5-1-2018

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Recommended Citation

Bahsi-Kaya, Gulbahar, "Composting of Cross Laminated Timber (CLT) Sawdust" (2018). *Theses and Dissertations*. 1128.
https://scholarsjunction.msstate.edu/td/1128

Composting of cross laminated timber (CLT) sawdust

By

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A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Sustainable Bioproduct
in the Department of Sustainable Bioproduct

Mississippi State, Mississippi

August 2018

Composting of cross laminated timber (CLT) sawdust

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A three-month study evaluated composting of cross laminated timber (CLT) sawdust amended with 10% and 20% chicken litter. Samples were collected at 0, 45, and 90-day intervals to measure weight loss, moisture content, pH, compost maturity, microbial count, and carbon-to-nitrogen ratio. Results indicated that composted CLT20 had much higher weight reduction than others at day 45 and 90. CLT10 and CLT20 had a higher initial pH than controls and showed a slow increase near to neutral-7 by day 90. The germination rate of radish seeds showed that composted CLT20 had significantly higher germination rate than the others at days 45 and 90. A greenhouse study of composted material showed also that the 20% treatment could be used as soil amendment due to its excellent C/N ratio but appears to be unsuitable for container media. Longer composting time is suggested for CLT sawdust to be cured and used for potting media.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Dr. Hamid Borazjani, my advisor, for his understanding, wisdom, patience, enthusiasm, and encouragement and pushing me farther than I thought I can do. I would like to genuinely thank my committee, C. Elizabeth Stokes, Hyungsuk Thomas Lim for all their support. I also would like to thank Dr. Jason Street for his assistance and guidance for ash content analysis also the Sustainable Bioproducts Department at Mississippi State University for letting me be a student here. Additionally, I would like to thank to Mr John Black and David Butler for their assistance during my research. Finally, I would like to thank my family who have been a great source of motivation in this educational endeavor.

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CHAPTER I

INTRODUCTION

The increase in the amount of wastes generated in our society has become a major problem. Wood wastes are an unavoidable by-product of forest product industry and approximately 16 million tons of wood waste is produced each year (EPA 2013). Cross-laminated timber is one of the new wood products which could be an efficient alternative to current building material. Production of CLT has increased in several countries due to its performance and capability. CLT can offer many advantages to the construction sector (Liu et al.2016). It provides great carbon storage, is cost-effective and decreases construction time (Stauder 2013).

Waste from CLT's by-product increases with its production and usage due to high demand. While it is currently recycled within facilities, the expansion of production will eventually lead to an excess of waste material. Thus, it is necessary to find a cost-effective, environmentally friendly and safe way to manage this problem.

In recent years, demand in poultry production is increasing. The concern about disposing of poultry wastes including manure and litter also causes pollution problem (Bolan et al. 2010). It was reported that broiler production was 18.7 million metric tons in the United States in 2017 (Statista 2017). Poultry litter can be used as an organic fertilizer because of the beneficial element it has; nitrogen, phosphorus, and potassium (Dalólio et al. 2017). However, excessive application of these component could cause air and water pollution.

Wood is a renewable resource, and conservation of wood wastes to value-added products are important to protect the environment and reduce the disposal cost. A large quantity of wood wastes is generated from both commercial and residential construction annually. The disposal of wood waste is a big problem for the industry; some companies have capabilities to utilize their wood waste for energy, by burning it to fuel boilers. But burning is not always a practical way for small manufacturers because they have to meet air pollution standard which is often. Another option is to transport wood waste to another facility for incineration. However, transportation is more expensive than the profit gained from the sale (Borazjani et al. 2000).

Composting of these two wastes could offer an alternative disposal technology for most small forest products companies (Wiltcher et al, 2000). Composting wood wastes with poultry wastes for container media or soil amendments is a cost-effective way when compare to sending waste to landfills. Also, composting/recycling of wood waste is necessary for sustainable forestry and environmental protection since it eliminates the requirement of fertilizer, conserves water, and reduces erosion. It is also used as an alternative to poultry litter disposal and handling problem (Bolan et al.2010). Composting is an economical and efficient method of poultry litter treatment.

Composting is a proven technology that can utilize both poultry wastes (litter) and CLT sawdust and convert them into a great value-added product that can be used as soil amendment or for container media. It also can be implemented at the plant site and requires limited knowledge, equipment, and space.

In previous composting studies, six months was needed to obtain mature compost product (Borazjani et al., 1997, Borazjani et al., 2000, Wiltcher et al, 2000, Hatten et al, 2009, Mangum et al, 2009.). Reducing composting time is important because it affects the cost of composted product, and demand of composting technology. In one study, hardwood bark was amended with different percentages of poultry litter for three months. Results showed that amended treatments showed higher weight reduction and the compost can be used commercial container media (Bakhshizadeh et al.2012)

The objective of this study was to evaluate short-term composting of cross-laminated timber (CLT) wood waste with different levels of chicken litter, and to compare the composted material with the most widely used commercial potting media (Metro Mix) in greenhouse study to determine the suitability of the composted material for ornamental plant media.

CHAPTER II

LITERATURE REVIEW

2.1 Cross Laminated Timber (CLT)

Many adverse environmental impacts are associated with building sector. Rising population and urbanization increase demand on the building sector. This requirement affects climate change, greenhouse gas emission, and acid rain. The U.S. building industry needs to find a solution to decrease its adverse environmental impacts (Fraser 2017). The building sector plays a pivotal role to reduce the threat of climate change by using more energy-efficient and climate-friendly structure. Therefore, construction sector decisions are vital to sustainable development.

The main idea of sustainable development for society is not to use more than can be replaced (Rowell et al. 2010). Wood plays a significant role in the development of civilization due to contribution to heat, transportation, and energy (Laguarda-Mallo and Espinoza, 2015). The characteristics of wood increases its application. Wood is a renewable, pure and sustainable resource (Buck et al. 2016) Also, transportation of wood is not difficult, and its availability is high (Laguarda-Mallo and Espinoza, 2015). Wood construction systems, as compared to steel and concrete construction, have some advantages (Buck et al. 2016). Due to its lower weight, soil load is reduced by 30 to 50 %. Shipping costs of prefabricated elements are low. Handling of wood is easy, and installation is fast. Less energy is required for processing of wooden building materials

(Stehn 2008). When compared with wood, energy consumption in construction is nine times higher for steel and three times higher for reinforced concrete (Kolb 2008)

The building sector needs to focus on new building system with renewable material for growing population (Chen 2012). To popularize sustainable buildings, low carbon and bio-based building material is an alternative. In recent years, the awareness of timber building is increasing due to its renewable material and little environmental impact (Liu et al. 2016). There are several engineered materials currently used in construction including cross-laminated timber (CLT), glued-laminated timber (Glulam), and structural composite lumber (SCL). (Buck et al. 2016). One of the newest innovation is cross-laminated timber. It is also known as “Cross-Lam”, “X-Lam” or “Massive Timber” (Laguarda-Mallo and Espinoza, 2015).

Cross-laminated timber is an example of engineered timber which is used as a prefabricated wall and floor element (Buck et al. 2016). It is a wooden panel structure normally consisting of 3 to 9 softwood boards layer bonded together (Horx-Strathern et al.2017). The individual boards are connected to one another orthogonally with adhesive to create a large-format timber panel element with specific engineering features (Horswill and Nielsen 2016). In the system, the grain direction of each layer is changed by 90° to improve stability, mechanical properties, and rigidity. Usually, an odd number of layers is used to get high dimensional stability and load-bearing capabilities across more directions (Buck et al. 2016). With this odd layer properties, moisture and temperature changes do not cause any damage to structure (Laguarda-Mallo and Espinoza, 2015). The primary type of wood for CLT is spruce although fir, pine, larch, Swiss pine and Douglas fir can be used. (Horx-Strathern et al.2017)

In the forest product industry, polyurethanes are used as adhesive to bond wood chips. Polyurethanes form a large family of polymeric materials, which include epoxies, unsaturated polyesters, and phenolics . Some advantages of polyurethane adhesive are low temperature resistance and good flexibility (Szycher 2013). Applications of polyurethane adhesive are furnishing, paints, construction, automotive parts and coatings. Traditionally, polyurethanes are produced by reacting petroleum-based polyols with isocyanates. In some study, other kind of sources such as seed oil and canola oil can be used to produce polyurethane (Kong 2011; Narine 2007).

CLT was developed in the early 1990s in Austria and Germany in the sawmill industry. Ease of handling and multi-way applicability of CLT increases to spread into the markets (Brandner 2013). In the mid-1990s, Austria began research and development of CLT (Mohammad et al.2012). After that time, production of CLT has risen, and it has been predicted that it will continue to increase in the next years due to global interest of CLT (Fraser 2017). In the 1970s and 1980s, the idea of CLT production occurred (Brandner et al. 2016). CLT was used for the first residential project and the first multi-story project in 1993 and in 1995, respectively (Brandner, 2013). In 1998 the first technical approval of CLT was given in Austria and Germany (Brandner, 2016). In the early 2000s, construction with CLT increased due to green building movement (Mohammad et al.2012). In 2000, after the research about CLT was presented by the European Cooperation in Science and Technology in Venice Italy, research, production, and use of CLT significantly increased

(Schickhofer et al. 2017). The use of CLT for residential and non-residential purposes in European countries has increased since then also (Davids et al. 2017).

CLT is becoming a well-known material that can change the building industry (Liu et al. 2016). Production of CLT began in the United State and Canada in 2010. One of the great examples of CLT building is in Vancouver, Canada located in British Colombia. It is the construction of the tallest timber hybrid building in the world. The building which is 53 meters high began construction in November of 2015 and completed 2017 (Gintoff 2016).

CLT's production and distribution are going up due to its structural performance and construction speed capability. Unawareness of CLT's advantages as a heavy construction material caused industrial and commercial demand in Canada and USA early on (Stauder 2013). CLT has become an alternative as a wood-based product to industry in North America since then (Karacabeyli and Douglas 2013). Myers Memorial United Methodist Church Bell Tower is the first North American non-residential CLT structure, and it was completed in 2010 in Gastonia, North Carolina (Laguarda-Mallo and Espinoza, 2014). In 2011 in Montana, the "Long Hall" is the first construction as a commercial building, and it was designed using concrete but then converted to CLT. The third CLT building in the U.S was combined with glulam beams and built Madison, Wisconsin (Laguarda-Mallo and Espinoza, 2014). According to the CLT handbook, it is expected that demand of CLT in the U.S will be around \$2 to \$6 billion annually (Karacabeyli and Douglas 2013). Locations of the CLT building are on the East Coast (Boston and New

York), the Great Lakes States (Minneapolis), California (Los Angeles), Washington (Seattle) and Texas (Dallas and Houston) (Laguarda-Mallo and Espinoza, 2014).

Wood is a renewable resource and offers multiple benefits to the environment. According to research associated with sustainable forest management and the lifecycle of wood products in construction, the advantages of harvesting forest regularly is higher than letting them grow for years (Ritter et al. 2011). Harvesting process can reduce insect-infested or diseased trees.

The environmental impacts of CLT and reinforced concrete structure are different. Laminated timber system could save 18% more non-renewable energy than reinforced concrete (Chen 2012). Life cycle analysis research on CLT has demonstrated that CLT has a less harmful effect on the human health and produce fewer greenhouse gases (Chen 2012). Ozone depletion, ecological toxicity, producing air pollutant acidification, and eutrophication are lower than reinforced concrete (Chen 2012). Also, CLT requires smaller amount of water, energy, and fossil fuels to transport when compared to concrete and steel (Laguarda-Mallo and Espinoza, 2015).

CLT is an efficient building material alternative that can be used for roof, walls and flooring structure (Laguarda-Mallo & Espinoza, 2015). On-site construction of CLT are rapid, so it decreases construction time and labor costs (Fraser 2017). CLT is favorable concerning strength when compared to other materials (Buck et al. 2015). Attached layers of CLT elements support each other because they are laminated orthogonally (Laguarda-Mallo & Espinoza, 2015).

According to the ASTM E119 standard which was tested in the Forest Product Lab, CLT can provide fire resistance due to its charring properties (Dagenais et al., 2012). Contrary to typical assumptions, woods burn more slowly because it produces a char layer to protect the non-charred wood. This phenomenon support that massive timber product can maintain its strength and dimensional stability when exposed to fire. The adhesive also affects fire behavior of CLT panels. Thus it is essential to use adhesive which has lower sensitivity to high temperatures (Laguarda-Mallo & Espinoza, 2015). The prefabricated nature of CLT decreases on-site labor. Due to prefabrication properties of CLT, they can be collected and reused as by-products of electricity, heat or, biofuel (Evans, 2013).

CLT panels have environmental benefits. CLT can be reused with little additional processing after deconstruction although a significant amount of concrete waste results in landfills. The embodied energy of the building using laminated timber structure is lower than the concrete structure, and this energy can be reused (Chen 2012). CLT has an excellent thermal insulation property, and it releases heat at night and stores heat during the day. Additionally, it acts as a thermal mass, so it lowers energy demand (Cambiaso and Pietrasanta, 2014).

2.2 Poultry Litter Issues

Poultry (*Gallus gallus domesticus*) production plays a vital role in the agricultural economy of United States and especially Mississippi (Edwards and Daniel 1991). In 2017, 18.7 million metric tons of broiler meat was produced in the United States (Statista 2017). Census of Agriculture reported that in 2012 there were 233,770 poultry farms, and in 2014 poultry industries produced 8.54 billion broilers in the United States (USDA 2015).

Manure, bedding material or litter, waste feed, dead birds, broken eggs, and feathers occur as waste in poultry industry (Kelleher et al. 2001).

Poultry litter is hugely precious resource, and is used for improving physical and biological soil fertility. Poultry litter has high phosphorus, potassium and very high nitrogen content. It is estimated that about 44.4 million tons of poultry manure were produced in 2008, and the poultry manure contains 2.2 million tons of Nitrogen, 1.4 million tons of potassium and 0.7 million tons of phosphorus (Bolan et al. 2010). Poultry litter is incorporated into the soil as an organic fertilizer because of nitrogen, phosphorus, and potassium. However, the excessive concentration of nitrogen and phosphorus from manures can be carried in run-off water, causing eutrophication (Dalólio et al. 2017). Poultry litter has been spread on soil, but over fertilization could result in the spread of pathogens, air pollution, high nutrient level in fresh waters, greenhouses gases, and phytotoxin production (Moore et al. 1995). Endocrine disruptors are considered one of the main problems related to the disposal of litter in the environment. 17 Beta-estradiol can cause sexual reversal in fish when a high amount of poultry litter is used in the soil, and then leaches to the water (DeLaune and Moore, 2013).

In recent years, demand for poultry production is increasing, and a large amount of solid waste is produced by the poultry industry (Moore et al. 1995). The solid waste includes bedding materials, manure, feed, feathers, sludge, abattoir waste (offal, blood, feathers and carcasses), hatchery waste (empty shells, infertile eggs, dead embryos and late hatchlings), shells, and mortality (Moreki and Chiripasi 2011). Power generation is considered one of the alternative uses for poultry litter. It is a potentially stable green fuel source that may help to decrease fossil fuel demand. The good burning capacity of poultry litter makes it a valuable fuel source (Perera et al. 2010). However, there is an upper boundary that will occur due to an effect of high moisture content (Bolan et al. 2010). High moisture content causes incomplete combustion and releases carbon monoxide to the environment (Ludwig et al. 2003). In the United States combustion of poultry litter has been implemented to generate electrical energy. In some cases, poultry litter is mixed with either coal or other biomass to produce electricity (Chastain et al. 2012). According to Chastain et al., there are many technical and economic barriers to using poultry litter as a source of biomass fuel and generation of energy power.

One of the significant environmental problems of the poultry industry is the effect it has on air quality. Dust, odors, and bio-aerosols such as microbes, endotoxins, and mycotoxins are main concerns at manure facilities (Bolan et al. 2010). They cause a local problem because of odor, which comes from manure, carcasses, feathers and bedding/litter (Kalu 2015). The odor gases include amines, amides, mercaptans, sulfides, and disulfides, and can cause respiratory problems in humans and animals (Bolan et al.,2010). People living near facilities are profoundly affected by odor emission (Kalu et al. 2016). Manure handling and storage facilities release carbon dioxide, methane, and nitrous oxide. These gases result in ozone depletion and global warming (Bolan et al. 2010). Finding efficient technologies to reduce the emission of these gases is essential. Another environmental issue of poultry litter is agricultural usages. The land application of poultry litter is recognized as a beneficial soil enhancer, however in addition to nitrates, heavy metals and micronutrients present in poultry litter also pose soil and water contamination threats when it is applied in high levels (Sims and Wolf 1994).

Poultry litter could be used for animal feed but the number of contaminants in poultry litter prohibits using it as an animal feed (Bolan et al.2010). Poultry litter includes antibiotics, pathogens, hormones, and heavy metals, so they pass to the animal through feed (Preusch et al., 2002). Also, poultry litter contains feathers and foreign materials such as plastic and glass, and they affect digestibility of poultry litter. Before feeding an animal with poultry litter, it would be necessary to remove these contents to prevent digestion problems (Bolan et al.2010).

Poultry litter waste that is inappropriately treated results in a high number of pathogenic microorganisms such as *Clostridium, Salmonella* and *Enterobacter* spp. Some fungal species occurring in litter can cause the production of mycotoxin (Bolan et al. 2010). Spreading of poultry litter to the land may also cause a high risk of botulism to cattle (Huang 2015). Fermentation, heating, or chemical treatment can be used to destroy pathogenic microorganism before using poultry litter waste (Bolan et al. 2010). Antibiotics, arsenicals, copper and zinc are added in poultry litter as feed additives, and they are excreted as a waste by-product. Copper and zinc are used to shorten the breeding time of poultry animals. When the poultry litters are used as soil amendment, they can increase toxicity level of heavy metals in the soil (Hao et al.2008). Developing effective technologies to minimize health and environmental impact of poultry litter waste is essential for poultry industries (Whitemore 2007).

Three options which are composting, centralized anaerobic digestion, and direct combustion with combined heat and power are accepted as alternative disposal methods for poultry litter (Kelleher et al. 2001). Aerobic composting is most commonly practiced to eliminate problems related with disposal and handling of poultry litter (Bolan et al. 2010) Composting is a useful and economical method for treatment of poultry litter to improve soil structure. Composting can enhance plant growth and increase organic matter of soil by decreasing plant pathogens (Guo et al. 2012). Composting reduces volume, weed seed viability, weight, and odor of poultry litter. During composting process, the number of pathogens can be decreased due to heat production by the process. More humidified substance is obtained because of inactivation of nitrogen and the result is a better soil amendment (Fine 2010)

2.3 Composting

Composting is a biological treatment process in which microorganisms convert organic material such as manure, sludge, leaves, paper and wood waste into stable humus at elevated temperatures (40-60 °C) (Borazjani et al. 2000). The U.S. EPA (the United States Environmental Protection Agency) reported that about 24 percent of waste in the U.S. can be composted, however only 8 percent of Americans compost their waste (EPA 2013). The composting also is an aerobic and thermophilic process (Sanchez et al.2017). The primary purpose of composting is to obtain a nutrient rich humus substance which can be used as a soil conditioner and organic fertilizer. The end product is easy to store and distribute and has decreased odor, pathogens, phytotoxic chemicals and weed seed (Kortei et al.2015). Agricultural, agro-industrial and organic residues are used as the main feedstock for composting. During the composting process, heat, nutrients, and CO_2 are released, and the humidified organic matter is formed. Physical, chemical and nutritional conditions play a crucial role in the performance of aerobic composting (Khan et al. 2014). Compost improves chemical and biological properties of soil such as increasing resistivity to the disease and toxicity (Bakhshizadeh 2012). Handling compost is easy, and compost stores for a long time without odor or fly problems when compared to original material. Manure handling and land application can be improved by composting. Also, composting decreases environmental risk. During composting process, the heat is produced, so it removes moisture, reduces the weight, killed pathogens, and weed seeds in the manure. Because of this reason, farmers, waste-generators, and environmentalists pay attention to the compost (Rynk et al. 1992). When compost is used on the surface of the soil, it reduces evaporation and results in a more suitable environment for root growth. (Al-Bataina et al. 2016)

2.4 Composting Process

Formulation of raw materials is the first step to make compost (Sanchez et al. 2017). In the composting process organic material is broken down into compost, carbon dioxide, ammonia, water, new cells, and heat (Bernal et al. 2009).

$$\text{Organic matter} + O_2 \rightarrow \text{Compost} + CO_2 + H_2O + NH_3 + \text{biomass} + \text{heat (Cao 2017)} \qquad (1)$$

In composting, organic matter is mineralized and metabolized by bacteria, fungi and other microorganisms (Bernal et al. 2009). There are three major stages, mesophilic, thermophilic, and cooling, occurring during the composting process (Tuomela et al. 2000).

Breakdown of organic matter depends on their susceptibility. Sugars, starches, glycerol, pectin, fatty acid, lipids, fats, amino acids, and nucleic acid are more susceptible to degradation, and they break down easily at the mesophilic phase (Epstein 1996). As the organic acids are formed, pH decreases at the first phase (Pace 2017). After that, pectin, cellulose, hemicellulose, and chitin are degraded at the thermophilic stage (Epstein 1996). Protein degradation causes ammonium release. Also, pH increases when protein is degraded. Due to microbial activity, the temperature increases during the active composting phase, mesophilic, and thermophilic. The high temperature reduces pathogens, destroys fly larvae and weed seeds (Wichuk & McCartney, 2007). However, lignin, lignocellulose, low molecular weight aromatic and aliphatic compounds are resistant to biodegradation, so probably they do not change during the process (Epstein 1996).

Composting is a complex process and needs to be controlled due to numerous microorganism and chemical reactions. Proper process management is necessary to obtain a quality agricultural product and prevent odors and greenhouse gases. During composting, there is a complicated interaction between physical, chemical, and biological factors (Pace 2017). Therefore, it is not easy to control all the parameters such as temperature, water content, aeration rate which depends on the process management and pH, C:N ratio, porosity, and particle size which relies on the formulation of composting mix (Bernal et al.2009). These factors play an essential role in the microbial development and organic matter degradation.

In general, the composting process can be divided into three phases, mesophilic, thermophilic, and cooling, which are based on the temperature changes. In mesophilic phase, mesophilic bacteria and fungi are active and the temperature increases quickly. During the thermophilic phase, maximum degradation of organic matter and destruction of pathogens occur. In the cooling or maturation phase, reduction of microbial activity causes temperature decline (Bernal et al. 2009), and chemical compounds are still degraded by fungi (Mitchell et al. 2015). During the cooling phase, mature compost is produced due to stabilization and humification of organic matter (Bernal et al. 2009).

Microorganisms play a crucial role in the process of composting because organic matter is decomposed by the different group of microbial population (Bernal et al. 2009). There is a strong connection between succession of microbial communities and compost quality. Controlled microbial growth is necessary to ensure the quality of compost and its application field (Kortei 2015). The activity of microorganism changes with the compost temperature. Bacteria are active mainly at mesophilic phase while actinomycetes predominate at cooling phase. On the other hand, fungi are active during the process as long as the water level below is 35 % and the temperature is below 60 °C (Bernal et al. 2009). Fungi can survive in extreme conditions when compared to other microorganisms which are active in composting process. Fungi can degrade complex polymers such as polyaromatic compounds or plastics and use lignocellulosic polymers as a carbon source (Miller 1996). According to Kusum, the number of thermophilic bacteria goes down in the cooling phase because it is considered the indication of maturity (Kusum 2016).

Microorganisms need carbon and nitrogen to decompose and transform organic matter (Bernal et al. 2009). Carbon is a source of energy and metabolism for microorganism and nitrogen is used to synthesize protein and reproduce cells (Huang et al.

2004). While wood chips and grass can be used as a carbon source, animal products such as chicken and horse manure can be used as nitrogen source (Paret 2017). The proper C: N ratio should be between 30 and 35 in the initial mixture of composting (Gil et al. 2008). Overall composting time will increase if initial C: N ratio is lower than 25. Some organic material has low nitrogen content, so nitrogen-rich material can be added to reach proper C: N ratio (Sanchez et al. 2017). The C: N ratio of compost should be between 25:1 and 35:1 in order to achieve a successful composting (Kusum 2016, Paret 2017, Sanchez et al. 2017) It is considered that the microorganisms need 30 parts of C per unit of N (Bernal et al. 2009). In the composting process, the ratio decreases due to the release of CO_2 and results in carbon loss from the system (Kusum 2016). If the ratio is too high, it makes the process very slow, and the process will not heat up enough. When the rate is too low, the compost will become anaerobic, and excess nitrogen can be lost as ammonia through leaching and volatilization. A bulking agent can be added to increase organic carbon and regulate C: N ratio to the proper level (Bernal et al. 2009, Gao et al. 2010). The appropriate range of C: N ratios are significant because it can decrease use of bulking agent and help accelerate the composting process (Huang et al. 2004).

Temperature is considered one of the major indicators for the occurrence of composting process and microbial activity (Cao 2017). Temperature is easily monitored to ensure the status of composting. While the mesophilic temperature range is 25-45°C, the thermophilic temperature is between 45-60°C. The adequate temperature range for composting is 40-65 °C (de Bertoldi et al. 1983). Temperature above 55°C is needed to inactivate a majority of pathogens (Bernal et al. 2009, Huet et al. 2012, Arikan et al. 2009, Mitchell et al. 2015). If the temperature exceeds 63 °C, it damages composting because above that temperature microbial activity decreases rapidly. However, the temperature is not the only parameter affecting pathogens inactivation. There are also other factors such as feedstock characteristics (i.e., C: N ratio and pH), operating conditions (i.e., aeration and turning) and weather. Aeration, feedstock, and mixing cause temperature changes, and the temperature controls pathogen inactivation. Foodborne pathogens, *Salmonella* spp. and *E. coli* O157: H7, are active at sub-optimal temperature, so temperature needs to be regularly monitored during composting process (Wichuk and McCartney 2007).

Physical parameters of compost such as bulk density, free air space, and thermal conductivity are affected by moisture content (Huet et al. 2012). The optimum water content for composting should be 50-60% (Bernal et al. 2009). If the moisture content exceeds 60%, air spaces will be filled with water, and air movement can be interrupted. Therefore, the process tends to become anaerobic. Besides that, if the moisture is too low, there will not be proper conditions for microbial growth, so the biochemical processes cannot occur during composting (Sanchez et al. 2017). There is a correlation between the amount of water and temperature in compost. To control temperature, a large quantity of water can be evaporated. If the water content is too low for microbial growth, rewetting is necessary to reach optimum moisture content (Bernal et al. 2009). Appropriate moisture content is essential to obtain high-quality compost (Cao 2017).

In the composting process, pH is not considered as a critical factor because most materials exist in the optimum pH range, which is between 5.5 and 8.0 (Bernal et al. 2009). However, pH is necessary to be controlled during the rapid biodegradation due to ammonium (NH^{4+}) releases. Ammonium acts as alkali and increases pH above to 8. As the compost matures, ammonium is nitrified, and the pH goes down (Kusum 2016). During composting, short-chain organic acids are produced, and ammonia affects pH because of microbial activity. It is considered that high and low pH can result in an unfavorable impact on composting. Therefore, in order to regulate pH to the required level, a bulking agent with high buffer capacity can be added as an option (Li et al. 2013). According to some researchers, a stabilized pH is an indication of maturity. On the other hand, some researchers consider that pH should approach neutral values as compost mature (Kusum 2016).

Aeration is vital for composting because it controls other parameters such as temperature, moisture, carbon dioxide and oxygen. Aeration sends away excess moisture from composting and provides O_2 which should be between 15% and 20% for biological processes; also, it keeps the temperature below 60-65°C (Bernal et al. 2009). Inappropriate air supply makes the process slower because air is necessary for microorganism's growth and activation. Without a consistent air supply, the process turns into anaerobic fermentation (Sanchez et al. 2017).

CHAPTER III

MATERIALS AND METHODS

3.1 Compost Set Up

CLT sawdust in this experiment was provided from Smartlam in Montana. Nitrogen sources for this study were obtained by using different levels of poultry litter. Dried poultry litter was provided by the Poultry Science Department at Mississippi State University (MSU). Southern yellow pine (SYP) sawdust was provided from a local lumber operation. CLT and SYP sawdust as well as poultry litter were sifted in order to separate large pieces after drying with air for 48 hours. After drying, samples were collected from sawdust and poultry litter to measure moisture content of each one. It was necessary to determine exact weight loss on dry weight basis. The moisture content of sawdust and chicken litter were determined to be approximately 10% and 20%, respectively.

Twelve 35-gallon (130 L) plastic cans were purchased at local hardware store. Five 3-cm holes were drilled in the bottom of each can. Plastic cans were drilled because they not only stabilize moisture content of composts, but also prevent the lack of oxygen creation and retaining water in the composts. Fabric mesh was put into bottom of each can to let the water pass through while preventing compost materials from passing through the 3-cm holes. The experiment was conducted outdoors at Sustainable Bioproducts Department complex (Figure 3.1).

The experimental treatments for this study were determined based on dry-weight are as follows (Figure 3.2):

- Control 1: consist of 11 Kg of CLT sawdust
- Control 2: consist of 11 Kg of southern yellow pine sawdust.
- CLT sawdust plus 10 percent poultry litter 1.1 Kg was consisted of 9.9 Kg of CLT sawdust.
- CLT sawdust plus 20 percent poultry litter 2.2 Kg was consisted of 8.8Kg sawdust.

This study consists of four treatments that were replicated three times. The content of each container was mixed before placing into the container. The compost cans were randomly placed at outside in one row (Figure 3.1). Then moisture was adjusted to above 50 % by rainwater

Figure 3.1 Containers placed outdoors in a random arrangement

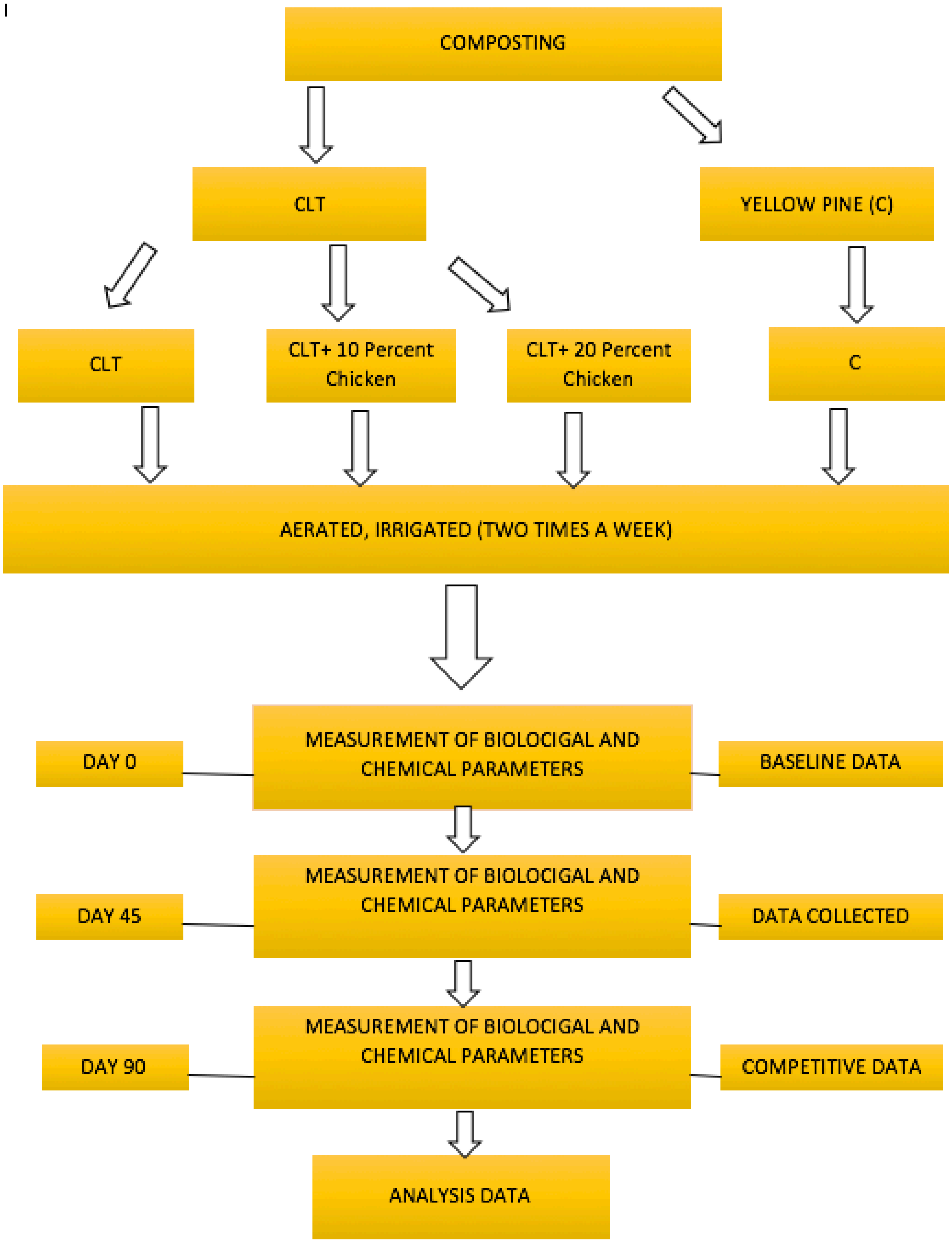


Figure 3.2 Experimental Design

Samples were collected at 0, 45 and 90 day intervals to test moisture content, pH, compost maturity, percent ash, microbial count, and nutrients. Controlling and adjusting moisture content was necessary for the step of this process. After taking samples from containers, weight loss of each container and sample were evaluated. Moisture content was a critical component of material and analyzed to make sure exact calculation of weight loss on a dry weight basis. During the collection process, eight hundred grams from each container were placed in plastic gallon bag and placed in a freezer (-20 °C). Approximately an 11 g sample was taken from each bag and placed in an aluminum dish. After placing the aluminum dish into an oven at 100°C, it was dried over night to calculate dry weight of the sample. Rainfall and distilled water were used to stabilize the moisture content between 50-65 %.

3.2 Aeration, Irrigation, and Temperature

The contents in containers were aerated by hand mixing once or twice a week depending on humidity, precipitation conditions, or how much distilled water was added. The moisture content of each compost was assessed at least once a week to keep moisture level at 50%-65%. Material in the containers was mixed by hand to get uniform treatment. Aeration was needed to ensure aerobic condition of each container.

Ambient air temperature is less than pile temperature, and it is an indicator for composting maturation. In the thermophilic stage of composting, approximately 71 °C, the pile should be warmer than ambient air. The size of composting material and ingredients affect pile temperature. The temperature of each treatment was monitored each week to determine thermophilic and mesophilic stages of composting and to ensure that composting kept going properly.

3.3 Collection and parameter measurement

As described earlier, samples were collected on days 0, 45, and 90 to analyze moisture content, pH, microbial count and for compost maturity test. Before collecting samples, containers were weighed to measure exact weight loss of each treatment. Then each treatment in the containers was mixed by hand to make sure the samples were uniform and homogenous. During the collection process approximately two handfuls (0.6 lbs dry weight basis) of a sample from each compost were placed in a plastic gallon bag. Moisture content and microbial count were analyzed immediately. The rest of the samples were placed in a freezer (-20 °C).

The oven-dry method was used to determine moisture content. For each sample, an aluminum dish was selected and weighed. The weight of the aluminum dish was recorded, and the scale was then zeroed out. Approximately 10 g of sample was taken from each bag and placed in an aluminum dish. After placing the aluminum dish into an oven at 100°C, it was dried over night to calculate dry weight of the sample. Dried samples were removed from the oven and weighed. The weight of the aluminum dish was subtracted from total weight. The resulting dry compost weight was subtracted from the compost wet weight to determine the weight attributed to moisture. The moisture weight was then converted to a percentage, yielding percent moisture content.

3.4 Microbial Counts

Microbiological analyses were done at the laboratory of the Sustainable Bioproducts Department at MSU. The dilution plate method was used for determination of bacteria and fungi. Because of the high number of microorganisms during composting, the dilution was necessary for counting.

1 ml of sample was added to 9 ml of suitable diluent which was autoclaved before use. The sample and diluent were mixed together. 1 ml of dilution was then added to another 9 ml of diluent. The number of dilutions made depended on the type of samples.

Nutrient agar (NA) and potato dextrose agar with antibiotics (PDAA) were prepared to measure total bacteria and fungi respectively. Fifty-eight and a half grams of PDA and thirty-four and half gram of NA agar were mixed separately with 1.5 ml deionized water then autoclaved to sterilize. After cooling to the 55°C, 15 ml NA was poured into sterile petri dishes and left to set. For fungi, 0.0045 g of chlortetracycline and 0.18 g of streptomycin sulfate were mixed with 5 ml of deionized water and added to PDA.

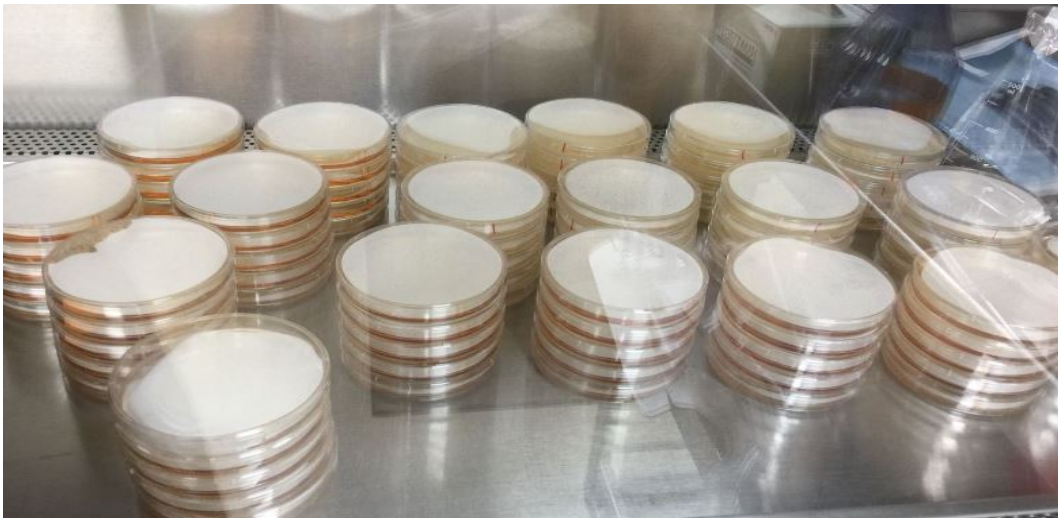


Figure 3.3 Nutrient agar (NA) and potato dextrose agar with antibiotics (PDAA)

0.1 ml of sample was pipetted onto agar surface and was spread by using a sterile glass rod. Three replicate plates for each of last dilution were prepared. Then, they were left to dry, and moved to an incubator at the suitable temperature for microorganism growth

(Figure 3.3). After waiting more than 24 hours depending on organism, the number of colonies were counted.

3.5 Composting Maturity Test

The compost maturity test was performed by using radish seed (*Raphanus raphanistrum sativus*) to determine whether the compost had matured. Samples were taken from day 0, 45 and 90 to conduct the test. Eight-ounce paper cups were used, and six radish seeds were placed into the compost samples in each cup. Radishes are sensitive, and environmental factors can affect the growth rapidly. Potting soil was used for 5 control samples, and the soil was provided from the greenhouse in the Plant and Soil Science Department at Mississippi State University (Figure 3.4). Cups were randomly placed outdoor and rainwater was added regularly to make sure the compost cups remained moist. After 10 days, germinated seeds' number was counted, and germination rate was determined.

Figure 3.4 Compost maturity of radish seed at day 0.

3.6 Nutrient Analysis and pH

Approximately 30 g samples from day 0, 45 and 90 were collected and were sent to the MSU Soil Testing Lab for nutrient testing. The concentration of macronutrients (P and K), the concentration of secondary nutrients (Ca and Mg), and the concentration of micronutrients (Zn and Na) were analyzed using Coupled Plasma Atomic Emission Spectroscopy in the soil lab. Total Kjedahl Nitrogen (TKN) was determined by using EPA Method 351.4, and was analyzed at the Mississippi State University Soil Testing Laboratory.

For the pH test, one gram of each compost sample was mixed with 9 mL of deionized water and placed in a test tube. The test tubes were sonicated in a water bath (Ultrasonic Cleaner Branson 2200) unit for ten minutes to ensure the particles from compost were thoroughly separated and mixed into the water phase by ultrasound. Then, the sample tubes were kept in the refrigerator overnight. The tubes were centrifuged for 20 minutes at 50,000 rpm to separate solid phase from liquid phase. A Mettler Toledo Seven Go Portable pH meter unit was used to measure the pH in the liquid phase of samples and the pH electrode arm was washed with distilled water after measuring the pH of each sample (Bakhshizadeh 2012).

3.7 Carbon Analysis

3.7.1 Volatile

Percent volatile matter was tested by ASTM E872-82 standard. The sample size was reduced to 1-mm or smaller screen by using a cutting type laboratory mill. An empty crucible and cover were ignited at 950 ºC and cooled in a desiccator. The crucible and cover were weighed to nearest 0.0001 g and this was recorded as crucible weight. Approximately 1 g of sample was placed in the crucible and recorded with cover to determine initial weight. The crucible was inserted into the furnace chamber which was arranged at 950+ ºC. After heating exactly 7 minutes, crucible was removed from the furnace. As soon as the sample is cold in a desiccator, the covered crucible is weighed and recorded as final weight.

$$Weight\ Loss, \% = 100\times(W_i - W_f)/(W_i - W_c) \qquad (2)$$

W_c: Weight of crucible and cover, g

W_i: Initial weight, g

W_f: Final weight, g

3.7.2 Ash

The ash percent was determined by using ASTM D1102-84 standard. An empty covered crucible was placed into furnace at 600°C and cooled in a desiccator. Two grams of sample was placed into the crucible, and the weight of crucible plus sample were calculated. They were placed in the drying oven at 100 °C to 105 °C. After 1 hour, the crucible was taken from oven, cooled in a desiccator, and then weighed. Drying and weighing were repeated until the weight was constant to within 0.2mg.

The crucible and contents were placed without cover into the oven at 100°C and ignited until all the carbon was eliminated. Heat was increased slowly to prevent flaming and mechanical loss of samples. The final ignition temperature was 580 to 600 °C. After 6 hours, the crucible was taken, cooled and weighted.

$$Ash, \% = (W_1/W_2)\times 100 \qquad (3)$$

W_1: Weight of ash, g

W_2: Weight of oven-dry sample, g

3.8 Weight Loss

On day 0, 45, and 90, the compost containers were weighed. After collecting samples, moisture content was calculated to determine weight reduction of each container. The percent moisture of each samples helps to measure dry weight of compost. The weight reduction percent for each container was calculated through 90-day sampling by subtracting weight of samples collected from previous sampling dates as well as considering the moisture content. This ensured that the weight reduction through each container was only dependent on composting. Also for the treatment containing chicken litter, the chicken litter weight loss was accounted as shown in appendix A.

3.9 Green House Study

In a greenhouse study, the suitability of composted materials was evaluated as a bedding media. Pansies (*Viola* sp.) were purchased from a local garden store and planted in the finished compost products (day 90) for a period of 4 weeks. Metro Mix was used as a commercial potting media to compare with composted treatments (Figure 3.5). Pansies require growing conditions such as cooling weather, full sunny location, moist, humus rich, and well drained bedding soil or compost.

One pansy was planted in each pot and 5 pots were used for each replicate of each treatment. All pots were placed inside a greenhouse with a completely randomized order, same condition and light (Figure 3.5). The plants were fertilized once a week with commercially available fertilizer to the nutrient requirements of pansies. The plants were also irrigated regularly to keep pots moist. At the end of the four weeks, plants were harvested at the ground level for dry mass weight determination.

Figure 3.5 Pansy in the greenhouse with random design.

3.10 Statistical Analysis

Weight loss, nitrogen content, pH, carbon, and microbial analysis from composting, and greenhouse studies were statistically analyzed using completely random design to determine significant differences between treatments. Three replications were used for each treatment. Mean comparisons were made using a least significant difference at the P=0.05 probability level by the Statistical Analysis Systems (SAS). Treatment description, abbreviated ID, and the number of replications is listed below in table 3.1.

Table 3.1 Sample Description, Reference Number and Composting Treatment Numbers

Sample	Reference ID	Treatment number	Replicates
Southern Yellow Pine	C	Treatment 1	3
CLT	CLT	Treatment 2	3
CLT+10% chicken litter	CLT10	Treatment 3	3
CLT+20% chicken litter	CLT20	Treatment 4	3

Note for Reference ID: C=Control, 10 and 20= Chicken Litter. Letters illustrate amount of mentioned parameter.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Weight Loss Result

Weight loss results for days 0, 45, 90 are summarized in Figure 4.1. The percent weight reduction at day 90 is shown in Figure 4.2. Weight reductions were observed in all treatment at day 45 and 90. The dry weight of CLT20 treatment at day 90 was significantly different when compared with day 0 and 45. The unamended CLT treatment showed the lowest weight reduction when compared to amended CLT and pine sawdust (C) as well. Greatest weight loss was observed in treatment amended with 20 % poultry litter (CLT20). These results in total agreement with findings of Wiltcher et al, 2000 , Mangum et al 2009, and Bakhshizadeh, 2012.

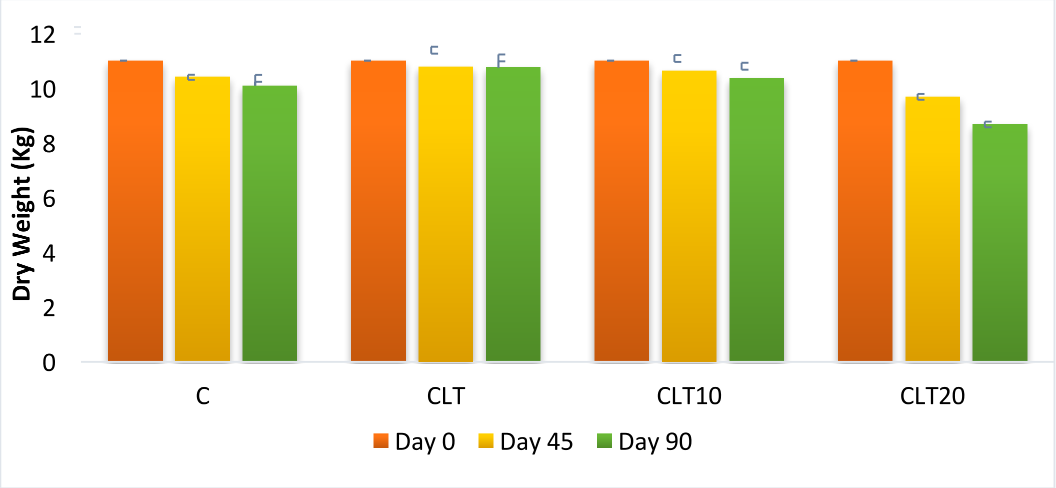


Figure 4.1 Treatment weight loss for day 0, 45, and 90. Error bars indicate a significant difference between weight loss at the α=0.05 level of significance

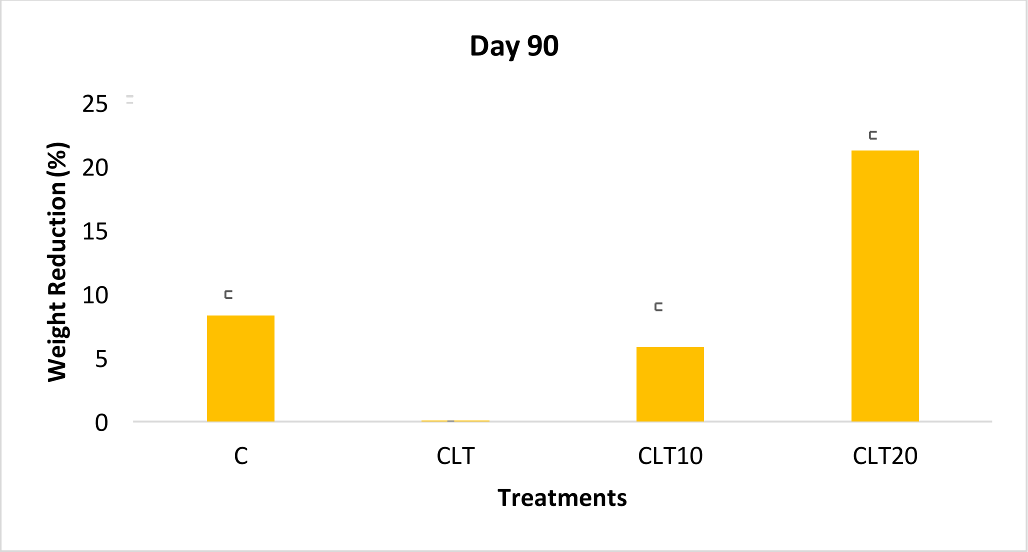


Figure 4.2 Percent weight loss for all treatments at 90 days.

Note: Error bars indicate a significant difference between weight loss at α=0.05 level of significance.

4.2 Microbial Results

Microbial analysis such as total bacteria and fungi of the raw waste and treated samples for days 0, 45 and 90 are summarized in table 4.1. The number of fungi in unamended treatment was significantly lower at day 0. Also, it was found that the composting process contributed to a significant increase in the number of total bacteria and fungi due to favorable composting conditions (proper aeration, temperature, and moisture content). That is an agreement with findings of Khan et al, 2012. The number of total bacteria for all treatment decreased from day 45 to day 90 while the number of fungi for all treatments increased.

Table 4.1 The total number of bacteria and fungi for all treatments at day 0,45 and 90.

	Bacteria			**Fungi**		
	Day 0	Day 45	Day 90	Day 0	Day 45	Day 90
C1	1.90E+04	7.36E+06	1.19E+06	6.80E+03	9.86E+05	1.31E+07
C2	2.00E+05	5.43E+06	1.21E+06	0.00E+00	6.10E+05	9.33E+06
C3	6.00E+05	8.33E+06	2.05E+06	0.00E+00	4.73E+06	6.59E+07
CLT 1	1.86E+05	7.00E+06	6.00E+05	6.66E+01	3.76E+05	2.57E+07
CLT 2	1.33E+02	1.73E+06	6.67E+05	0.00E+00	3.53E+05	2.56E+07
CLT 3	6.70E+03	6.23E+06	8.20E+05	6.80E+03	4.73E+05	5.07E+07
CLT 10-1	3.80E+05	1.83E+07	6.60E+06	1.60E+03	4.93E+06	1.08E+09
CLT 10-2	2.00E+04	3.36E+07	4.00E+06	6.10E+03	5.26E+06	5.87E+08
CLT 10-3	3.30E+04	3.06E+07	5.00E+06	5.70E+03	3.43E+06	8.04E+08
CLT 20-1	2.13E+05	4.30E+07	5.47E+06	6.20E+03	3.43E+06	9.45E+08
CLT 20-2	1.48E+06	6.40E+07	1.47E+06	2.86E+04	1.13E+06	1.32E+09
CLT 20-3	8.80E+05	5.10E+07	6.00E+06	1.66E+04	1.16E+07	1.62E+09

Note: Colony-Forming Unit (CFU) is used to count the number of bacteria and fungi

4.3 Temperature during composting process

The treatment containing poultry litter reached a temperature of 84 F by 4 weeks. Table 4.2 shows that the ambient temperature did not affect the composting temperature significantly. While ambient temperature was too high or low, composting temperature remained still similar to outside temperature. Table 4.3 showed the temperatures at different weeks. As shown, the composting treatments did not reach thermophilic temperature in this study.

Table 4.2 Treatments temperature at different ambient temperature.

Ambient Temp(F)	81	48
C	68	68
CLT	68	69
CLT10	69	70
CLT20	69	69

Table 4.3 The treatments temperature at 3rd ,7th and 14th weeks

	3rd week	7th week	14th week
Ambient Temp(F)	67	68	66
C	70	69	68
CLT	70	70	69
CLT10	83	71	70
CLT20	84	72	70

4.4 Plant and Germination Rates

Seed germination rates for all sampling periods are illustrated in Figure 4.3. The most improvement was shown for the treatment amended with 20% poultry litter (CLT-20) when compared with CLT and CLT10. The germination rate of radish seeds for CLT20 at day 90 is significantly higher than CLT10 and not significantly different from C treatment. Figure 4.4 shows comparison of CLT20 at day 90 and commercial media. Also, figure 4.5 illustrates the overall germination results of CLT20 for day 45 and 90. According to the Florida's Composting Center if 75% or more of the seed sprout and grow into radishes, the compost can be used in any application (Bakhshizadeh 2012). In comparison with other studies, (Hatten et al 2009, Bakhshizadeh, 2012). These results have indicated that the 90-day compost was not mature enough for CLT treatments to be used as plant media (Figure 4.3) (Hatten et al 2009, Bakhshizadeh, 2012). Figure 4.6 shows that the percent germination rate of all treatments except unamended CLT are approximately 95 percent at day 150. The results illustrate that longer composting time is needed for the CLT treatments. Also, CLT20 looks better in comparison with unamended CLT in figure 4.7. Due to availability of samples that were left outdoors, the compost maturity test was performed, and results are presented in Figures 4.6 and 4.7. The results showed over 95% germination of treated CLT samples that proves a longer composting time is required for this type wood waste.

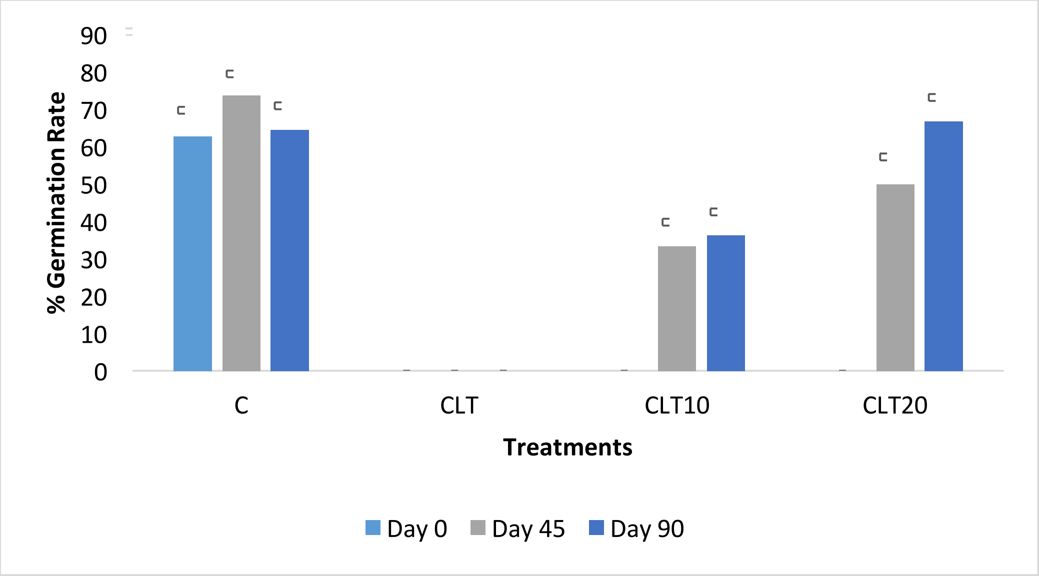


Figure 4.3 % Germination rate for each treatment at day 0, 45 and 90.

Notes: Error bars indicate a significant difference between weight loss at the α=0.05 level of significance

Figure 4.4 Germination of CLT20 at day 90 and commercial media (Soil)

CLT20 at day 45

CLT20 at day 90

Figure 4.5 Overall visual germination results of CLT20 with radish seeds.

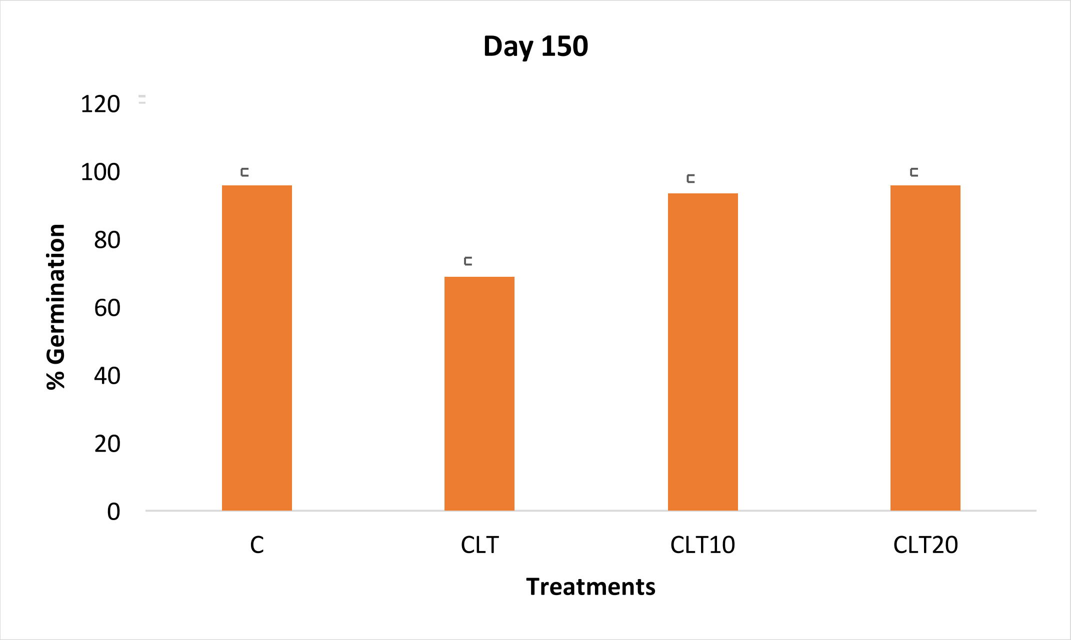


Figure 4.6 % Germination rate of all treatments at day 150.

Notes: Error bars in the figure indicate significant difference in pH at the P=0.05 level of significance.

(a) (b)

Figure 4.7 Overall visual germination results of CLT (a) and CLT 20 (b) with radish seeds at day 150

4.5 PH Results

Figure 4.8 shows the result of pH for days 0, 45, and 90. Results increased optimum pH for all treatment by the day 90 except unamended CLT which had significantly lower pH. CLT and C treatments were more acidic compared to other treatments at day 90. CLT20 had a pH near the neutral 7 by the day 90. According to the study, increased pH near to neutral 7 is an indication of good degradation rate (Borazjani et al 2000, Mangum et al 2009).

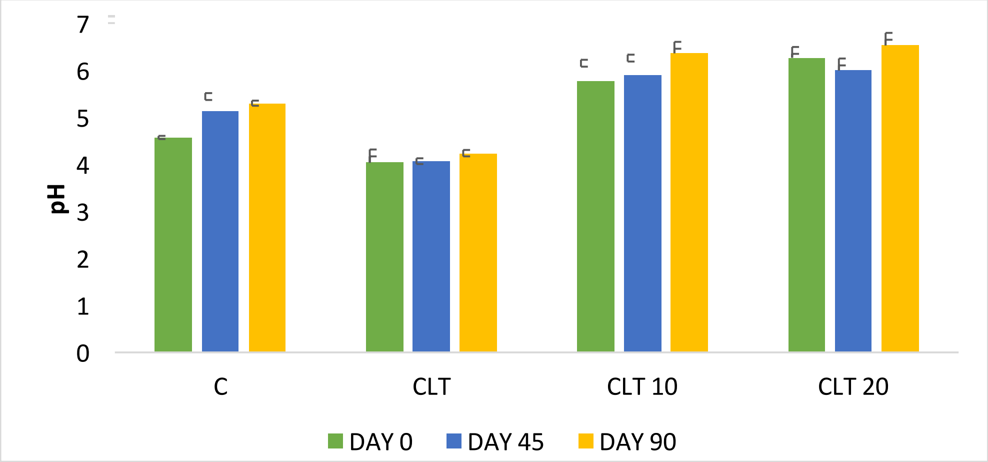


Figure 4.8 Result of pH for all treatment at day 0,45 and 90. Error bars in the figure indicate significant difference in pH at the P=0.05 level of significance.

4.6 C: N Ratio Results

All treatments showed an increase in the percentage of nitrogen by the day 90, except yellow pine sawdust (C). The treatment amended with 10% and 20% poultry litter indicated an increase in the percent carbon, but the percent carbon for CLT and C was lower at day 90. For treatments CLT, CLT10, and CLT20, the C: N ratios were decreased from day 0 to day 90. There was also a significant difference between amended and unamended treatment in C: N ratios. The treatment CLT20's C: N ratio is 31:1 at day 90.

C: N ratios are detailed in table 4.4. Also, figure 4.9 presents a graphical representation of beginning and ending C: N. These results are also in full agreement with findings of previous authors (, Mangum et al, 2009, Hatten et al, 2009 Bakhshizadeh, 2012). Again, a longer composting period could have improved this important parameter to below 30.

Table 4.4 Percent Carbon, Nitrogen and Carbon Nitrogen ratio for day 0 and 90

	Carbon%		**Nitrogen %**		**C: N**	
	Day 0	**Day 90**	**Day 0**	**Day 90**	**Day 0**	**Day 90**
C	13.692	12.178	0.08	0.08	171:1	152:1
CLT	11.622	11.594	0.0667	0.08	174:1	145:1
CLT10	14.122	15.637	0.313	0.39	45:1	40:1
CLT20	14.807	18.139	0.443	0.576	33:1	31:1

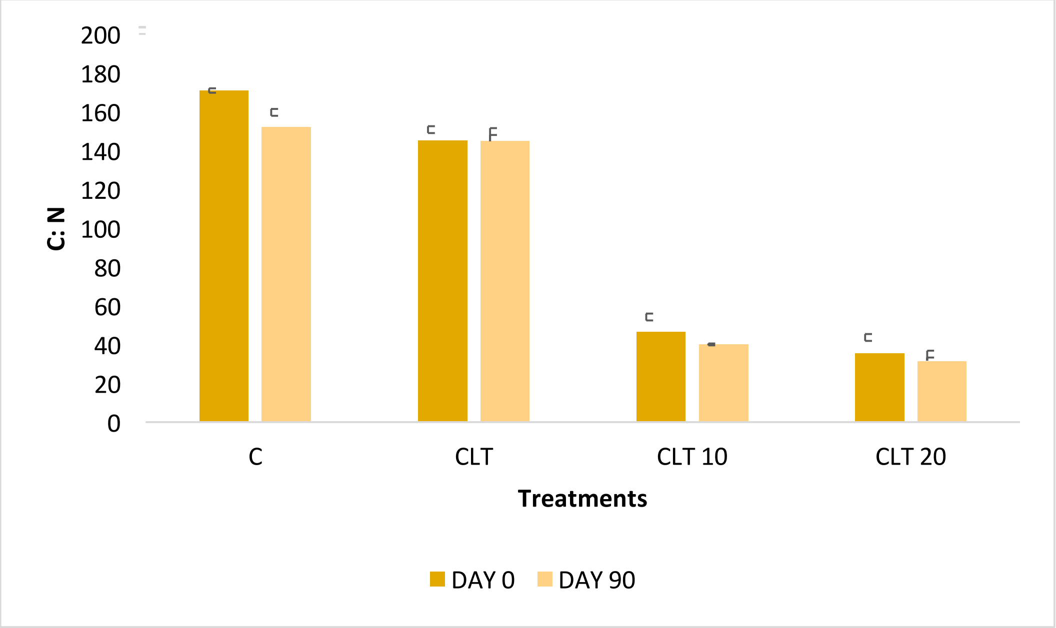


Figure 4.9 Change in Carbon to Nitrogen Ratio.

Note: Error bars indicate a significant difference in C: N ratio at the P=0.05 probability level.

4.7 Greenhouse Results

The pansy's dry weight grown in 90-day composted treatment are shown in figure 4.10. The pictures of greenhouse study of day 90 composted treatments with pansy are shown in picture 4.11 and 4.12. A few replicates of each treatment dried by end of the four weeks Figure 4.11. The weight of plant grown in CLT20 and CLT10 treatment are higher than CLT treatment. The dry weight of pansy for CLT20 and CLT treatment were the same as commercial media. Figure 4.12a, 4.12b, 4.12c, and 4.12d illustrate different appearance of plant growth in selected treatment replicates and potting media. Only a few replicates of C and CLT treatment flowered. Overall the greenhouse study results were disappointing. It showed that much longer time is needed for this type sawdust to be used as a potting media or container media.

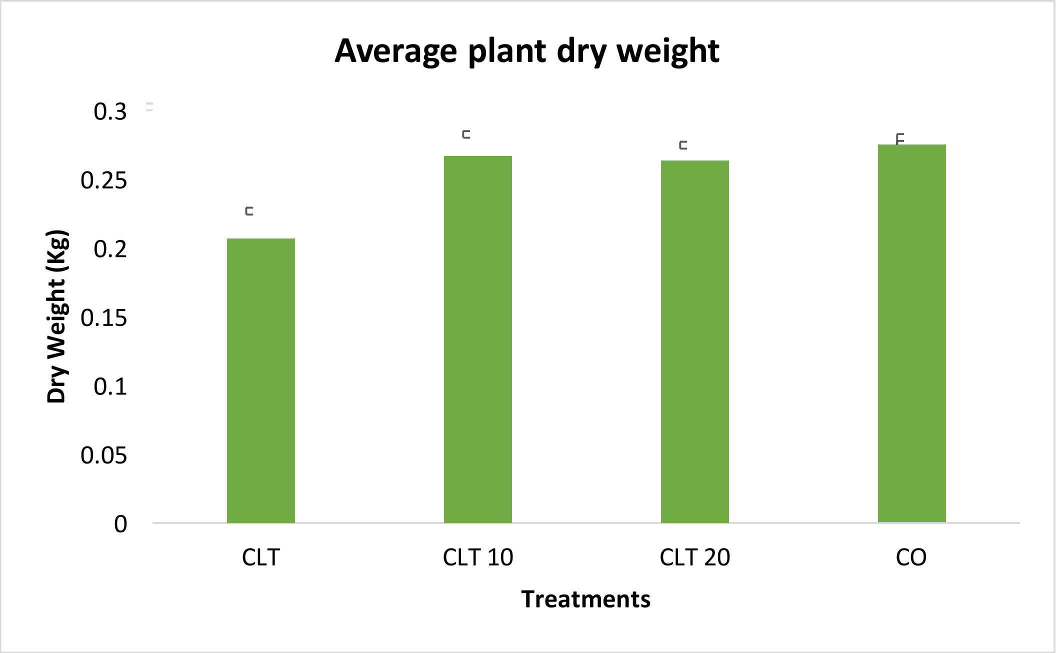
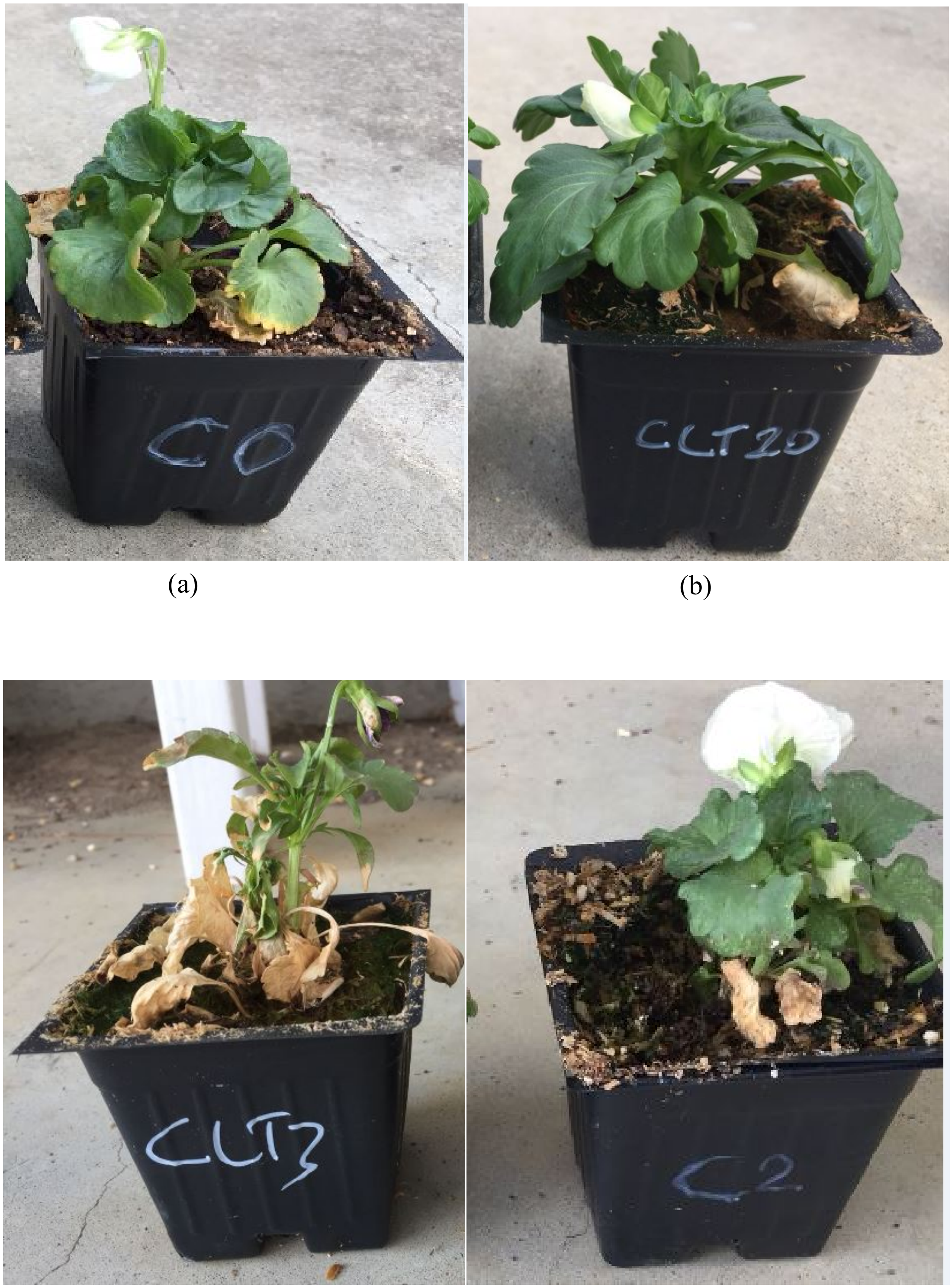


Figure 4.10 Average Plant Dry Weight.

Note: Error bars indicate a significant difference in dry weight at the P=0.05 probability level.

Figure 4.11 Pansy Growth at Day 90



(a) (b)

(c) (d)

Figure 4.12 An example of control grown in standard potting mix. Figure b is a replicate from treatment 4 (CLT20). Figure c is a replicate from treatment 2 (CLT). Figure d is a replicate from treatment 1 (C).

CHAPTER V

CONCLUSION

This research was conducted to evaluate the quick composting of CLT sawdust with different level of chicken litter, and to compare the finished products with commercial media for potting media.

Chicken litter is rich in nitrogen, and sawdust is rich in carbon. Adding chicken litter to the CLT enhanced decomposition rate and reduced bulk of wood waste significantly. Using composted product for potting media was one of the purposes of this study. However, immaturity of composted material after 90 days should be the most important factor that could prevent any adverse effect on plant growth. Microbial activity, C: N ratio, weight reduction, and pH must be measured to define stability of compost. However, it is considered that each of these parameters alone will not ensure maturity of composted material. It can be suggested that using combination of these tests could define and provide better understanding for maturity and stability of composted material. A compost could have a good C:N ratio, pH, and other nutrients but if it is not cured then composted substrates will not be suitable for growing ornamentals flowering plants such as pansies.

Regardless of very good weight loss, improved pH and significant number of microbes, it seems that a longer composting time than 90 days will be needed to ensure production of high-quality compost for either potting or composting media with CLT wood wastes.

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APPENDIX A

A.1 Nutrient Analysis

All treatment showed a drop in P and K concentration. Through the compost study, the concentration of other macronutrients (Ca and Mg) and micronutrients (Zn and Na) for most treatment decreased except CLT and CLT 10. Nutrient results are detailed in table A.1.

	C			CLT			CLT 10			CLT 20		
	Day 0	**Day 45**	**Day 90**	**Day 0**	**Day 45**	**Day 90**	**Day 0**	**Day 45**	**Day 90**	**Day 0**	**Day 45**	**Day 90**
P	55	6	3	4	3	2	221	100	131	654	583	235
K	423	68	53	20	26	11	559	283	287	706	391	208
CA	377	352	271	124	253	123	552	959	718	888	1703	1188
MG	142	88	78	15	30	17	121	186	160	284	343	240
ZN	4.2	3.5	3.47	1.5	2.6	1.8	6.0	10.6	9.7	14.8	20.8	16.5
NA	19	16	17	15	19	16	69	58	25	298	78	42

Table A.1 Nutrient Result of Treatment at day 0, 45 and 90

A.2 C: N Ratio Results at day 150

Table A.2 Percent Carbon, Nitrogen and Carbon Nitrogen ratio at day 150

Day 150	Carbon %	Nitrogen%	C: N
C	86.815	0.78	111:1
CLT	87.532	0.78	112:1
CLT10	81.203	3.26	25:1
CLT20	76.731	5.5	14:1

A.3 Chicken Litter

Chicken litters were replicated three times and placed at outside which was the same condition with compost cans (Figure A.1). The percent weight reduction of chicken litter at day 45 and 90 is shown in Figure A.2.

Figure A.1 Chicken litter (Ch) plastic cans were placed outdoor

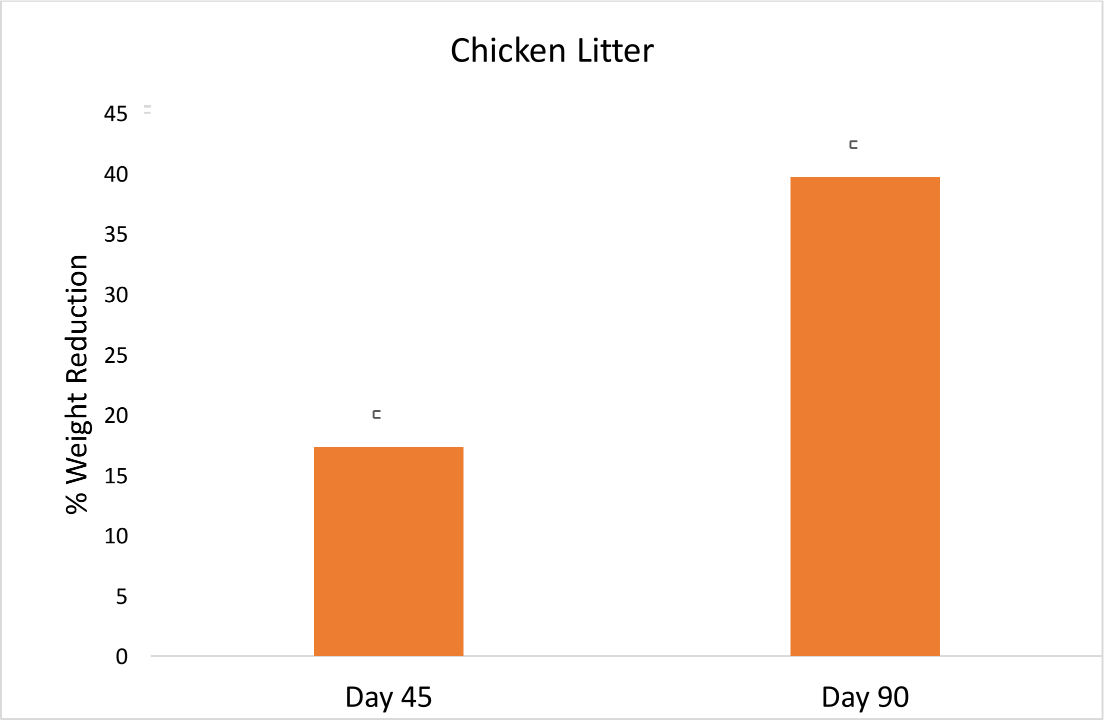

Figure A.2 Percent weight reduction of chicken litter at day 45 and 90.

Notes: Error bars indicates a significant difference between weight loss at the α=0.05 level of significance