerobic composting environment allowing compost to reach thermophillic temperatures within 24 hours (Freeman and Cawthon, 1999). The residence time within the in-vessel system depends upon the level of composting desired. Additional curing time outside the in-vessel composter can be used to finish the composting process (Dougherty, Personal Communication). Composting drums are available in sizes from one meter in diameter and 3.6 meters long to 5 meters in diameter and up to 70 meters long (3 feet in diameter and 12 feet long to 16 feet in diameter and 230 feet long).

Composting begins as soon as appropriate biologically active materials are mixed together. Initial mixing of raw materials introduces enough air to start the microbial process. Almost immediately, microorganisms consume oxygen, and settling materials expel air from pore spaces. Aeration is provided by passive air exchange, by forced aeration, or turning (Dougherty, 1999). Temperatures of composting materials usually increase rapidly to 38-60°C (100-140°F) and remain in this range for up to several weeks (Dougherty, 1999). Mature compost provides a stabilized form of organic matter (humus) and has the potential to enhance nutrient release in the soil more than other organic wastes because plants are not competing with soil microorganisms for nutrients (Adediran et al., 2003). Time to maturity, however, depends on factors such as type of substrate, organic components of the substrate, and the temperature regime during composting (Taiwo, 1997; John et al., 1995). Other essential elements in the composting process are carbon-to-nitrogen ratio of the initial mix which should be in the range of 20:1-40:1 (C:N ratios above 30 will minimize the potential for odors). C:N ratios are influenced by the materials in which the compost pile is composed of such as manure with an added carbon source (e.g., sawdust). An initial feedstock moisture content of 40%-60% wet basis is recommended and depends upon the specific materials, pile size, and weather conditions. Moisture content has a direct effect on oxygen levels within the compost. When a pile is too moist, air spaces within the compost pile can become filled by water, causing undesirable anaerobic conditions. Initial particle sizes of 1.3-5.1 cm (0.5-2 inches) are recommended so they will be broken down easier. Pile porosity greater than 40% is critical because it permits air to enter and diffuse into the composting mass. Bulk density of 480-710 kg/m^3 (1400-2000 lbs/yd^3) will meet the basic aeration and moisture needs of composting microbes (Dougherty, 1999). If these guidelines are followed it is possible to create an environment that is suitable for composting.

Although there are numerous methods available to compost PL, the purpose of this research was to evaluate differences between windrow composting and in-vessel composting of PL. The results of this research demonstrate the suitability of turned windrow or in-vessel composter composting of PL for growth of horticultural crops in the green industry.

Materials and Methods

Windrow composting procedures: On July 25, 2007 the windrow composting process began at E.V. Smith's Waste Management Research Center in Tallassee, Alabama. The project utilized broiler PL purchased on April 12, 2007 from a certified waste hauler in Greenville, Alabama. The fresh PL was stored on site under cover of a tarpaulin until the project was ready to begin. At the beginning of the composting process, measured feedstock parameters included C:N ratio (TrueSpec, LECO®, St. Joseph, MI) and moisture content (Ohaus MB35, Ohaus Corporation, Pine Brook, NJ). Optimum (target) C:N ratios were obtained based on NRAES Handbook 114 (Dougherty, 1999).

Sample collection for analysis of feedstock and compost consisted of non composite sampling from random locations of the compost piles at an average depth of 24 inches. Samples were then labeled and sent for laboratory analysis.

Recipe formulation was a two step process. First C:N ratio was satisfied by proper mixing of sawdust to fresh poultry litter. Approximately 50 yd^3 of sawdust was added to the east windrow with an additional 50 yd^3 added to the west windrow at beginning of composting (Figure 1). Equation (1) was used to approximate C:N of 40:1 in the initial mix. The C:N of the fresh PL was 8:1. Step two involved addition of water because of the relatively dry moisture level of both feedstocks (Table 1). Equation (2) was used to determine the amount the addition amount of water needed to bring the windrow moisture content to 40% wet basis. Approximately 7,200 gallons of water was applied to the windrow (Table 1). PL, sawdust, and water were mixed using the windrow turner to assure factors such as C:N ratio and moisture content were at optimal conditions for composting. Two temperature probes (Dickson SM 325, The Dickson Company, Addison, IL) were inserted in each windrow (East Windrow and West Windrow).

The size of the windrow (East-West) was approximately 150 feet long by 4 feet high by 10 feet wide, with an initial volume of approximately 111 cubic yards. However, we treated the east half of the windrow as a separate windrow and essentially had two windrows (East- West) each consisting of approximately 55.5 yd^3 of PL compost (Figure 1). A decision was made to monitor the east end separate from the west end due to the significant difference in initial moisture contents found between ends (53% west; 33% east). The reason for the initial moisture content difference is due to the west windrow cover being removed by a rain storm. On 3/18/2008 an additional 50 yd^3 of sawdust was added to the east windrow to adjust for a more optimal C:N of 20:1 in the east windrow. When the additional 50 yd^3 of sawdust was added the windrows were separated by a front end loader to ensure that no extra carbon was incorporated into the west windrow.

The methods used to determine the amount of sawdust and water to add are described as:

Equation (1)

$$a = \frac{\%Nb}{\%Na} \times \frac{(R - Rb)}{(Ra - R)} \times \frac{(1 - mb)}{(1 - ma)}$$

$$a = \frac{3.19}{.8} \times \frac{(40 - 8)}{(200 - 40)} \times \frac{(1 - 0.18)}{(1 - 0.14)}$$

$$a = 3.99 \times .20 \times .953$$

$a = 0.76$ lbs. of sawdust/lb. of PL or ~1.3lbs. PL/lb. of sawdust

a= pounds of ingredient a per pound of ingredient b

M= desired mix moisture content, wet basis

ma= moisture content of ingredient a

mb= moisture content of ingredient b

R= desired C:N ratio (by weight) of the mix

Ra= C:N ratio (by weight) of ingredient a

Rb= C:N ratio (by weight) of ingredient b

(Ingredient a = the carbon source to add to the compost material, sawdust)

(Ingredient b = the material to be composted, poultry litter)

Equation (2)

$$MC = \frac{(Wb + Wa)}{Wt + Wb}$$

$$\frac{40}{100} = \frac{Wb + 19{,}680}{139{,}680 + Wb}$$

$$60Wb = 3{,}619{,}200$$

$$Wb = 60{,}320 lbs$$

$$60{,}320 / 8.34 = 7{,}200 gallons$$

MC= desired mix moisture content, wet basis

Wb= weight of water to add to mix, lbs

Wa= weight of water in ingredient a and b ingredients, lbs

Wt= total weight of compost pile, lbs

Data collected during and at the beginning of the project included: temperature data logging (Dickson SM 325, The Dickson Company, Addison, IL), moisture contents, carbon to nitrogen ratios, bacteriological samples (*Enterococci*, *Salmonella*, and fecal coliform. On July 25, 2007 a sample of mixed compost was taken to the ALFA soil testing laboratory in Auburn, AL to determine initial chemical composition. The procedure used to determine the mineral composition for fresh poultry litter was the dry ash method. Total nitrogen for fresh PL was determined by the Dumas combustion method. Mature compost from the west windrow and from the in-vessel composter was analyzed on September 12, 2008 using the saturated paste extraction of organic material procedure (Table 2). Data was collected with the objective to evaluate which composting method is best suited for the production of PL compost for use in the green industry. In Tables 3, 4, 5, 6, and 7 results of the analyses carried out on the samples are presented. The methods that were used to determine *Enterococci* and fecal coliform bacteria levels are further described by Eaton et al. (2005). *Enterococci* levels were determined by using method 9230C (Eaton et al., 2005). Fecal coliforms were detected using methods 9221E and 9222E (Eaton et al., 2005). *Salmonella* isolation and identification was performed as described by Andrews and Hammack (1998). Dates for collection were decided by factors such as perceived maturity of the compost and relevant closeness to the pile or windrow turning dates.

The windrow was turned with a windrow turning machine SCAT 482B (SCAT Engineering, INC. Hopkinton, IA) (Figure 2), at dates determined by parameters mentioned by Misra and Roy (2002) such as rate of decomposition, moisture contents, and recorded temperatures. The importance of turning a compost pile is to replace oxygen that has been depleted by micro organism consumption. Temperature response to turning is the indicator we can most easily use to determine compost stability (Dougherty, Personal Communication).

In-vessel composting procedures: Approximately 12 cubic yards of fresh poultry litter was added to the in-vessel composter (BW Organics, INC. Model 616, Sulphur Springs, TX) (Figure 3). The poultry litter that went into the in-vessel composter did not have an additional carbon source added to it because it was hypothesized that this method would not need any type of extra carbon to produce stable compost, based on previous studies of in-vessel PL compost with no additional carbon source that produced saleable horticulture crops (Boyer et al., 2007). The PL remained in the in-vessel composter for a period of 8 days. Once removed, the volume of the PL had been reduced to approximately 7 yd^3 of compost. A sub-sample of approximately 4 yd^3 of in-vessel compost was then placed beside the east windrow and two temperature probes (Dickson SM 325 data loggers, The Dickson Company, Addison, IL) placed in it to automatically monitor temperature every hour. This was done in order to monitor the curing in-vessel compost pile to see if it was stable after only 8 days of composting in the in-vessel reactor. Data loggers remained in place until February 18, 2008 or approximately 29 weeks after which the temperatures in the pile remained consistently close to ambient temperatures. During that time the pile was turned and temperatures were being monitored. Moisture contents, bacteria samples, and C:N ratios were also analyzed using identical methods that were described for the windrow composting approach. Turning of compost originating from the in-vessel composter was performed on occasion using a front end loader tractor. Dates for turning were based on moisture content, perceived compost maturity, and temperature data. Dates for sample collection were determined based on factors such as perceived maturity of the compost and relevant closeness to pile turning dates.

Ambient air temperatures along with rainfall (www.awis.com) were used to further evaluate temperatures and moisture contents within the compost piles. The air temperatures were compared to the temperatures within the compost piles to determine if ambient temperature played a significant role in affecting pile temperature. The rainfall data was collected to determine if there was a direct correlation of rainfall and moisture contents within the compost piles.

Procedures for determining particle size distribution (PSD) for the west windrow compost and in-vessel compost was done as described by (Boyer, 2008). Three random samples of compost were taken from the west windrow and in-vessel compost pile placed in brown paper bags and oven dried in a Grieve SC-350 oven dryer (The Grieve Corp. Round Lake, IL) at 155°F for a period of 48 hours. PSD was analyzed by passing a 100-g air-dried sample through 12.5, 9.5, 6.35, 3.35, 2.36, 2.0, 1.4, 1.0, 0.5, 0.25, and 0.11 mm sieves with particles passing the 0.11-mm sieve collected in a pan (Table 8). Sieves were shaken for 3 min with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations/min, 159 taps/min).

A weed seed germination study was also conducted (March, 2008) (Paterson Greenhouse Complex, Auburn University) using composts from the west windrow and in-vessel composter. The purpose of the study was to determine if one method of composting was more effective in weed seed suppression than the other. East windrow compost was not used during the weed germination test because it had not matured at the time the study was conducted. This study consisted of potting up 12 four inch cups (3-¾ inch width by 3-⅜ inch height) (Dillen Manufacturing, Middlefield, OH) with windrow composted poultry litter and 12 four inch cups (Dillen Manufacturing, Middlefield, OH) with in-vessel digester composted poultry litter. Treatments were placed in a temperature controlled greenhouse using a completely randomized block design and hand watered daily using city water. The study lasted a total of 6 weeks during which weekly weed germination counts were observed.

Results and Discussion

Data collection for the compost pile originating from the in-vessel composter lasted for a period of approximately 29 weeks (Fig. 4; Tables 2, 3, 4, 7, 8). The cutoff for data collection was determined by temperatures within the in-vessel compost pile stabilizing. Temperature stability is described as a length of time in which the temperatures within the compost pile did not increase greatly after turning. As previously stated by Fitzpatrick et al. (2005), the length of time that PL remains in the in-vessel composter is shorter than the length of time for windrow composting. During this study the material was composted in the in-vessel composter for eight days. Once the material was removed from the vessel it continued to have a temperature response to turning, indicating that composting was continuing in the static pile. The results of our study disprove our hypothesis that in-vessel composter composting produces stable compost in a matter of days versus weeks as determined by the temperatures that were recorded. By looking at data (Figure 4) temperatures within the in-vessel compost pile continued to rise and fall steadily over time, indicating that the microbes within the compost were still at work breaking down the carbon into a more stable end product. More importantly, manual turning of the in-vessel pile with a front-end loader showed that when more oxygen was incorporated into the pile the microbes were re-activated leading to further respiration and stabilization of the compost. Temperature response to turning was the indicator most easily used in this study to determine relative compost stability (Dougherty, Personal Communication).

Compost piles are actively composting when temperatures are in the range of 104-140°F (Dougherty, 1999). The temperature ranges for the in-vessel composter pile stayed in the thermophilic range until approximately 12/24/2007 at which point the in-vessel compost was considered mature (Figure 4). Moisture contents for the in-vessel method revealed that the pile stayed in the range of 22.2% and 42.3% (wet weight basis) (Table 3). The small size of the in-vessel pile likely affected its ability to retain moisture; therefore adversely affecting its maturity rate as well. Although, there are no standards for C:N ratios for finished compost products, the C:N ratios from the in-vessel composter were between 10:1 to 8:1, decreasing over time. This result was expected due to micro-organisms respiring carbon dioxide (Table 4). The reason for the low initial C:N in the in-vessel compost is no carbon source being added to the in-vessel PL before composting.

Bacteria data for the in-vessel compost revealed that no fecal coliforms were present at the start or end of the composting process. *Salmonella* was not present at any time during in-vessel composting either. *Enterococcus was* present at the start of the experiment but at the end of the study no *Enterococci* was observed in compost samples derived by in-vessel composter method (Table 7). *Enterococci* can be found in most composts and the levels present in composts analyzed in this study are normal for manure composts (Feng, Personal Communication). No correlation was found relating rainfall data to moisture contents within the in-vessel pile. This was because a breathable, water repellant compost blanket was used to cover the pile. The cover not only blocked moisture from penetrating the blanket, but allowed air to flow through as it was designed.

Data collection for west windrow composting began on 7/18/2007 and ended approximately 65 weeks later. Temperatures within the west windrow remained at or around thermophillic range until around December 20, 2007 at this time the temperatures fell below thermophilic range but responded with an increase in temperature to just below thermophilic range after the third turning (3/17/2008) (Figure 5). As previously mentioned, the temperature ranges for thermophilic bacteria are 104 - 140°F and the main affect that turning has on a compost is the incorporation of oxygen into the compost material. The microbes that are present in a compost pile are constantly using oxygen during the decomposition process and need to be replenished with oxygen frequently enough to keep them alive. After the fourth turning of the west windrow (5/19/08) there was only a small change in temperature which meant that the west windrow was likely stable enough for further evaluation using ornamental crops. Moisture contents for the west windrow stayed within ranges of 40 – 60% for the majority of the experiment (Table 3). C:N ratios for west windrow were highest (16:1) at the start of the experiment an by the end of the experiment had dropped to 13:1 (Table 4). The drop in C:N ratio was expected due to microbes respiring carbon dioxide during the composting process. The sawdust that was added to the compost pile at the beginning of the study was apparently not enough to bring initial levels to the desired C:N ratio of 20:1 – 40:1 (Table 4).

Bacteria data revealed that fecal coliforms and *Salmonella* were not present when composting began or finished. *Enterococci* data revealed that the levels of the bacteria within the compost decreased over time until the 2/17/2008 sample date upon which time data reveals that the bacteria had reproduced. *Enterococci* bacteria will go dormant during cooler weather and start to reproduce as atmospheric temperatures rise (Feng, Personal Communication).

The west windrow temperatures stabilized around 5/30/2008 at which time there was no response to turning of the windrow and it could be considered finished compost.

East windrow compost was not used further as it was found to differ from the west windrow in various aspects. The temperatures for the east pile remained at or above thermophilic range (104 - 105°F) for the entire length of the study (Figure 6). This could show that even after 65 weeks of composting the east windrow continues to break down towards a more stable end product. The moisture contents of the east windrow stayed consistently lower than the moisture contents of west windrow (Table 3) indicating uneven moisture distribution at the beginning of the study. C:N ratios for east windrow were lower than the recommended ranges for composting (20:1 – 40:1) (Table 4). The C:N ratios for east windrow ranged from 11.5:1 at the beginning of composting to 15:1 at the end of composting. The higher C:N ratio at the end of sampling was due to the addition of 50 yd^3 sawdust to the east windrow on 3/17/08 (Table 4).

Bacteria data revealed that fecal coliforms and *Salmonella* were not present when composting began or finished. *Enterococci* data revealed that the levels of the bacteria within the compost decreased over time until the 2/17/2008 sample date upon which time data reveals that the bacteria had reproduced. *Enterococci* bacteria will go dormant during cooler weather and start to reproduce as atmospheric temperatures rise (Feng, Personal Communication).

No correlation can be found to relate rainfall data to moisture contents within the west windrow. This could be because the compost blanket that was used to cover the pile not only blocked moisture from penetrating the blanket but allowed air to flow through as it was designed.

Particle size distribution (PSD) data (Table 8) revealed that the composts from west windrow and in-vessel was within acceptable ranges for green industry use (Klock-Moore et al., 2000). The east windrow compost was not analyzed for particle size distribution due to perceived lack of maturity. The study revealed that there were no significant differences between means for the coarse, medium, and fine textures of the composts. This analysis confirms that the compost is suitable for use as a substrate amendment. Chemical properties (Table 2) revealed that the level of nitrate nitrogen in windrow (31,940 ppm) and in-vessel composting (19,167 ppm) are unacceptable for plant use if used as a sole ingredient in a substrate. However, as reported by Yeager et al. (2007), if the amount of compost used to amend a substrate is between 20-50% most complications can be avoided. As Brodie et al. (2000) stated, the inference of trends may be considered subjective in that there was insufficient replication of ingredient mixes and pile configurations to allow statistically meaningful measurement. The composting period extended over a period of 65 weeks allowing little time for repetition of the study.

Weed suppression data revealed that there were no significant differences for windrow composting or in-vessel composting. During the weed test, no weed seed germinated during the 6 week study. Although no comparable tests were run of fresh PL or sawdust feedstocks, results suggest that windrow and in-vessel composting of PL are equally capable of neutralizing any weed seed present during the composting process.

In conclusion, the data revealed that windrow composting (although it takes a longer time to complete using the methods mentioned in this chapter) is a more reliable method than in-vessel composting for producing composts for the green industry based on compost stability throughout the entire monitoring process. The differences that were found between the east and west windrows reveal that moisture content and C:N ratios within a compost play a significant role in the rate of maturity for a compost, and were likely the two most important limiting factors for this study. Temperature data indicates that the windrow method is a more reliable method than in-vessel composting for producing PL compost. Temperature data that was collected throughout the composting process for both systems demonstrate that compost temperatures generally follow ambient air temperatures. The moisture contents found in the west windrow started out at 53% wet basis and stayed within recommended ranges for the length of the study. The moisture contents for east windrow were below recommended ranges for approximately half of the study. C:N ratios for the west windrow were closer to optimal ranges than the C:N ratios of east windrow at the start of the study which aided production of a more stable end product. This study revealed that the east windrow never reached the same level of maturity that west windrow did. Heating that occurred (Figure 4) in the in-vessel pile after removal from the composter confirmed that although the compost removed from the reactor appeared completely composted, it was in fact not completely mature after only eight days within the vessel. Composts that are produced via in-vessel composter should be allotted ample amount of time to mature before being used as a container substrate. In addition, sufficient care of recipe mixing with regard to C:N ratio and moisture content should be taken. The levels of bacteria found in composts produced during this study are normal for manure composts and are safe levels for human interaction (Feng, Personal Communication).

It is of utmost importance for a green industry professional to understand the process at which composts are produced if they are planning to incorporate composts into a container substrate. Producers should have an idea of the maturity level for composts being utilized in substrates. Chemical analysis should be conducted prior to use as a substrate in order to adjust for pH and high levels of soluble salts found in PL composts. The more the grower knows about how the compost is produced and the materials it is derived from, the more prepared they will be to deal with problems that may arise during the production process.

Literature Cited

Alabama Agricultural Statistics (AAS). 2007. Bulletin 49. Dept. of Ag. and Industries 39-42.

Adediran, J.A., L.B. Taiwo, and R.A. Sobulo. 2003. Effect of organic wastes and method of composting on compost maturity, nutrient composition of compost and yields of two vegetable crops. J. of Sust. Agri. 22: 95-109.

Andrews, W.H., and T.S. Hammack. 1998. Bacteriological analytical manual, 8th ed. revision A. U.S. FDA.

Atkinson, C.F., D.D. Jones, and J.J. Gauther. 1996. Biodegradability and microbial activities during composting of poultry litter. Poultry Science 75:608-617.

Boyer, C.R. 2008. Evaluation of clean chip residual as an alternative substrate for container-grown plants. PhD Dissertation. 204pp.

Boyer, C.R., C.H. Gilliam, G.B. Fain, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2007. Clean chip residual amended with composted poultry litter as a substrate for *Lantana camara*. SNA Res. Conf. Proc. 52: 495-488.

Brodie, H.L., L.E. Carr, and P. Condon. 2000. A comparison of static pile and turned windrow methods for poultry litter compost production. J. Compost Sci. Util. 8: 178-189.

Buchanan, M. and S.R. Gliessman. 1991. How compost fertilization affects soil nitrogen and crop yield. BioCycle 32: 72-77.

Cooperband, L.R., and J.H. Middleton. 1996. Changes in chemical, physical and biological properties of passively-aerated co composted poultry litter and municipal solid waste compost. J. Compost Sci. Util. 4:24-34.

Dougherty, M. 1999. Field guide to on-farm composting. NRAES Ithaca, NY. 114.

Edwards, J.H., E.C. Burt, R.L. Raper, and R.H. Walker. 1995. Issues affecting application of noncomposted organic waste to agricultural land. pp. *In Agricultural Utilization and Industrial Byproducts;* Kalen et al. Eds.; Agron. Special Publication No 58, ASA, CSSA, SSSA: Madison, WI. pp. 225-249.

Eaton, A.D., L.S. Clesceri, E.W. Rice, and A.E. Greenberg. 2005. Standard methods for the examination of water and wastewater. 21 ed. APHA, AWW, WEF.

FAO, 1987. Soil management: compost production and use in tropical and subtropical environments. FAO, Food and Agri. Org. of United Nations, Rome, FAO Soil Bulletin 56, 177 p.

Fasina, O.O., D.I. Bransby, J.R. Kessler, C.H. Gilliam, and J.L. Sibley. 2005. Pelleted poultry litter provides viable fuel source for greenhouse heat. SNA Res. Conf. Proc. 50:362-364.

Faucette, B. 2001. Georgia builds poultry litter composting infrastructure. Biocycle, August 2001:23-26.

Freeman, T.M., and D.L. Cawthon. 1999. Use of composted dairy cattle solid biomass, poultry litter and municipal biosolids as greenhouse growth media. Compost Sci. & Util. 7:66-71.

Fitzpatrick, G.E., E.C. Worden, and W.A. Vendrame. 2005. Historical development of composting technology during the 20th century. HortTechnology 15:48-51.

Fritsch, D.A., and A.R. Collins. 1993. The economic feasibility of poultry litter composting facilities in eastern West Virginia. WVU. Agr. Expt. Sta. Scientific Article. 2351.

Gray, K.R., and A.J. Briddlestone. 1981. The composting of agricultural wastes. In: B. Stonehouse (ed.). Biological Husbandry. Butterworths Publications, London, England. 99-112.

Guertal, E.A., B.K. Behe, and J.M. Kemble. 1997. Composted poultry litter as potting media does not affect transplant nitrogen content of final crop yield. HortTechnology 7:142-145.

John, N.M., G.O. Adeoye, and M.K.C. Shridhar. 1995. Effect of a binding agent and sawdust amendment on the stabilization of compost, soil properties and crop growth. Proceedings of the 23rd all African soil science conference 383-394.

Kaplan, J.D., R.C. Johansson, and M. Peters. 2004. The manure hits the land: economic and environmental implications when land application of nutrients is constrained. Amer. J. Agr. Econ. 86:688-700.

Klock-Moore, K.A., G.E. Fitzpatrick, and G. Zinati. 2000. Container production of ornamental horticultural crops. Biocycle 41:58-60.

Lopez, R., C. Duran, J.M. Murillo, and F. Cabrera. 1998. Geranium's response to compost based substrates. Acta Horticulturae 469:255-262.

Macklin, K. 2008. Litter management. North Carolina broiler supervisor's short course. NCSU.

Misra, R.V., and R.N. Roy. 2002. On-farm composting methods. FAO, Rome.

Mitchell, C.C., J.O. Donald, and J. Martin. 1989. The value and use of poultry waste as fertilizer. Poultry byproduct management-agronomy. Alabama Coop. Ext. Serv.: Auburn University, AL., ANR-244:6.

Mkhabela, T.S. 2006. A review of the use of manure in small-scale crop production systems in South Africa. J. of Plant Nutrition 29: 1157-1185.

Parr, J.F., R.I. Papendick, and D. Colacicco. 1986. Recycling of organic wastes for a sustainable agriculture. Bio. Agri. and Hort. 3:115-130.

Rynk, R. Editor. 1992. On-farm composting handbook. NRAES. 54.

Spencer, R.L. 2007. In-Vessel composting: rotating drums. BioCycle, June 2007:28-32.

Taiwo, L.B. 1997. Development of organic-based fertilizer form sorted urban wastes. PhD Dissertation. 205pp.

Tyler, H.H., S.L. Warren, T.E. Bilderback, and K.B. Perry. 1993. Composted turkey litter: II. Effect on plant growth. J. Environ. Hort. 11:137-141.

Tyson, S.C. and M.L. Cabrera. 1993. Nitrogen mineralization in soils amended with composted and uncomposted poultry litter. Commun. Soil Sci. Plant Anal. 24: 2361-2374.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best Management Practices: Guide for Producing Nursery Crops. 2nd Edition. 103 pages. Southern Nursery Assoc., 1827 Powers Ferry Road, Atlanta, GA.

www.awis.com. Awis.com: consulting, data and forecasts for ag, energy, retail and industry. 9/17/08.

http://www.msstate.edu/dept/poultry/pub1998.htm. Broiler litter as a feed or fertilizer in livestock operations. 9/17/2008.

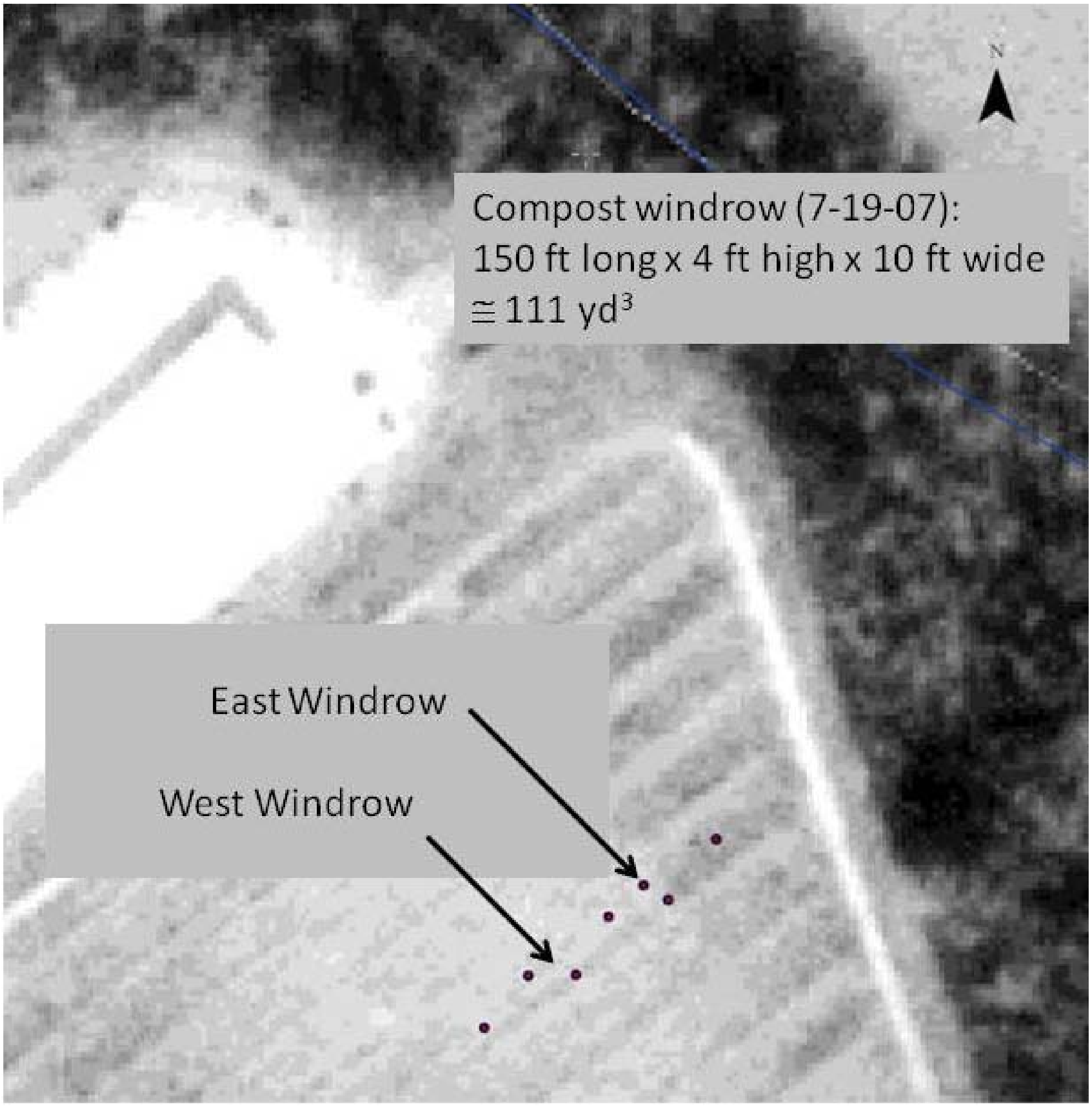

Figure 1. Site map depicting east and west windrow.

Figure 2. Picture of windrow turning machine (SCAT Engineering, Inc., Hopkinton, IA). Machine is pulled by a tractor of at least 100 horsepower.

Figure 3. Picture of in-vessel composter (BW Organics, Inc., Sulphur Springs, TX).

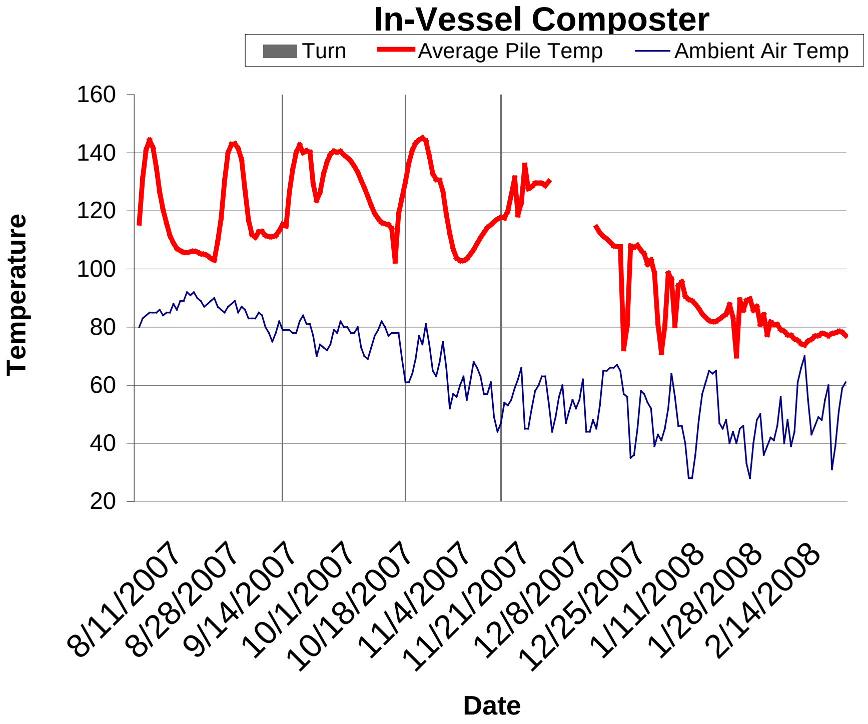

Figure 4. Temperature fluctuations (°F) in a static pile of poultry litter compost originating from an in-vessel composter. Vertical lines represent the date at which turning occurred for the compost. Turning equipment used for turning the compost originating from the in-vessel composter was a 25 horsepower tractor with a front end loader. Breaks in average pile temp indicate missing data due to data logger malfunction.

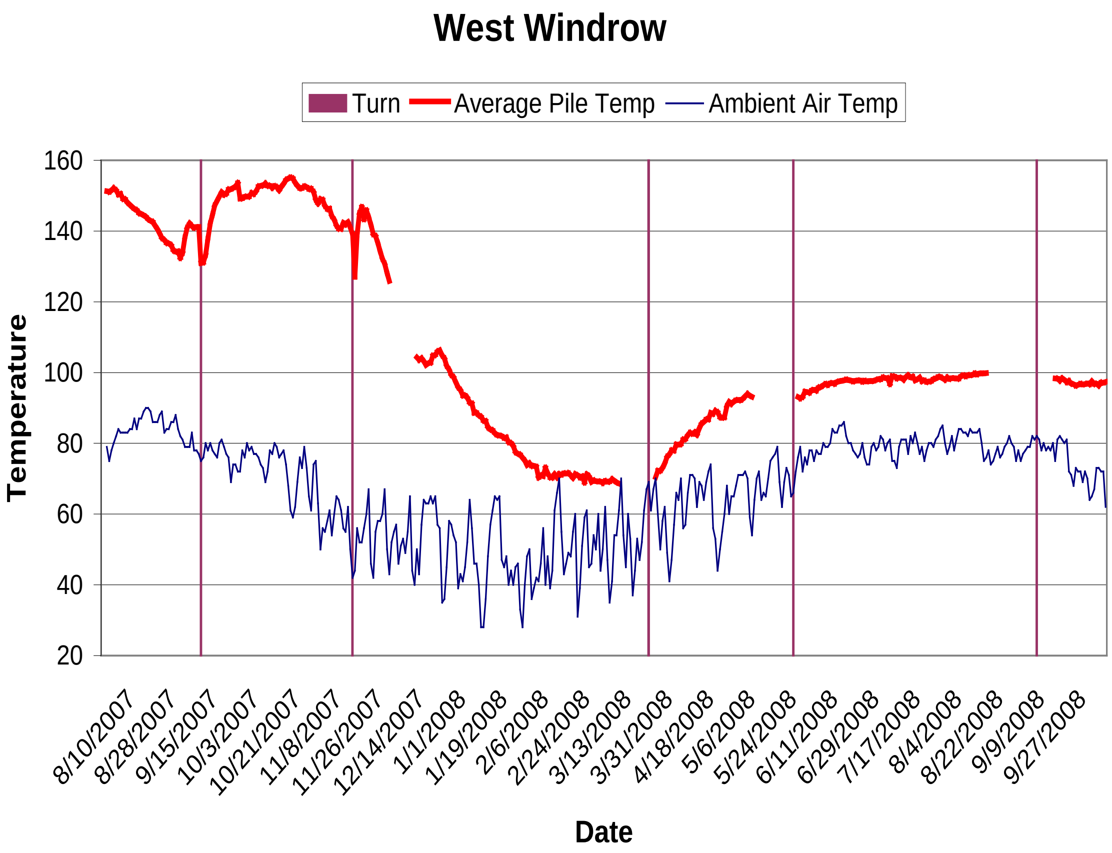

Figure 5. Temperature fluctuations (°F) of windrow composted poultry litter. Vertical lines represent the dates that the windrow was turned. Windrow was turned using a windrow turning machine SCAT 482B (SCAT Engineering, INC., Hopkinton, IA) pulled by a 115 horsepower tractor. Breaks in average pile temp indicate missing data due to data logger malfunction.

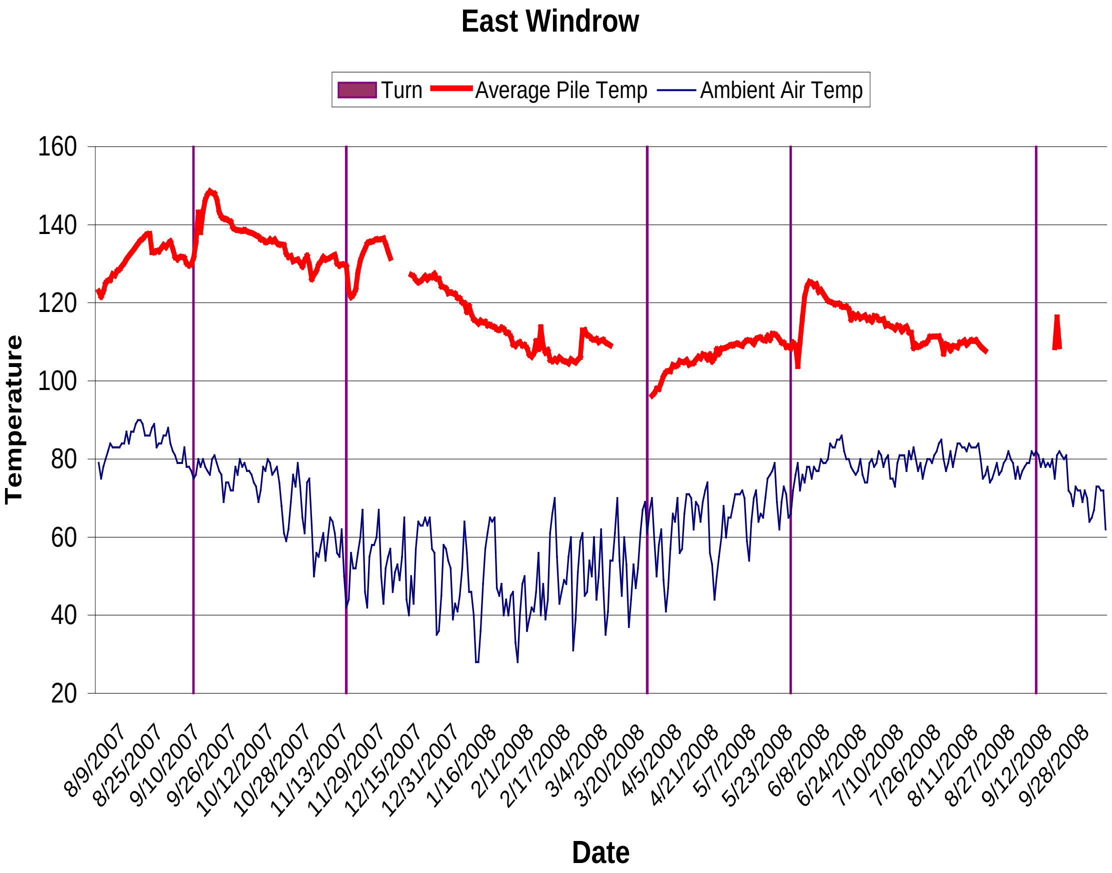

Figure 6. Temperature fluctuations (°F) of windrow composted poultry litter. Vertical lines represent the dates at which the windrow was turned. Windrow was turned by a windrow turning machine SCAT 482B (SCAT Engineering, INC., Hopkinton, IA) that is pulled by 115 horsepower tractor. Breaks in average pile temp indicate missing data due to data logger malfunction.

Table 1. Values used to calculate additional amounts of sawdust and water needed for optimal C:N of 40:1 and moisture content of 40% for windrow composting at beginning of study.

Material	MC%[Z]	N%	C:N[Y]	Weight[X]	Vol.[W]
Sawdust[V]	14	0.8	200:1	24	100
Poultry Litter[U]	18	3.19	8:1	36	95
Desired Mix[T]	40[S]		40:1	60	111[R]

[Z] MC%= moisture content of materials on a wet weight basis at beginning of composting.

[Y] C:N= carbon:nitrogen ratios of materials at beginning of composting

[X] Weight in tons of materials at beginning of composting.

[W] Volume in cubic yards of materials at beginning of composting

[V] Sawdust is ingredient 'a'.

[U] Poultry litter is ingredient 'b'.

[T] Mix= Sawdust and poultry litter mixed together. Values represent desired levels at beginning of composting 7/18/2007.

[S] Water to be added =7200 gallons.

[R] Reason for only 111 yd^3 is because difference in poultry litter and sawdust bulk densities upon mixing.

Table 2. Chemical properties for un-composted poultry litter and composted poultry litter by two different methods.

		Substrate micro-nutrient content[Y]				
Substrate[Z]	pH	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Fresh Poultry Litter	8.46	40	3180	438	125	338
West Windrow	6.66	3.1	3.3	0.3	0.7	1.1
In-Vessel Composter	9.16	8	119	5.3	32	32
	Substrate macro-nutrient content					
	NO_3-N (ppm)	NH_4-N (ppm)	P (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)
Fresh Poultry Litter	NA[X]	NA	16700	22600	5900	31200
West Windrow	31940	3.6	198	3375	812	1926
In-Vessel Composter	19167	183	175	15623	41	211

[Z] Fresh poultry litter is uncomposted (7/18/07); windrow is sample of composted poultry litter from west windrow (9/25/08); in-vessel composter is sample of composted poultry litter from in-vessel composter (9/25/08).

[Y] Substrate analysis performed on non-amended substrates.

[X] NA= not available because of different analytical procedures.

Table 3. Moisture analysis for compost.[Z]

Date	Moisture West[Y]	Moisture East[X]	Moisture In-Vessel Composter[W]
7/25/2007	53.9	32.74	31.65
7/26/2007	50.4	34	----
7/30/2007	41.4	30.07	----
8/2/2007	41.1	32.6	22.19
8/13/2007	42.9	37.2	27.4
8/17/2007	31.61	28.18	----
8/30/2007	29.13	28.54	26.84
9/4/2007[V]	----	----	----
9/6/2007	45.04	32.24	24.04
9/20/2007	40.48	30.23	27.22
10/12/2007	38.63	32.78	27.2
11/5/2007	48.24	42.02	27.05
11/9/2007[U]	49.36	40.08	42.32
11/28/2007	55.4	36.84	27.38
12/7/2007	50.75	48.59	37.25
12/13/2007	45.24	44.61	29.99
1/9/2008	47.86	35.25	27.7
1/29/2008	38.33	37.28	27.28
2/18/2008[T]	53.79	52.02	----
2/25/2008	56.37	40.69	----
3/18/2008[S]	----	----	----
3/20/2008	46.64	52.85	----
3/25/2008	44.35	49.89	----
4/8/2008	50.73	45.26	----
5/2/2008	45.06	43.02	----
5/19/2008[R]	----	----	----
5/21/2008	48.58	44	----
7/1/2008	51.02	45	----
8/11/2008	53.04	46.6	----
9/2/2008[Q]	----	----	----

[Z] Moisture analysis performed on a wet weight basis. Numbers represent % wetness.

[Y] West windrow compost pile.

[X] East windrow compost pile.

[W] In-vessel composter compost pile.

[V] Date represents turning of windrow and in-vessel compost piles.

[U] Date represents turning of windrow and in-vessel compost piles.

[T] Date represents the exact date that the data collection for in-vessel compost ceased.

[S] Date represents when East windrow was mechanically separated from west windrow and 50 cubic yards of saw dust was added to east windrow with both being turned.

[R] Date represents turning of the east windrow.

[Q] Date represents turning of the east windrow.

Table 4. Carbon: Nitrogen (C:N) ratios for east and west windrow composts along with in-vessel composter compost.

Date[Z]	West[Y]	East[X]	In-Vessel[W]
9/6/2007	16.0:1	11.5:1	10.4:1
10/12/2007	11.8:1	9.1:1	10.7:1
12/13/2007	12.8:1	9.4:1	9.7:1
1/29/2008	11.1:1	8.8:1	8.3:1
2/18/2008	13.3:1[V]	13.9:1[V]	
9/15/2008	10.2:1	15.3:1[U]	

[Z] Dates represent collection of sample for C:N analysis. Samples were collected at depths of 24 inches at various points within the correlating compost pile.

[Y] West windrow compost C:N value.

[X] East windrow compost C:N value.

[W] In-Vessel compost C:N value.

[V] Increase in C:N values for 2/18/2008 date most likely due to sampling error. C:N ratios will decrease over time due to the breakdown of carbon via microbial organisms.

[U] Increase for east windrow on 9/15/2008 is expected due to additional 50yd^3 sawdust that was incorporated into east windrow on 3/17/2008.

Table 5. Bacteria analysis for samples collected from east windrow compost.

Date[Z]	*Enterococci* cells/g wet Wt	*Enterococci* cells/g dry Wt	Fecal coliforms cells/g wet Wt	Fecal coliforms cells/g dry Wt	*Salmonella*
4/11/2007	1.00E+07	1.39E+07	150	208	0
7/16/2007	6.50E+06	1.05E+07	9.20E+03	1.48E+04	0
10/14/2007	850	1308	0	0	0
12/12/2007	37.5	68	0	0	0
1/28/2008	0	0	0	0	0
2/17/2008[Y]	907.5	1681	0	0	0
9/15/2008	1825	3967[X]	0	0	0

[Z] Dates represent day sampling occurred for analysis. Samples were taken at 24 inch depth from random areas of the east windrow.

[Y] Increase in *Enterococci* level is due to bacteria breaking dormancy.

[X] Levels of bacteria reported are safe for human interaction.

Table 6. Bacteria analysis for samples collected from west windrow compost.

Date[Z]	*Enterococci* cells/g wet Wt	*Enterococci* cells/g dry Wt	Fecal coliforms cells/g wet Wt	Fecal coliforms cells/g dry Wt	*Salmonella*
4/11/2007	1.00E+07	1.39E+07	150	208	0
7/16/2007	6.50E+06	1.05E+07	9.20E+03	1.48E+04	0
10/14/2007	1300	2000	0	0	0
12/12/2007	7.5	13	0	0	0
1/28/2008	765	1275	0	0	0
2/17/2008[Y]	1125	1974	0	0	0
9/15/2008	35	60[X]	0	0	0

[Z] Dates represent day sampling occurred for analysis. Samples were taken at 24 inch depth from random areas of the west windrow.

[Y] Increase in *Enterococci* level is due to bacteria breaking dormancy.

[X] Levels of bacteria reported are safe for human interaction.

Table 7. Bacteria analysis for samples collected from in-vessel compost.

Date[Z]	*Enterococci* cells/g wet Wt	*Enterococci* cells/g dry Wt	Fecal coliforms cells/g wet Wt	Fecal coliforms cells/g dry Wt	*Salmonella*
7/17/2007	10	14	0	0	0
7/23/2007[Y]	1164	1877	0	0	0
10/14/2007	750	1103[X]	0	0	0
12/12/2007	0	0	0	0	0
1/28/2008	0	0	0	0	0

[Z] Dates represent day sampling occurred for analysis. Samples were taken at 24 inch depth from random areas of the in-vessel compost pile.

[Y] Increase in *Enterococci* level is due to bacteria reproducing.

[X] Levels of bacteria reported are safe for human interaction.

Table 8. Particle size distribution for poultry litter composted by two different methods.

U.S. standard sieve no.	Sieve opening (mm)[Z]	100% WR[Y]	100% IV[X]
1/2	12.50	0.5b	6.6a
3/8	9.50	1.7a	2.4a
1/4	6.35	6.6a	6.7a
6	3.35	15.9a	17.3a
8	2.36	10.4b	11.4a
10	2.00	4.4a	5.0a
14	1.40	11.4a	12.9a
18	1.00	10.5a	11.2a
35	0.50	15.4a	17.5a
60	0.25	9.1a	9.7a
140	0.11	3.4b	5.9a
270	0.05	0.8b	1.6a
pan	0.00	0.7a	0.8a
Texture[V]			
Coarse		26.9a	30.8a
Medium		37.5a	39.8a
Fine		31.7a	33.3a

[Z] 1mm = 0.0394 inch.

[Y] WR = Compost produced using windrow composting technique. Samples taken from west windrow.

[X] IV = Compost derived using in-vessel method.

[W] Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Tukey's Studentized Range Test ($\alpha = 0.05$, n =3)

[V] Coarse = 3.35-12.50 mm; Medium = 1.00-2.36 mm; Fine = 0.00-0.50 mm.

CHAPTER III

EVALUATION OF WINDROW VERSUS IN-VESSEL DIGESTOR POULTRY LITTER FOR GREENHOUSE USE

Abstract

Compost from windrow composting was compared to in-vessel digester composting using poultry litter as the compost media. In order to compare the two compost methods, temperature, moisture, C:N ratio, and bacteria were monitored during production of the compost. Once the compost from each method was considered stable, a greenhouse growth study using *Impatiens walleriana* Trailing Fanfare™ 'Blush' for a total of seven weeks was conducted. Analysis of data revealed plants grown in windrow-compost significantly out performed plants grown using in-vessel digester compost when the ratio of in-vessel compost within the media was greater than 7:1 pine bark: in-vessel compost. Both methods produced weed free compost material with satisfactory physical properties for use as a container substrate component.

Introduction

Poultry production is a rapidly growing industry in the United States. As a nation the U.S. produces 8.9 billion birds annually with Alabama currently third in production with 11.9% (1.1 billion birds) of U.S. totals (AAS, 2007). Typically, on a commercial broiler farm, litter is used for six or more consecutive grow-outs. Each grow-out generally lasts 6+ weeks; which means that litter is generally being utilized for at least one year (Macklin, 2008). Currently a conservative estimate of 16.6 million tons of poultry litter is produced in the United States each year. In Alabama alone the poultry and egg industry represents approximately $2.7 billion in gross farm receipts and employs approximately 78,000 people. One impact of this industry is that millions of pounds of waste material, particularly ~ 2 million tons of litter are generated by the poultry and egg industry in Alabama annually (Edwards et al., 1995).

In agriculture, poultry litter (PL) or broiler litter is a material used as bedding in poultry operations to render the floor more manageable. Common litter materials in the southeast can consist of wood shavings, sawdust, peanut hulls, straw, and other dry, absorbent, low-cost organic materials. After use, the litter consists primarily of poultry manure, but also contains the original litter material, feathers, and spilled feed (Freeman and Cawthon, 1999). Typical PL has an average wet weight moisture content of 20-40% and a dry nitrogen content of 1.5-4% (Rynk, 1992). Poultry manure has been used successfully as a fertilizer for the production of maize, small grains, fruits, forage grasses, and vegetables. Poultry manure has been reported to increase nutrient concentration in the soil, to improve nutrient uptake by plants, and to increase crop yields (Mkhabela, 2006). Manure may improve soil structure and subsequently soil permeability, water-holding capacity, aeration, and also supply micronutrients. Thus, structural deterioration of soils can be reversed and soil fertility can be restored by manure (Mkhabela, 2006). PL contains the equivalent of approximately 26- 22- 17 kilograms per metric ton (63-53-41 pounds per U.S. ton) of N-P_2O_5-K_2O on a dry basis, which is equivalent to a bagged, commercial fertilizer analyzing approximately 3-2.5-2 percent of N-P_2O_5-K_2O, respectively. Based upon current fertilizer prices, PL would be worth about $30 to $40 per ton as a fertilizer, not including spreading and transportation charges. PL applications of 1.8 to 3.6 metric tons per acre (2-4 U.S. tons) have been effective in promoting grass growth in pasture (http://www.msstate.edu/dept/poultry/pub1998.htm, 1998).

In recent years there has been concern for disposing of agricultural waste in the United States and elsewhere in the world. Some of the resulting issues facing the poultry production industry with regards to waste management include: reduced land area on farms to apply increasing amounts of litter; nutrient management plans that are based on phosphorous indexes; land applying PL to clay soils that already have high phosphorous (P); land application of poultry litter can promote degradation of water quality by promoting increases in groundwater NO_3 content and in cases where N is not limited, leaching may occur when PL is applied to agricultural land at rates in excess of the nitrogen requirement of the crop (Faucette, 2001; Kaplan et al., 2004; Mitchell et al., 1989). Poultry litter is typically land applied according to the amount of nitrogen it can supply. Although P tends not to move in soils, repeated applications of PL can lead to P build-up, which can result in P runoff and affect surface water. Also, P is a limiting element in many processes in plant and microbe development. Increases in P can cause proliferation in plant and microbe growth in lakes and streams, a process known as eutrophication.

Poultry litter can be used by many industries. Studies evaluating PL as a fuel source (Fasina et al., 2005); cattle feed, container media in nurseries, erosion control, and as a fertilizer (Atkinson et al., 1996; Guertal et al., 1997; Lopez et al., 1998; Tyler et al., 1993) have been conducted. Nursery crop growers are looking for substrates that are consistent, available, easy to handle and mix, cost effective, and have the appropriate physical and chemical properties for the crop they are growing (Klock-Moore et al., 2000). Composts meet many of these requirements and therefore can be considered a suitable component of the potting media (Freeman and Cawthon, 1999). Fritsch and Collins (1993) define compost as the biological stabilization of organic wastes under controlled conditions of oxygen, moisture, and temperature. The end result is a stable organic product which improves soil fertility by providing nutrients, reducing bulk density, increasing cation exchange capacity, and enhancing populations of soil microorganisms. Scientists and industry have an increased awareness of composts; in particular PL compost due to the increasing amounts of litter produced each year and the resulting environmental challenges that are associated with PL.

The environmental issues associated with raw manure application could be mitigated by chemically or biologically stabilizing soluble nutrients. Composting of PL converts soluble nutrients to more stable organic forms, thereby reducing their bioavailability and susceptibility to loss when applied to crop fields (Buchanan and Gliessman 1991; Cooperband and Middleton, 1996; Tyson and Cabrera, 1993). Processing of PL wastes by composting therefore provides an opportunity to reduce volume and odor, while increasing the nutritive values of the material (FAO, 1987; Gray and Briddlestone, 1981; Parr et al., 1986).

Currently there are numerous ways to produce compost products, including: open pile, aerated static pile, windrow, and in-vessel composter. Open-pile composting is suitable for small to moderate- sized farms operating under a low level of management. This method involves forming piles of organic materials and leaving them undisturbed until the materials have decomposed into a stabilized product. Small piles are designed to take advantage of natural air movement. In general, larger piles are more difficult to aerate effectively because of pile compaction. Under proper feedstock and moisture conditions, however, pile temperatures increase, contributing to production of good compost. The costs of the labor and equipment used to form and mix the initial piles are the largest operational expenses. Farm loaders and manure spreaders can typically be diverted from other farm uses to form and mix piles (Dougherty, 1999).

The *aerated* static pile system is different in that the compost materials are placed into rows, but the windrows are built on top of an air distribution system composed of flexible perforated pipes embedded in woodchips. Fans are used to provide forced aeration into the pile or induced draft aeration from the pile. The aerated static pile system has been successful in providing high levels of aeration and is used throughout the world to make compost from excessively moist, hard to aerate materials such as municipal and industrial sludges (Dougherty, 1999; Fitzpatrick, 2005).

Windrow composting is an example of an open composting system that uses active tuning with relatively low-level technology. Compost materials are placed in rows and turned periodically using mechanical equipment. Windrow systems are popular because they do not necessarily require dedicated specialized equipment (Fitzpatrick et al., 2005). Windrow composting consists of piles usually ranging from 94 cm in height to heights of 3.7 meters (3ft by 12 ft) with the widths depending on the equipment used to turn the rows. Between turning, windrows aerate by natural or passive air movement (Misra and Roy, 2002). The frequency of turning depends on the rate of decomposition (indicated by temperature rise), the moisture content and porosity of the materials, and the desired composting time (Misra and Roy, 2002). The required frequency of turning windrows usually decreases over time due to the aging of the materials (Misra and Roy, 2002). In a windrow situation, eight weeks is a common period for manure composting operation (Misra and Roy, 2002).

In-vessel composting involves confining actively composting materials within a building, container, or vessel. Many in-vessel systems use a rotating drum. The first of which was developed in the U.S. by Eric Eweson in the 1940s. Eweson designed a system in which compost material anaerobically ferments in a large rotary drum for a period of 3-6 days. Unlike many of the early mechanical composting systems, the rotary drum system has been successful and there are many such systems operating throughout the world at the present time (Fitzpatrick et al., 2005). In-vessel systems are the most aggressively managed and generally the most capital intensive of the composting technologies (Dougherty, 1999). The in-vessel process of composting is an aerobic process by which the materials are constantly tumbled upon each other forcing oxygen inside the mix. Most drum systems include blowers to maintain aerobic conditions and minimize excessive temperatures, with one technology injecting oxygen (Spencer, 2007). Rotating drums are the most common in-vessel method in part because the combination of pulping action and biological degradation in the drum breaks down organic materials in just a few days to a rough, though unfinished compost (Spencer, 2007). The in-vessel system can create an adequate aerobic composting environment allowing compost to reach thermophillic temperatures within 24 hours (Freeman and Cawthon, 1999). The residence time within the in-vessel system depends upon the level of composting desired. Additional curing time outside the in-vessel composter can be used to finish the composting process (Dougherty, Personal Communication). Composting drums are available in sizes from one meter in diameter and 3.6 meters long to 5 meters in diameter and up to 70 meters long (3 feet in diameter and 12 feet long to 16 feet in diameter and 230 feet long).

Composting begins as soon as appropriate biologically active materials are mixed together. Initial mixing of raw materials introduces enough air to start the microbial process. Almost immediately, microorganisms consume oxygen, and settling materials expel air from pore spaces. Aeration is provided by passive air exchange, by forced aeration, or turning (Dougherty, 1999). Temperatures of composting materials usually increase rapidly to 38-60°C (100-140°F) and remain in this range for up to several weeks (Dougherty, 1999). Mature compost provides a stabilized form of organic matter (humus) and has the potential to enhance nutrient release in the soil more than other organic wastes because plants are not competing with soil micro organisms for nutrients (Adediran et al., 2003). Time to maturity, however, depends on factors such as type of substrate, organic components of the substrate, and the temperature regime during composting (Taiwo, 1997; John et al., 1995). Other essential elements in the composting process are carbon-to-nitrogen ratio of the initial mix which should be in the range of 20:1-40:1 (C:N ratios above 30 will minimize the potential for odors). C:N ratios are influenced by the materials in which the compost pile is composed of such as manure with an added carbon source (sawdust). An initial feedstock moisture content of 40%-60% wet basis is recommended and depends upon the specific materials, pile size, and weather conditions. Moisture content has a direct effect on oxygen levels within the compost. When a pile is too moist, air spaces within the compost pile can become filled by water, causing undesirable anaerobic conditions. Initial particle sizes of 1.3-5.1 cm

(0.5-2 inches) will be broken down easier. Pile porosity greater than 40% is critical because it permits air to enter and diffuse into the composting mass. Bulk density of 480-710 kg/m^3 (1400-2000 lbs/yd^3) will meet the basic aeration and moisture needs of composting microbes (Dougherty, 1999). If these guidelines are followed it is possible to create an environment that is suitable for composting.

Although there are numerous ways in which to compost PL, the purpose of this research was to evaluate differences between windrow composting and in-vessel composting of PL. The results of this research demonstrate the suitability of turned windrow or in-vessel composter composting of PL for growth of horticultural crops in the green industry.

Materials and Methods

On July 25, 2007 composting of poultry litter arranged in an open-field windrow comprised of about 95 cubic yards of fresh poultry litter (PL) and 100 cubic yards of carbon feedstock (sawdust) with the moisture adjusted to 40% through irrigation of the windrow began. The combining of the two materials led to a windrow of approximately 111 yd^3 of PL compost. The windrow was then divided and monitored as two separate windrows (East, West) due to differences in moisture contents of the halves. Two temperature data loggers (Dickson SM325, The Dickson Company, Addison, IL) were placed into each windrow which automatically recorded temperatures every hour. Substrates in this study consisted of PL composts from the west windrow only.

Also on July 25, 2007 approximately 12 cubic yards of fresh poultry litter was added to an in-vessel digester (Model 616 BW Organics INC., Sulphur Springs, TX) to begin composting. After eight days in the in-vessel digester the litter volume was reduced to about 7 cubic yards of compost, removed, and a subsample of this compost placed outdoors in a pile beside the windrows with two temperature data loggers (Dickson SM 325, The Dickson Company, Addison, IL) inserted to record at the same interval as the windrows. Therefore, virtually the same atmospheric conditions occurred for both treatments. In addition to temperature data, moisture content (analyzed on an as sampled basis, using an Ohaus MB35 moisture analyzer, Ohaus Corporation, Pine Brook, NJ), carbon to nitrogen ratios (TrueSpec, LECO®, St. Joseph, MI), and bacterial samples were analyzed periodically by Dr. Yucheng Feng of Auburn University's Agronomy and Soils department for each method. The methods that were used to determine *Enterococci* and fecal coliform bacteria levels are further described by Eaton et al. (2005). *Enterococci* levels were determined by using method 9230C (Eaton et al., 2005). Fecal coliforms were detected using methods 9221E and 9222E (Eaton et al., 2005). *Salmonella* isolation and identification was performed as described by Andrews and Hammack (1998). Dates for collection of samples were decided by factors such as maturity of the compost and relevant closeness to the turning dates.

Plant materials for the greenhouse growth test (Paterson Greenhouse Complex, Auburn University) consisted of *Impatiens walleriana* Trailing Fanfare™ 'Blush'. Substrates were blended (Vol:Vol) consisting of varying ratios of pine bark: compost with the control being pine bark: peat moss for a total of 9 treatment blends with ten replications per treatment. Treatments were as follows: 1.) 2:1 pine bark (PB): peat moss (PM), 2.) 4:1 PB: PM, 3.) 7:1 PB: PM, 4.) 2:1 PB: windrow (W), 5.) 4:1 PB: W, 6.) 7:1 PB: W, 7.) 2:1 PB: in-vessel (IV), 8.) 4:1 PB: IV, and 9.) 7:1 PB: IV. All substrates were prepared and placed in four inch cups (529ml) (Dillen Manufacturing, Middlefield, Ohio) using a completely randomized block design in a temperature controlled greenhouse (Figure 1). Once the cups were placed on the bench, plugs of *Impatiens walleriana* Trailing Fanfare™ 'Blush' were inserted into the pots and watered in. Data collection at the first day of planting consisted of shrinkage (soil line level in centimeters below the top of the container), growth indices (GI) [(height + width + perpendicular width)/three (mm)], and leachates (for the determination of pH and EC values). Shrinkage data was measured at the beginning of the study and then once again at termination. Values for shrinkage were calculated by subtracting the final height of media in the cup from the initial level in the cup. GI was measured at the first day of planting and then again at termination. Leachates of impatiens were determined at 0, 21, and 42 days after planting (DAP) using the PourThru technique (Wright, 1986). The test was initiated on 3/18/2008 and terminated seven weeks later (Figures 1 and 2). During the test, plants were watered by hand using a Dosatron® with 200ppm N fertilizer. At termination of the test, plants were cut off at the soil line and placed in a Grieve SC-350 oven dryer (The Grieve Corp. Round Lake, IL) at 155°F for 48 hours in order to obtain dry weights. In addition to dry weights, final leachates along with shrinkage and GI were recorded. Results were analyzed using Tukey's Studentized range test ($P \leq 0.05$) using a statistical software package (SAS® Institute version 9.1, Cary, NC).

Results and Discussion

Bacteria data analyzed by Dr. Feng revealed that the levels of bacteria present in our compost were considered safe for human interaction. It is also noted that *Enterococci* are normally found in manure composts and the levels at which they were found during this experiment are normal for PL compost (Feng, Personal Communication).

Results of the shrinkage data revealed no significant differences between substrate means (α=0.05, n=45) (Table 1,), which confirmed the stability of the compost. Comparison of substrate pH and electrical conductivity (EC) over the course of the study revealed interesting results (Table 2) (α=0.05, n=27). Substrate pH showed that means were significantly different among blends (Table 2) (Blythe and Merhaut, 2007). Substrates containing in-vessel composted PL had a significantly higher pH than all other treatments at the end of the study. However, as reported by Cooperband and Middleton (1996) the pH level of in-vessel compost substrates at termination was within acceptable ranges for plant growth. Over time there were significant differences between recorded means for substrate EC (α=0.05, n=27). Analysis of substrate EC is a common diagnostic tool used in nursery industry to assess fertility of the growing media (McLachlan et al. 2004). EC data revealed that at the start of the study, containers with 2:1 and 4:1 pine bark: in-vessel compost, had EC measurements of 6.19ms/cm and 4.38ms/cm, and were well out of the acceptable ranges (0.8ms/cm to 1.5ms/cm, Yeager et al., 2007) for greenhouse plant growth. However, previous studies using in-vessel composted PL have shown that production of greenhouse crops is possible (Boyer et al., 2007). However, the wet-ability, stability, chemical, and physical characteristics may limit the proportion of compost materials to be used in a potting substrate. Composted animal wastes have high salt levels, and therefore should be limited to 10 to 20% of the substrate volume (Yeager, et al., 2007). The treatments for this study were either within the 10 to 20% range or slightly above it. Since EC values in the 2:1 and 4:1 treatments of in-vessel composts had high values the noticeable plant mortalities can be attributed to high EC levels (Figure 2). However, by the end of the study, the EC had dropped significantly enough to be grouped with all other treatment means. This is similar to previous studies conducted by Kahtz and Gawel (2003) and Bradley et al. (1996), which showed a general decline in EC over the length of the study, and it could be similarly concluded that the results found by Eaton et al. (2002) could apply to this experiment in the sense that substrate physical and chemical properties depend both on compost product and proportional mix with pine bark.

Had the decline in substrate EC occurred prior to planting, the plant material within the 2:1 and 4:1 in-vessel treatments would have likely shown less mortalities. Subsequent studies revealed that if in-vessel compost was leached prior to being incorporated into a substrate that the EC within the substrate was suitable for greenhouse plant production (Boyer et al., 2007).

There were a few significant differences between treatment means for dry weights (α=0.05, n=90) of *Impatiens walleriana* Trailing Fanfare™ 'Blush' (Table 3). Windrow composting compared well to the control treatments of PB:PM and in some cases out performed the control. Growth indices for plants in 2:1 pine bark: windrow compost out performed 2:1 pine bark: in-vessel compost and plants grown in 4:1 pine bark: in-vessel compost (Table 4) (α=0.05, n=90).

The *Impatiens walleriana* Trailing Fanfare™ 'Blush' growth test revealed that windrow composting out-performs in-vessel composting as long as the ratio of compost from in-vessel is at a 7:1 pine bark: in-vessel or above rate. The significance of these results points out the importance for a grower to know how the compost that is added to a potting media is produced. It is also advised that the grower know for certain what stage of maturity the compost is in. The more the grower knows about how the compost is produced and the methods the compost producer is using to quantify maturity, the better informed the grower can be on making a decision on how to use these composts.

Literature Cited

Alabama Agricultural Statistics (AAS). 2007. Bulletin 49. Dept. of Ag. and Industries 39-42.

Adediran, J.A., L.B. Taiwo, and R.A. Sobulo. 2003. Effect of organic wastes and method of composting on compost maturity, nutrient composition of compost and yields of two vegetable crops. J. of Sust. Agri. 22(4): 95-109.

Andrews, W.H., and T.S. Hammack. 1998. Bacteriological analytical manual, 8th ed. revision A. U.S. FDA.

Atkinson, C.F., D.D. Jones, and J.J. Gauther. 1996. Biodegradability and microbial activities during composting of poultry litter. Poultry Science 75:608-617.

Blythe, E.K. and D.J. Merhaut. 2007. Testing the assumption of normality for pH and electrical conductivity of substrate extract obtained using the pour-through method. HortScience 42: 661-669.

Boyer, C.R., C.H. Gilliam, G.B. Fain, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2007. Clean chip residual amended with composted poultry litter as a substrate for *Lantana camara*. SNA Res. Conf. Proc. 52: 495-488.

Bradley, G.J., M.H. Glass, and T.E. Bilderback. 1996. Dairy cow compost as a potting substrate for growing hybrid rhododendrons. SNA Res. Conf. Proc. 41:128-129.

Buchanan, M. and S.R. Gliessman. 1991. How compost fertilization affects soil nitrogen and crop yield. BioCycle 32: 72-77.

Cooperband, L.R., and J.H. Middleton. 1996. Changes in chemical, physical and biological properties of passively-aerated co composted poultry litter and municipal solid waste compost. J. Compost Sci. Util. 4:24-43.

Dougherty, M. 1999. Field guide to on-farm composting. NRAES Ithaca, NY. 114.

Eaton, A.D., L.S. Clesceri, E.W. Rice, and A.E. Greenberg. 2005. Standard methods for the examination of water and wastewater. 21 ed. APHA, AWW, WEF.

Eaton, G.K., J.R. Harris, and T. Martin. 2002. Variation in physical and chemical properties of compost-amended pine bark substrates. SNA Res. Conf. Proc. 47:80-83.

Edwards, J.H., E.C. Burt, R.L. Raper, and R.H. Walker. 1995. Issues affecting application of noncomposted organic waste to agricultural land. pp. *In Agricultural Utilization and Industrial Byproducts;* Kalen et al. Eds.; Agron. Special Publication No 58, ASA, CSSA, SSSA: Madison, WI. pp. 225-249.

FAO, 1987. Soil management: compost production and use in tropical and subtropical environments. FAO, Food and Agri. Org. of United Nations, Rome, FAO Soil Bulletin 56, 177 p.

Fasina, O.O., D.I. Bransby, J.R. Kessler, C.H. Gilliam, and J.L. Sibley. 2005. Pelleted poultry litter provides viable fuel source for greenhouse heat. SNA Res. Conf. Proc. 50:362-364.

Faucette, B. 2001. Georgia builds poultry litter composting infrastructure. Biocycle, August 2001:23-26.

Freeman, T.M., and D.L. Cawthon. 1999. Use of composted dairy cattle solid biomass, poultry litter and municipal biosolids as greenhouse growth media. Compost Sci. & Util. 7:66-71.

Fitzpatrick, G.E., E.C. Worden, and W.A. Vendrame. 2005. Historical development of composting technology during the 20th century. HortTechnology 15:48-51.

Fritsch, D.A., and A.R. Collins. 1993. The economic feasibility of poultry litter composting facilities in eastern West Virginia. WVU. Agr. Expt. Sta. Scientific Article. 2351.

Gray, K.R., and A.J. Briddlestone. 1981. The composting of agricultural wastes. In: B. Stonehouse (ed.). Biological Husbandry. Butterworths Publications, London, England. 99-112.

Guertal, E.A., B.K. Behe, and J.M. Kemble. 1997. Composted poultry litter as potting media does not affect transplant nitrogen content of final crop yield. HortTechnology 7:142-145.

John, N.M., G.O. Adeoye, and M.K.C. Shridhar. 1995. Effect of a binding agent and sawdust amendment on the stabilization of compost, soil properties and crop growth. Proceedings of the 23rd all African Soil Science Conference. 383-394.

Kahtz, A.W., and N.J. Gawel. 2003. Use of recycled waste as an amendment in container production media. SNA Res. Conf. Proc. 48:71-73.

Kaplan, J.D., R.C. Johansson, and M. Peters. 2004. The manure hits the land: economic and environmental implications when land application of nutrients is constrained. Amer. J. Agr. Econ. 86:688-700.

Klock-Moore, K.A., G.E. Fitzpatrick, and G. Zinati. 2000. Container production of ornamental horticultural crops. Biocycle 41:58-60.

Lopez, R., C. Duran, J.M. Murillo, and F. Cabrera. 1998. Geranium's response to compost based substrates. Acta Horticulturae 469:255-262.

Macklin, K. 2008. Litter management. North Carolina broiler supervisor's short course. NCSU.

McLachlan, K.L., C. Chong, R.P. Voroney, H.W. Liu, and B.E. Holbein. 2004. Variability of soluble salts using different extraction methods on composts and other substrates. J. Compost Sci. and Util. 12:180-184.

Misra, R.V., and R.N. Roy. 2002. On-farm composting methods. FAO, Rome.

Mitchell, C.C., J.O. Donald, and J. Martin. 1989. The value and use of poultry waste as a fertilizer. Poultry byproduct management-agronomy. Alabama Coop. Ext. Serv.: Auburn University, AL., ANR-244:6.

Mkhabela, T.S. 2006. A review of the use of manure in small-scale crop production systems in South Africa. J. of Plant Nutrition. 29: 1157-1185.

Parr, J.F., R.I. Papendick, and D. Colacicco. 1986. Recycling of organic wastes for a sustainable agriculture. Bio. Agri. and Hort. 3: 115-130.

Rynk, R. Editor. 1992. On-farm composting handbook. NRAES. 54.

Spencer, R.L. 2007. In-Vessel composting: rotating drums. BioCycle, June 2007:28-32.

Taiwo, L.B. 1997. Development of organic-based fertilizer form sorted urban wastes. PhD Dissertation. 205pp.

Tyler, H.H., S.L. Warren, T.E. Bilderback, and K.B. Perry. 1993. Composted turkey litter: II. Effect on plant growth. J. Environ. Hort. 11:137-141.

Tyson, S.C. and M.L. Cabrera. 1993. Nitrogen mineralization in soils amended with composted and uncomposted poultry litter. Commun. Soil Sci. Plant Anal. 24: 2361-2374.

Wright, R.D. 1986. The pour-thru nutrient extraction procedure. HortScience 21:227-229.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best Management Practices: Guide for Producing Nursery Crops. 2nd Edition. 103 pages. Southern Nursery Assoc., 1827 Powers Ferry Road, Atlanta, GA.

http://www.msstate.edu/dept/poultry/pub1998.htm. Broiler litter as a feed or fertilizer in livestock operations. 9/17/2008.

Table 1. Substrate shrinkage data for substrates comprised of poultry litter composted by two different methods[Z].

Treatment[Y]	Shrinkage[X]
	F-I
2:1 PB:PM	0.25a[W]
4:1 PB:PM	0.41a
7:1 PB:PM	0.77a
2:1 PB:W	0.26a
4:1 PB:W	0.23a
7:1 PB:W	0.33a
2:1 PB:IV	0.41a
4:1 PB:IV	0.43a
7:1 PB:IV	0.27a

[Z] Methods of composting poultry litter were windrow composting and in-vessel digester composting.

[Y] Treatments (on a Vol:Vol ratio) were PB = Pine Bark; PM = Peat Moss; W = Windrow; IV = In-vessel digester.

[X] Substrate shrinkage reported in centimeters. Values obtained by subtracting initial media distance from top of container from final media distance from top of container.

[W] Means in columns followed by different letters are significant according to Tukey's Studentized Range Test (α= 0.05, n=45).

Table 1. Substrate shrinkage for substrates comprised of poultry litter by two different methods[Z].

Treatment[Y]	Shrinkage
	F-I[X]
2:1 PB:PM	.250a[V]
4:1 PB:PM	.405a
7:1 PB:PM	.765a
2:1 PB:W	.255a
4:1 PB:W	.225a
7:1 PB:W	.330a

2:1 PB:IV	.405a
4:1 PB:IV	.425a
7:1 PB:IV	.270a

[Z] Substrate shrinkage reported in centimeters.

[Y] Treatments (on a Vol:Vol ratio) were PB = Pine Bark; PM = Peat Moss; W = Windrow; IV = In-Vessel Digester.

[X] F = Final Measurement; I = Initial Measurement.

[V] values in columns followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05).

Table 2. Substrate electrical conductivity (EC) and pH for substrates containing poultry litter composted by two different methods[Z].

Treatment[Y]	pH			EC[X]		
	0 DAP[W]	21 DAP	42 DAP	0 DAP	21 DAP	42 DAP
2:1 PB:PM	3.4e[V]	3.6d	3.9c	0.97cd	1.86b	1.93a
4:1 PB:PM	3.4e	5.0cd	4.2c	0.99cd	1.65b	1.98a
7:1 PB:PM	3.6e	3.8cd	4.1c	0.85cd	1.58b	1.83a
2:1 PB:W	6.1bc	5.8ab	5.7b	0.90cd	1.37b	1.60a
4:1 PB:W	5.9dc	5.8ab	6.0b	0.58d	1.29b	1.23a
7:1 PB:W	5.6d	5.4abc	5.9b	0.51d	1.50b	1.18a
2:1 PB:IV	6.9a	6.7a	6.5a	6.19a	2.79a	2.24a
4:1 PB:IV	6.5ab	6.9a	6.3a	4.38b	1.74b	1.88a
7:1 PB:IV	6.5ab	6.6ab	6.3a	1.85c	1.34b	1.56a

[Z] Substrate chemical properties were measured using the Virginia Tech pour through method.

[Y] Treatments (on a Vol:Vol ratio) were: PB = Pine Bark; PM = Peat Moss; W = Windrow; IV= In-Vessel Digester.

[X] EC = electrical conductivity reported in mS/CM (milliSiemens per centimeter).

[W] DAP = days after planting.

[V] Means within columns followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05, n=27).

Table 3. Plant dry weights for substrates comprised of poultry litter composted by two different methods[Z].

Treatment[Y]	Dry Weight[X]
	Grams
2:1 PB:PM	0.42abc[V]
4:1 PB:PM	0.60ab
7:1 PB:PM	0.48ab
2:1 PB:W	0.79a
4:1 PB:W	0.46abc
7:1 PB:W	0.54ab
2:1 PB:IV	0.02d
4:1 PB:IV	0.07cd
7:1 PB:IV	0.37bcd

[Z] Dry weights are oven dried at 155°F for 48 hours.

[Y] Treatments (on a Vol:Vol ratio) were PB = Pine Bark; PM = Peat Moss; W = Windrow method; IV = In-Vessel Composter method.

[X] Dry weights in grams.

[V] Means in columns followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$, n=90).

Table 4. Growth indices for substrates comprised of poultry litter composted by two different methods[Z].

Treatment[Y]	GI[X]
	Millimeters
2:1 PB:PM	64.2ab[V]
4:1 PB:PM	73.5ab
7:1 PB:PM	49.3ab
2:1 PB:W	80.0a
4:1 PB:W	52.8ab
7:1 PB:W	55.3ab
2:1 PB:IV	3.7c
4:1 PB:IV	7.5c
7:1 PB:IV	44.0b

[Z] Growth indices taken [(height x width^1 x width^2)/3] presented in millimeters.

[Y] Treatments (on a Vol:Vol ratio) were PB = Pine Bark; PM = Peat Moss; W = Windrow; IV = In-vessel digester.

[X] GI = Growth Indices.

[V] Means in columns followed by different letters are significant according to Tukey's Studentized Range Test ($\alpha = 0.05$, n=90).

Figure 1. *Impatiens walleriana* Trailing Fanfare™ ‘Blush’ at time of planting.

Figure 2. Derandomized picture of *Impatiens walleriana* Trailing Fanfare™ 'Blush' prior to harvest. Treatments are left to right with the first row on right representing treatment one. Treatment 1 = 2:1 pine bark: peat moss; Treatment 2 = 2:1 pine bark: windrow composted poultry litter; Treatment 3 = 2:1 pine bark: in-vessel composter poultry litter; Treatment 4 = 4:1 pine bark: peat moss; Treatment 5 = 4:1 pine bark: windrow composted poultry litter; Treatment 6 = 4:1 pine bark: in-vessel composter poultry litter; Treatment 7 = 7:1 pine bark: peat moss; Treatment 8 = 7:1 pine bark: windrow composted poultry litter; Treatment 9 = 7:1 pine bark: in-vessel composter poultry litter.

CHAPTER IV

EVALUATION OF WINDROW VERSUS IN-VESSEL COMPOSTER COMPOSTED POULTRY LITTER FOR NURSERY USE

Abstract

Poultry litter compost from two composting methods; windrow composting and in-vessel digester composting were compared. In order to compare the two compost methods, temperature, moisture, C:N ratio, and bacteria were monitored during production of the compost. Once the compost from each method was considered stable, a nursery growth study was initiated using *Hemerocalis spp*. ‘Pardon Me’ as the plant material. The nursery study lasted a total of ten weeks at which time the plants were harvested and dry weights were recorded. Analysis of plant dry weight data revealed that 4:1 pine bark: windrow compost out performed the 1:1 ratio of pine bark: in-vessel composter compost. Data analysis of daylily growth revealed no significant differences. Statistical analysis of pH data revealed that pH of 1:1 pine bark: in-vessel composter compost was significantly higher than all other treatments at the beginning of the study. Electrical conductivity measurements revealed that 1:1 pine bark: in-vessel digester method produced higher means than all treatments except 4:1 pine bark: in-vessel composter. Both methods of compost produced weed free compost material with satisfactory physical properties for use as a container substrate.

Introduction

Poultry production is a rapidly growing industry in the United States. As a nation the U.S. produces 8.9 billion birds annually with Alabama currently third in production with 11.9% (1.1 billion birds) of U.S. totals (AAS, 2007). Typically, on a commercial broiler farm, litter is used for six or more consecutive grow-outs. Each grow-out generally lasts 6+ weeks; which means that litter is generally being utilized for at least one year (Macklin, 2008). Currently a conservative estimate of 16.6 million tons of poultry litter is produced in the United States each year. In Alabama alone the poultry and egg industry represents approximately $2.7 billion in gross farm receipts and employs approximately 78,000 people. One impact of this industry is that millions of pounds of waste material, particularly ~ 2 million tons of litter are generated by the poultry and egg industry in Alabama annually (Edwards et al., 1995).

In agriculture, poultry litter (PL) or broiler litter is a material used as bedding in poultry operations to render the floor more manageable. Common litter materials in the southeast can consist of wood shavings, sawdust, peanut hulls, straw, and other dry, absorbent, low-cost organic materials. After use, the litter consists primarily of poultry manure, but also contains the original litter material, feathers, and spilled feed (Freeman and Cawthon, 1999). Typical PL has an average wet weight moisture content of 20-40% and a dry nitrogen content of 1.5-4% (Rynk, 1992). Poultry manure has been used successfully as a fertilizer for the production of maize, small grains, fruits, forage grasses, and vegetables. Poultry manure has been reported to increase nutrient concentration in the soil, to improve nutrient uptake by plants, and to increase crop yields (Mkhabela, 2006). Manure may improve soil structure and subsequently soil permeability, water-holding capacity, aeration, and also supply micronutrients. Thus, structural deterioration of soils can be reversed and soil fertility can be restored by manure (Mkhabela, 2006). PL contains the equivalent of approximately 26- 22- 17 kilograms per metric ton (63-53-41 pounds per U.S. ton) of N-P_2O_5-K_2O on a dry basis, which is equivalent to a bagged, commercial fertilizer analyzing approximately 3-2.5-2 percent of N-P_2O_5-K_2O, respectively. Based upon current fertilizer prices, PL would be worth about $30 to $40 per ton as a fertilizer, not including spreading and transportation charges. PL applications of 1.8 to 3.6 metric tons per acre (2-4 U.S. tons) have been effective in promoting grass growth in pasture (http://www.msstate.edu/dept/poultry/pub1998.htm, 1998).

In recent years there has been concern for disposing of agricultural waste in the United States and elsewhere in the world. Some of the resulting issues facing the poultry production industry with regards to waste management include: reduced land area on farms to apply increasing amounts of litter; nutrient management plans that are based on phosphorous indexes; land applying PL to clay soils that already have high phosphorous (P); land application of poultry litter can promote degradation of water quality by promoting increases in groundwater NO_3 content and in cases where N is not limited, leaching may occur when PL is applied to agricultural land at rates in excess of the nitrogen requirement of the crop (Faucette, 2001; Kaplan et al., 2004; Mitchell et al., 1989). Poultry litter is typically land applied according to the amount of nitrogen it can supply. Although P tends not to move in soils, repeated applications of PL can lead to P build-up, which can result in P runoff and affect surface water. Also, P is a limiting element in many processes in plant and microbe development. Increases in P can cause proliferation in plant and microbe growth in lakes and streams, a process known as eutrophication.

Poultry litter can be used by many industries. Studies evaluating PL as a fuel source (Fasina et al., 2005); cattle feed, container media in nurseries, erosion control, and as a fertilizer (Atkinson et al., 1996; Guertal et al., 1997; Lopez et al., 1998; Tyler et al., 1993) have been conducted. Nursery crop growers are looking for substrates that are consistent, available, easy to handle and mix, cost effective, and have the appropriate physical and chemical properties for the crop they are growing (Klock-Moore et al., 2000). Composts meet many of these requirements and therefore can be considered a suitable component of the potting media (Freeman and Cawthon, 1999). Fritsch and Collins (1993) define compost as the biological stabilization of organic wastes under controlled conditions of oxygen, moisture, and temperature. The end result is a stable organic product which improves soil fertility by providing nutrients, reducing bulk density, increasing cation exchange capacity, and enhancing populations of soil microorganisms. Scientists and industry have an increased awareness of composts; in particular PL compost due to the increasing amounts of litter produced each year and the resulting environmental challenges that are associated with PL.

The environmental issues associated with raw manure application could be mitigated by chemically or biologically stabilizing soluble nutrients. Composting of PL converts soluble nutrients to more stable organic forms, thereby reducing their bioavailability and susceptibility to loss when applied to crop fields (Buchanan and Gliessman 1991; Cooperband and Middleton, 1996; Tyson and Cabrera, 1993). Processing of PL wastes by composting therefore provides an opportunity to reduce volume and odor, while increasing the nutritive values of the material (FAO, 1987; Gray and Briddlestone, 1981; Parr et al., 1986).

Currently there are numerous ways to produce compost products, including: open pile, aerated static pile, windrow, and in-vessel composter. Open-pile composting is suitable for small to moderate- sized farms operating under a low level of management. This method involves forming piles of organic materials and leaving them undisturbed until the materials have decomposed into a stabilized product. Small piles are designed to take advantage of natural air movement. In general, larger piles are more difficult to aerate effectively because of pile compaction. Under proper feedstock and moisture conditions, however, pile temperatures increase, contributing to production of good compost. The costs of the labor and equipment used to form and mix the initial piles are the largest operational expenses. Farm loaders and manure spreaders can typically be diverted from other farm uses to form and mix piles (Dougherty, 1999).

The *aerated* static pile system is different in that the compost materials are placed into rows, but the windrows are built on top of an air distribution system composed of flexible perforated pipes embedded in woodchips. Fans are used to provide forced aeration into the pile or induced draft aeration from the pile. The aerated static pile system has been successful in providing high levels of aeration and is used throughout the world to make compost from excessively moist, hard to aerate materials such as municipal and industrial sludges (Dougherty, 1999; Fitzpatrick, 2005).

Windrow composting is an example of an open composting system that uses active tuning with relatively low-level technology. Compost materials are placed in rows and turned periodically using mechanical equipment. Windrow systems are popular because they do not necessarily require dedicated specialized equipment (Fitzpatrick et al., 2005). Windrow composting consists of piles usually ranging from 94 cm in height to heights of 3.7 meters (3ft by 12 ft) with the widths depending on the equipment used to turn the rows. Between turning, windrows aerate by natural or passive air movement (Misra and Roy, 2002). The frequency of turning depends on the rate of decomposition (indicated by temperature rise), the moisture content and porosity of the materials, and the desired composting time (Misra and Roy, 2002). The required frequency of turning windrows usually decreases over time due to the aging of the materials (Misra and Roy, 2002). In a windrow situation, eight weeks is a common period for manure composting operation (Misra and Roy, 2002).

In-vessel composting involves confining actively composting materials within a building, container, or vessel. Many in-vessel systems use a rotating drum. The first of which was developed in the U.S. by Eric Eweson in the 1940s. Eweson designed a system in which compost material anaerobically ferments in a large rotary drum for a period of 3-6 days. Unlike many of the early mechanical composting systems, the rotary drum system has been successful and there are many such systems operating throughout the world at the present time (Fitzpatrick et al., 2005). In-vessel systems are the most aggressively managed and generally the most capital intensive of the composting technologies (Dougherty, 1999). The in-vessel process of composting is an aerobic process by which the materials are constantly tumbled upon each other forcing oxygen inside the mix. Most drum systems include blowers to maintain aerobic conditions and minimize excessive temperatures, with one technology injecting oxygen (Spencer, 2007). Rotating drums are the most common in-vessel method in part because the combination of pulping action and biological degradation in the drum breaks down organic materials in just a few days to a rough, though unfinished compost (Spencer, 2007). The in-vessel system can create an adequate aerobic composting environment allowing compost to reach thermophillic temperatures within 24 hours (Freeman and Cawthon, 1999). The residence time within the in-vessel system depends upon the level of composting desired. Additional curing time outside the in-vessel composter can be used to finish the composting process (Dougherty, Personal Communication). Composting drums are available in sizes from one meter in diameter and 3.6 meters long to 5 meters in diameter and up to 70 meters long (3 feet in diameter and 12 feet long to 16 feet in diameter and 230 feet long).

Composting begins as soon as appropriate biologically active materials are mixed together. Initial mixing of raw materials introduces enough air to start the microbial process. Almost immediately, microorganisms consume oxygen, and settling materials expel air from pore spaces. Aeration is provided by passive air exchange, by forced aeration, or turning (Dougherty, 1999). Temperatures of composting materials usually increase rapidly to 38-60°C (100-140°F) and remain in this range for up to several weeks (Dougherty, 1999). Mature compost provides a stabilized form of organic matter (humus) and has the potential to enhance nutrient release in the soil more than other organic wastes because plants are not competing with soil micro organisms for nutrients (Adediran et al., 2003). Time to maturity, however, depends on factors such as type of substrate, organic components of the substrate, and the temperature regime during composting (Taiwo, 1997; John et al., 1995). Other essential elements in the composting process are carbon-to-nitrogen ratio of the initial mix which should be in the range of

20:1-40:1 (C:N ratios above 30 will minimize the potential for odors). C:N ratios are influenced by the materials in which the compost pile is composed of such as manure with an added carbon source (sawdust). An initial feedstock moisture content of 40%-60% wet basis is recommended and depends upon the specific materials, pile size, and weather conditions. Moisture content has a direct effect on oxygen levels within the compost. When a pile is too moist, air spaces within the compost pile can become filled by water, causing undesirable anaerobic conditions. Initial particle sizes of 1.3-5.1 cm (0.5-2 inches) will be broken down easier. Pile porosity greater than 40% is critical because it permits air to enter and diffuse into the composting mass. Bulk density of 480-710 kg/m^3 (1400-2000 lbs/yd^3) will meet the basic aeration and moisture needs of composting microbes (Dougherty, 1999). If these guidelines are followed it is possible to create an environment that is suitable for composting.

Although there are numerous ways in which to compost PL, the purpose of this research was to evaluate differences between windrow composting and in-vessel composting of PL. The results of this research demonstrate the suitability of turned windrow or in-vessel composter composting of PL for growth of horticultural crops in the green industry.

Materials and Methods

On July 25, 2007 composting of poultry litter arranged in an open-field windrow comprised of about 95 cubic yards of fresh poultry litter (PL) and 100 cubic yards of carbon feedstock (sawdust) with the moisture adjusted to 40% through irrigation of the windrow began. The combining of the two materials led to a windrow of approximately 111 yd^3 of PL compost. The windrow was then divided and monitored as two separate windrows (East, West) due to a difference in moisture content at the initial reading. Two temperature data loggers (Dickson SM325, The Dickson Company, Addison, IL) were placed into each windrow which automatically recorded temperatures every hour. Substrates that were utilized in this study consisted of PL compost from the west windrow only.

Also on July 25, 2007 approximately 12 cubic yards of fresh poultry litter was added to an in-vessel digester (Model 616, BW Organics INC., Sulphur Springs, TX) to begin composting. After eight days in the in-vessel digester the litter volume was reduced to about 7 cubic yards of compost, removed, and a subsample of this compost placed outdoors in a pile beside the windrow with two temperature data loggers (The Dickson Company, Addison, IL) inserted to record at the same interval as the windrow. Therefore, virtually the same atmospheric conditions occurred for both treatments. In addition to temperature data, moisture content (analyzed on an as sampled basis, using an Ohaus MB35 moisture analyzer, Ohaus Corporation, Pine Brook, NJ), carbon to nitrogen ratios (TrueSpec, LECO®, St. Joseph, MI), and bacterial samples were analyzed periodically by Dr. Yucheng Feng of Auburn University’s Agronomy and Soils department for each method. The methods that were used to determine *Enterococci* and fecal coliform bacteria levels are further described by Eaton et al. (2005). *Enterococci* levels were determined by using method 9230C (Eaton et al., 2005). Fecal coliforms were detected using methods 9221E and 9222E (Eaton et al., 2005). *Salmonella* isolation and identification was performed as described by Andrews and Hammack (1998). Dates for collection of samples were decided by factors such as maturity of the compost and relevant closeness to the turning dates.

Plant materials for the nursery growth test (Paterson Greenhouse Complex, Auburn University, AL Lat: 32.59 Lon: 85.48) consisted of *Hemerocalis spp.* ‘Pardon Me’. Substrates (Vol:Vol) were blended consisting of varying ratios of pine bark: compost with the control being pine bark: peat moss for a total of 9 treatment blends with 20 replications per treatment. Treatments were as follows: 1.) 1:1 pine bark (PB): peat moss (PM), 2.) 4:1 PB: PM, 3.) 6:1 PB: PM, 4.) 1:1 PB: windrow (W), 5.) 4:1 PB: W, 6.) 6:1 PB: W, 7.) 1:1 PB: in-vessel (IV), 8.) 4:1 PB: IV, and 9.) 6:1 PB: IV. Each substrate was pre-plant incorporated with 3 pounds per cubic yard 17N-2.16P-9.08K (17-5-11) Polyon® (Harrell’s Fertilizer, Inc., Sylacauga, AL) control release fertilizer (9 month); 5 pounds per cubic yard dolomitic limestone and 1.5 pounds per cubic yard of Micromax® (The Scotts Company, Marysville, OH). Trade gallon containers (6.5” tall by 6.5” wide) (Nursery Supplies, Chambersburg, PA) were filled and treatments placed in a completely randomized block design on an outdoor nursery container pad. The daylilies were potted into the trade gallon containers and watered in. The test was installed on 7/21/2008 and grew for a total of ten weeks (9/29/2008) during which data collection consisted of initial fan counts (fan is defined as an offshoot), leachate collection occurred at 0, 21, 42, and 63 days after planting (DAP) using the Virginia Tech PourThru method (Yeager et al, 2007), final fan counts, and dry weights. At termination of the test plants were cut off at the soil line and placed in a Grieve SC-350 oven dryer (The Grieve Corp. Round Lake, IL) at 155°F for a period of 72 hours. Data were analyzed using Tukey’s Studentized Range Test ($P = 0.05$) using a statistical software package (SAS® Institute version 9.1, Cary, NC). Fan count data then was further analyzed in Excel® to obtain standard deviations of the treatment means.

Results and Discussion

Bacteria data analyzed by Dr. Feng revealed that the levels of bacteria present from either compost method were at levels considered safe for human interaction. It is also noted that *Enterococci* are normally found in manure composts and the levels at which they were found during this experiment are normal for PL compost (Feng, Personal Communication).

At the beginning of the nursery study, the pH means of leachates from the 1:1 pine bark: in-vessel treatment were significantly higher than all other treatments (Table 1) with pH of 4:1 pine bark: in-vessel significantly different than 1:1 pine bark: windrow and 4:1 pine bark: windrow treatments. However, by the end of the study the pH means of 1:1 pine bark: in-vessel were not significantly different than most other treatments (Blythe and Merhaut, 2007). The pH of the treatments containing composts were higher than the recommended ranges given by Yeager et al. (2007) and remained higher than these suggested ranges through out the entire length of the study. With the pH of the composts being higher than that of peat moss the need for the addition of lime may be alleviated. Previous studies conducted by Kahtz and Gawel (2003) and Bradley et al. (1996), found that the increased pH of composts could reduce the need for an added lime amendment, which could help alleviate some costs for growers by reducing the amount of inputs in their production regime.

At initiation of the nursery study the electrical conductivity (EC) which is a common diagnostic tool used in the nursery industry to assess fertility of the growing media (McLachlan et al. 2004), revealed 1:1 pine bark: in-vessel treatment was significantly higher than all other treatments except 4:1 pine bark: in-vessel treatment

(Table 1). The level of soluble salts within the 1:1 pine bark: in-vessel treatment remained significantly higher than all other treatments at the end of the study. This could be due to the high concentrations of in-vessel compost that is within the container. However, the wet-ability, stability, chemical, and physical characteristics may limit the proportion of compost materials to be used in a potting substrate (Yeager et al., 2007). Composted animal wastes have high salt levels, and therefore should be limited to 10 to 20% of the substrate volume (Yeager, et al., 2007). Since the 1:1 treatments of composts within this study contained 50% composted animal wastes it could be deduced that the 1:1 ratio is the cause of high EC readings. All treatments containing composted PL showed a general decline in EC readings from beginning to end. This is similar to previous studies conducted by Kahtz and Gawel (2003) and Bradley et al. (1996), which showed a general decline in EC over the length of the study, and it could be similarly concluded that the results found by Eaton et al. (2002) could apply to this experiment in the sense that substrate physical and chemical properties depend both on compost product and proportional mix with pine bark.

Fan count analysis (Table 3, Figure 1) revealed that there were no significant differences among treatment means. This could reveal that daylilies are not as sensitive to high amounts of salts within their potting substrates. Dry weight analysis of the ‘Pardon Me’ daylilies revealed that there was a significant difference between 4:1 pine bark: windrow treatment and 1:1 pine bark: in-vessel composter treatment. The difference in overall size of the plant weight could be attributed to the high EC of the 1:1 treatment of pine bark: in-vessel composter during the study.

All plant material produced during this study yielded saleable products. There were no noticeable visual differences between treatments (Figure 1). Our results indicate that the in-vessel composter technique allows compost to retain more nutrients than windrow technique due to reduced leaching while undergoing its first stages of decomposition in the reactor. Subsequent studies are needed to evaluate different plant responses to the levels of soluble salts found within in-vessel composted PL.

Composting is as much an art form as it is a science (Jeff Sibley, Personal Communication). During the compost production process several differences between windrow technique and in-vessel technique were noticed. The time that it takes to produce stable windrow composts can vary greatly depending on factors such as moisture content, C:N, and turning frequency. During this study two windrows were evaluated and only one produced mature compost. The length of time to produce mature compost for west windrow using methods in this study was a period of approximately 44 weeks while the other windrow continued to compost after a period of 65 weeks, meanwhile, compost derived using the in-vessel method were mature after approximately 21 weeks. Continued decomposition when these composts are added to growth media may have negative impacts on plant growth due to reduced oxygen in the root zone, reduced available nitrogen, or the presence of phytotoxic compounds (Brinton, 2000). Therefore, a grower must be able to distinguish the differences between mature composts and composts that are still undergoing physical and chemical breakdown. Compost stability and maturity are difficult to assess simply by sight or smell, although mature compost will not contain recognizable feedstock material, should smell like rich soil, and should not smell foul or ammonia like (CEPA, 2002). These are guidelines for assessing composts before incorporating them into substrates.

It is very important that a grower understands how the composts that are being incorporated into substrates is produced. Chemical property analysis should be conducted on composts to be certain of the soluble salt and pH levels present. By knowing more about the compost prior to incorporation into the substrate the grower will be more prepared to solve potential problems that may arise during production.

Literature Cited

Alabama Agricultural Statistics (AAS). 2007. Bulletin 49. Dept. of Ag. and Industries 39-42.

Andrews, W.H., and T.S. Hammack. 1998. Bacteriological analytical manual, 8th ed. revision A. U.S. FDA.

Adediran, J.A., L.B. Taiwo, and R.A. Sobulo. 2003. Effect of organic wastes and method of composting on compost maturity, nutrient composition of compost and yields of two vegetable crops. J. of Sust. Agri. 22: 95-109.

Atkinson, C.F., D.D. Jones, and J.J. Gauther. 1996. Biodegradability and microbial activities during composting of poultry litter. Poultry Science 75:608-617.

Blythe, E.K. and D.J. Merhaut. 2007. Testing the assumption of normality for pH and electrical conductivity of substrate extract obtained using the pour-through method. HortScience 42: 661-669.

Bradley, G.J., M.H. Glass, and T.E. Bilderback. 1996. Dairy cow compost as a potting substrate for growing hybrid rhododendrons. SNA Res. Conf. Proc. 41:128-129.

Brinton, W.F. 2000. Compost quality standards and guidelines. Final report to New York State Association of Recyclers. Woods End Research Laboratory, Inc.

Buchanan, M. and S.R. Gliessman. 1991. How compost fertilization affects soil nitrogen and crop yield. BioCycle 32: 72-77.

California Environmental Protection Agency (CEPA). 2002. Bulletin 443-00-005. CA Integrated Waste Management Board. 9pp.

Cooperband, L.R., and J.H. Middleton. 1996. Changes in chemical, physical and biological properties of passively-aerated co composted poultry litter and municipal solid waste compost. J. Compost Sci. Util. 4: 24-34.

Dougherty, M. 1999. Field guide to on-farm composting. NRAES Ithaca, NY. 114.

Eaton, A.D., L.S. Clesceri, E.W. Rice, and A.E. Greenberg. 2005. Standard methods for the examination of water and wastewater. 21 ed. APHA, AWW, WEF.

Eaton, G.K., J.R. Harris, and T. Martin. 2002. Variation in physical and chemical properties of compost-amended pine bark substrates. SNA Res. Conf. Proc. 47: 80-83.

Edwards, J.H., E.C. Burt, R.L. Raper, and R.H. Walker. 1995. Issues affecting application of noncomposted organic waste to agricultural land. pp. *In Agricultural Utilization and Industrial Byproducts;* Kalen et al. Eds.; Agron. Special Publication No 58, ASA, CSSA, SSSA: Madison, WI. pp. 225-249.

FAO, 1987. Soil management: compost production and use in tropical and subtropical environments. FAO, Food and Agri. Org. of United Nations, Rome, FAO Soil Bulletin 56, 177 p.

Fasina, O.O., D.I. Bransby, J.R. Kessler, C.H. Gilliam, and J.L. Sibley. 2005. Pelleted poultry litter provides viable fuel source for greenhouse heat. SNA Res. Conf. Proc. 50: 362-364.

Faucette, B. 2001. Georgia builds poultry litter composting infrastructure. Biocycle, August 2001:23-26.

Freeman, T.M., and D.L. Cawthon. 1999. Use of composted dairy cattle solid biomass, poultry litter and municipal biosolids as greenhouse growth media. Compost Sci. & Util. 7:66-71.

Fitzpatrick, G.E., E.C. Worden, and W.A. Vendrame. 2005. Historical development of composting technology during the 20th century. HortTechnology 15: 48-51.

Fritsch, D.A., and A.R. Collins. 1993. The economic feasibility of poultry litter composting facilities in eastern West Virginia. WVU. Agr. Expt. Sta. Scientific Article. 2351.

Gray, K.R., and A.J. Briddlestone. 1981. The composting of agricultural wastes. In: B. Stonehouse (ed.). Biological Husbandry. Butterworths Publications, London, England. 99-112.

Guertal, E.A., B.K. Behe, and J.M. Kemble. 1997. Composted poultry litter as potting media does not affect transplant nitrogen content of final crop yield. HortTechnology 7:142-145.

John, N.M., G.O. Adeoye, and M.K.C. Shridhar. 1995. Effect of a binding agent and sawdust amendment on the stabilization of compost, soil properties and crop growth. Proceedings of the 23rd all African Soil Science Conference 383-394.

Kahtz, A.W., and N.J. Gawel. 2003. Use of recycled waste as an amendment in container production media. SNA Res. Conf. Proc. 48: 71-73.

Kaplan, J.D., R.C. Johansson, and M. Peters. 2004. The manure hits the land: economic and environmental implications when land application of nutrients is constrained. Amer. J. Agr. Econ. 86:688-700.

Klock-Moore, K.A., G.E. Fitzpatrick, and G. Zinati. 2000. Container production of ornamental horticultural crops. Biocycle 41:58-60.

Lopez, R., C. Duran, J.M. Murillo, and F. Cabrera. 1998. Geranium's response to compost based substrates. Acta Horticulturae 469:255-262.

Macklin, K. 2008. Litter management. North Carolina broiler supervisor's short course. NCSU.

McLachlan, K.L., C. Chong, R.P. Voroney, H.W. Liu, and B.E. Holbein. 2004. Variability of soluble salts using different extraction methods on composts and other substrates. J. Compost Sci. and Util. 12:180-184.

Misra, R.V., and R.N. Roy. 2002. On-farm composting methods. FAO, Rome.

Mitchell, C.C., J.O. Donald, and J. Martin. 1989. The value and use of poultry waste as fertilizer. Poultry byproduct management-agronomy. Alabama Coop. Ext. Serv.: Auburn University, AL., ANR-244:6.

Mkhabela, T.S. 2006. A review of the use of manure in small-scale crop production systems in South Africa. J. of Plant Nutrition 29: 1157-1185.

Parr, J.F., R.I. Papendick, and D. Colacicco. 1986. Recycling of organic wastes for a sustainable agriculture. Bio. Agri. and Hort. 3:115-130.

Rynk, R. Editor. 1992. On-farm composting handbook. NRAES. 54.

Spencer, R.L. 2007. In-Vessel composting: rotating drums. BioCycle, June 2007:28-32.

Taiwo, L.B. 1997. Development of organic-based fertilizer form sorted urban wastes. PhD Dissertation. 205pp.

Tyler, H.H., S.L. Warren, T.E. Bilderback, and K.B. Perry. 1993. Composted turkey litter: II. Effect on plant growth. J. Environ. Hort. 11:137-141.

Tyson, S.C. and M.L. Cabrera. 1993. Nitrogen mineralization in soils amended with composted and uncomposted poultry litter. Commun. Soil Sci. Plant Anal. 24: 2361-2374.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. Wright. 2007. Best Management Practices: Guide for Producing Nursery Crops. 2nd Edition. 103 pages. Southern Nursery Assoc., 1827 Powers Ferry Road, Atlanta, GA.

http://www.msstate.edu/dept/poultry/pub1998.htm. Broiler litter as a feed or fertilizer in livestock operations. 9/17/2008.

Table 1. Substrate chemical properties for substrates comprised of poultry litter (PL) composted by two different methods.

Treatment[Y]	pH				EC[X]			
	0 DAP[W]	21 DAP	42 DAP	63 DAP	0 DAP	21 DAP	42 DAP	63 DAP
1:1 PB:PM	7.00bc[V]	6.75bc	6.67def	7.14abc	3.94b	0.42a	0.35b	0.36b
4:1 PB:PM	6.97bcV	6.56c	6.62ef	6.83c	2.84b	0.51a	0.35b	0.33b
6:1 PB:PM	6.99bc	6.56c	6.58f	7.04bc	1.84b	0.41a	0.31b	0.38b
1:1 PB:W	6.49c	6.87abc	6.84bcd	7.25ab	8.42b	0.53a	0.44ab	0.38b
4:1 PB:W	6.72bc	6.71bc	6.79cde	7.17ab	5.19b	0.72a	0.35b	0.35b
6:1 PB:W	6.53c	6.89abc	6.76def	7.13abc	4.55b	0.54a	0.35b	0.37b
1:1 PB:IV	7.77a	7.30a	7.15a	7.39a	22.99a	0.95a	0.73a	0.67a
4:1 PB:IV	7.21b	7.09ab	7.00ab	7.31ab	12.44ab	0.59a	0.43ab	0.41b
6:1 PB:IV	6.91bc	6.85bc	6.99abc	7.16ab	9.24b	0.62a	0.38b	0.39b

[Z] Substrate chemical properties were measured using the Virginia Tech pour through method.

[Y] Treatments (on a Vol:Vol ratio) were: PB = Pine Bark; PM = Peat Moss; W = Windrow composted PL; IV = In-vessel composted PL

[X] EC = electrical conductivity reported in mS/CM (milliSiemens per centimeter).

[W] DAP = Days After Planting.

[V] Means in columns followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05, n=36).

Table 2. Plant dry weights for daylilies grown in substrates comprised of poultry litter (PL) composted by two different methods[Z].

Treatment[Y]	Dry Weight[X]
	Grams
1:1 PB:PM	8.64ab[V]
4:1 PB:PM	10.20ab
6:1 PB:PM	8.73ab
1:1 PB:W	9.39ab
4:1 PB:W	11.77a
6:1 PB:W	8.95ab
1:1 PB:IV	7.09b
4:1 PB:IV	8.79ab
6:1 PB:IV	7.77ab

[Z] Dry weights are oven dried at 155°F for 72 hours.

[Y] Treatments (on a Vol:Vol ratio) were PB = Pine Bark; PM = Peat Moss; W = Windrow composted PL; and IV = In-Vessel composted PL.

[X] Dry weights in grams.

[V] Means in columns followed by different letters are significant according to Tukey's Studentized Range Test (α = 0.05, n=180).

Table 3. Mean fan counts and standard deviations for daylilies grown in substrates comprised of poultry litter (PL) composted by two different methods[Z].

Treatment[Y]	Fan Count[X]
1:1 PB:PM	1.4 ± 1.4a
4:1 PB:PM	1.6 ± 1.6a
6:1 PB:PM	1.5 ± 1.3a
1:1 PB:W	1.4 ± 1.0a
4:1 PB:W	2.6 ± 1.6a
6:1 PB:W	1.8 ± 1.4a
1:1 PB:IV	2.0 ± 1.7a
4:1 PB:IV	2.2 ± 1.7a
6:1 PB:IV	1.2 ± 1.2a

[Z] Fan count is the number of fans per rep at termination of the study minus the number of initial fans per rep at the start of the study.

[Y] Treatments (on a Vol:Vol ratio) were PB = Pine Bark; PM = Peat Moss; W = Windrow composted PL; IV = In-Vessel composted PL.

[X] Mean values and standard deviations in columns followed by same letter are not significantly different according to Tukey's Studentized Range Test (α = 0.05, n=180).

Figure 1. Pardon Me daylily at harvest. Treatments are 1-9 left to right. Treatment 1 = 1:1 pine bark: peat moss; Treatment 2 = 4:1 pine bark: peat moss; Treatment 3 = 7:1 pine bark: peat moss; Treatment 4 = 1:1 pine bark: windrow composted poultry litter (PL); Treatment 5 = 4:1 pine bark: windrow composted PL; Treatment 6 = 7:1 pine bark: windrow composted PL; Treatment 7 = 1:1 pine bark: in-vessel composter composted PL; Treatment 8 = 4:1 pine bark: in-vessel composter composted PL; Treatment 9 = 7:1 pine bark: in-vessel composter PL (treatments on a Vol:Vol ratio).

CHAPTER V

FINAL DISSCUSION

The purpose of these studies was to evaluate two methods of composting poultry litter to determine which method was more practical for use in the green industry. Due to rising transportation costs of peat and pine bark poultry litter could possibly make a suitable alternative to one or both of these potting amendments and if so it would provide benefits to the producers bottom line and to the environmental strain that land application of poultry litter has on our nations crop lands and waterways. All plant growth tests contained windrow composts from the west windrow only, since the east windrow never fell below thermophilic temperature ranges during the entire length of this study.

In Chapter 2 we began evaluating the two methods of composting poultry litter by collecting data throughout the composting process. Both methods of composting were monitored throughout the compost process for temperature changes, carbon to nitrogen ratio, moisture content, and bacteria. The data collected for the methods was then analyzed and used to determine maturity rate and stability. During this process the in-vessel composter method was not completely composted after 8 days in the digester. After six days inside the in-vessel digester we assumed the poultry litter would be completely broken down into stable, useable, compost for use in the green industry. Instead we found that the material removed from the composter looked and smelled as if it were composted but the temperature monitoring told a different story. Fluctuations in temperature revealed that the compost was still going through active composting. If in fact the compost had been finished after removal from the digester, temperatures should have stayed within the ranges of $^{+-}$20°F ambient air temperature based on the data that was collected throughout this study. On the other hand feedstocks inside the in-vessel composter appear to undergo quicker initial reaction than windrows, although temperature monitoring within the composter was not done.

Our results with the in-vessel composts indicate that if the PL that was produced by the in-vessel composter method had been brought to a higher C:N ratio prior to in-vessel digestion then the resulting outcomes may have differed from those reported in this thesis. Also if turning of the windrows had occurred more frequently during the first month, perhaps once per day as suggested by some literature, then the time to produce stable finished compost would have been reduced significantly and would have allowed more tests to be conducted to evaluate the hypothesis that one method of composting out performs another.

In Chapter III of this thesis the author reported a study for growing greenhouse crops with compost produced using two methods of composting. The compost used in the treatments was comprised of varying ratios of pine bark: windrow composted poultry litter and pine bark: in-vessel composter composted poultry litter. Our results with high numbers of mortalities noticed in treatments that contained in-vessel composter compost indicate that higher amounts of nitrogen from the compost derived using in-vessel composter method is not acceptable for use on tender herbaceous plants. The windrow composted poultry litter on the other hand performed well in all ratios indicating that this method of composting poultry litter produces a more suitable material for a greenhouse production regime.

In Chapter IV of this thesis the author reported a study for growing nursery crops with compost produced using two different methods. The plant material chosen for this study was *Hemerocalis spp.* ‘Pardon Me’. The reason the author chose this plant material was because it is a hardy plant that can withstand fairly extreme environmental stresses. Data collection showed that there were a few significant differences between the pH and EC at the start of the study. However at the end of the study, the electrical conductivity for the 1: 1 ratio of pine bark: in-vessel composter was significantly different from all other treatments indicating that the level of nitrogen present from the in-vessel composter method is significantly higher than that of the windrow method making it more susceptible to leach into groundwater or streams causing nitrate pollution.

In summary our work demonstrates that composted poultry litter could be a suitable amendment for use in the green industry. However, the method in which the material is to be composted should be paid close attention to when purchasing these materials for container plant production. Our results indicate that using an in-vessel digester for composting poultry litter without adjusting the carbon to nitrogen ratio before processing the waste is a recipe for having unstable and unfinished compost. In short the author would like to state that windrow composting of poultry litter as carried out in this study allows for the producer and the grower to obtain a more stable and useable end product that is safe for use in the green industry.

Further studies are needed to determine the difference in economies of scale, equipment and labor costs, and proper storage of finished products relative to the windrow and in-vessel approaches to composting.