Evaluation of Composted Poultry Litter Use in Horticulture

by

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Abstract

The U.S. poultry and egg industry is valued at billions of dollars in gross farm receipts and employs hundreds of thousands of people. A Survey by the United States Department of Agriculture in 2008 revealed that in Alabama alone, the poultry industry generates over $2 billion in gross farm receipts and employs over 78,000 people. Over the past several decades the poultry industry has expanded exponentially. With this growth comes the problem of poultry waste disposal. It is estimated that 16.6 million tons of poultry litter is produced in the United States each year and 2 million tons of litter is generated by the poultry and egg industry each year in Alabama alone. Poultry farmers face the challenge of storing this material, which occupies valuable space on their farms. Often disposal can be costly, and there are also many environmental problems which arise when large amounts of poultry litter are mishandled. Poultry producers must find a way to dispose of this manure in a way that is both economically sound and environmentally safe. The objective of this research was to evaluate the use of composted poultry litter and determine what areas of the horticulture industry that CPL can be the most beneficial. Results from these studies may help determine how composted poultry litter can be used beneficially in the landscape and container nursery industries while providing poultry producers an environmentally sound means of waste disposal. Two experiments were conducted evaluating a variety of commonly grown nursery crops for growth in alternative wood based substrates. Whole Tree (WT) and Clean Chip Residual (CCR) are potential new nursery substrates that are by-products of the forestry industry containing high wood content. Initial immobilization of nitrogen is one limitation of these new substrates; however the addition of composted poultry litter (CPL) to substrates containing high wood content could balance initial nitrogen immobilization and provide an inexpensive fertilizer source for growers. This study evaluated the growth of five woody nursery crops being grown in WT, CCR, and pinebark (PB) with the addition of CPL or peat as a substrate amendment. Results indicate that woody nursery crops can be grown successfully in WT and CCR substrates 6:1 (v:v) with CPL. Use of CPL in WT and CCR substrates provides an alternative to traditional PB plus peat based combinations in container plant production while providing poultry producers an environmentally sound means of waste disposal.

Three additional experiments involved the application of CPL to landscape annual beds and the evaluation of plant performance as well as non-point water pollution potential. The objective of these studies was to evaluate composted poultry litter as a fertilizer source for bedding plants at various rates in comparison with commercially available inorganic fertilizers for three commonly used landscape annual bedding species, 'Quartz Scarlet' verbena, 'Celebrity Red' petunia, and Dusty Miller. Raised beds were constructed and before planting 10 treatments were applied: Peafowl garden grade fertilizer 13N-5.6P-10.9K (13-13-13) at rates of 4.9 g N/m^2 (1 lb N/1000 ft^2) and 9.8 g N/m^2 (2 lb N/1000 ft^2), Polyon 13N-5.6P-10.9K (13-13-13) at rates of 4.9 g N/m^2 (1 lb N/1000 ft^2) and 9.8 g N/m^2 (2 lb N/1000 ft^2) and composted poultry litter at rates of 4.9 g

N/m^2 (1 lb N/1000 ft^2), 9.8 g N/m^2 (2 lb N/1000 ft^2), 19.6 g N/m^2 (4 lb N/1000 ft^2), 29.4 g N/m^2 (6 lb N/1000 ft^2), 39.2 g N/m^2 (8 lb N/1000 ft^2), and 49 g N/m^2 (10 lb N/1000 ft^2). A control group receiving no fertilizer application was also maintained. Soil water leachates were collected using suction cup lysimeters 0.6 m (2ft) long and 5.1 cm (2 in) in diameter with a ceramic cap 7.6 cm (3 in) long and 5.1 cm (2 in) wide. Results from these experiments provides evidence that composted poultry litter could be used as a substitute for conventional inorganic fertilizers when used at the same nitrogen rate and may also be applied at much higher rates than inorganic fertilizers resulting in plants with greater size while minimizing negative environmental impacts.

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CHAPTER I

Introduction and Literature Review

The U.S. poultry and egg industry is valued at billions of dollars in gross farm receipts and employs hundreds of thousands of people. In Alabama alone, the poultry industry generates over $2 billion in gross farm receipts and employs over 78,000 people (USDA, 2008). Over the past several decades the poultry industry has expanded exponentially. Increasing demand for low cholesterol meat products along with the recent cost saving changes in the farming industry from small family farms to large commercial farming practices have attributed to this expansion (Moore et al., 1996).

Combined value of production from broilers, eggs, turkeys, and the value of sales from chickens in 2007 was $31.9 billion, up 24% from the $25.8 billion in 2006 (USDA, 2008). Poultry production in the United States is predominately concentrated in the mid south region with Arkansas, Georgia, North Carolina, and Alabama accounting for 40 percent of the nation's poultry industry (Moore et al. 1995). 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). A conservative estimate of 16.6 million tons of poultry litter is produced in the United States each year and 2 million tons of litter is generated by the poultry and egg industry each year in Alabama alone (Edwards et al., 1995). Poultry farmers face the challenge of storing this material, which occupies valuable space on their farms. Often disposal can be costly, and there are also many environmental problems which arise when large amounts of poultry litter are mishandled (Moore et al., 1995). Poultry producers must find a way to dispose of this manure in a way that is both economically sound and environmentally safe.

The most common type of waste produced from poultry operations is poultry litter or broiler litter, which includes all floor type birds such as broiler, pullets, and floor layers. Some type of bedding or litter material is used on the floors of the poultry houses such as pinebark, sawdust, straw, paper, peanut or rice hulls, etc, depending upon locality (Moore et al., 1996). Waste from the poultry production systems includes a mixture of excreta (manure) and the bedding material listed above. During the production cycle accumulating manure becomes mixed with litter (bedding material) and at the end of the cycle both are removed together (Kelleher et al., 2002). The term poultry litter refers to the bedding material used during the poultry production cycle (materials such as straw, sawdust, wood shavings, shredded paper, and peanut or rice hulls). When manure is mixed with bedding material and removed from poultry houses it is referred to as poultry litter or broiler litter.

Some poultry production systems result in liquid poultry manures (those containing less than 150 g of dry matter kg^{-1}). Liquid poultry manures are usually limited to laying-hen operations. Caged layer manure is free from litter material and generally contains higher moisture content than manure from broiler houses. All types of manure will contain feathers, wasted food, and dead birds (Mitchell et al., 1995). Moisture content can range from 20-75% depending on moisture levels, temperature, amount and kind of litter material used, and the conditions under which the litter was stored. Typical poultry litter will have the following nutrient ranges: Nitrogen from 2.1 to 6%, Phosphorus from 1.4 to 9%, Potassium from 0.8 to 6.2%, Calcium from 0.8 to 6.1%, Magnesium from 0.2 to 2.1%, and sulfur from 0.1 to 0.8%, on a dry-weight basis (Mitchell et al., 1995). Most litter is spread raw, before composting, because of the need to dispose of the manure quickly and the time constraints of fertilizer applications due to the time consuming process of composting (Mitchell et al., 1995). For poultry litter to be used in a non-agronomic setting, composting would be necessary to ensure a stable fertilizer source that would have little odor or pathogen concerns.

Historically, poultry wastes have been used as a source of fertilizer and soil amendment in agronomic row cropping systems. Land application offers the best solution to managing large amounts of poultry litter (Moore et al., 1996). Excluding the small amounts used in animal feed, or as an alternative fuel source, almost ninety-percent of all poultry litter produced is applied to agricultural land, usually no more than a few miles from where litter is produced (Moore et al., 1995). This is usually a viable option since the majority of time poultry manure is often produced in areas where it can be utilized on neighboring farms to fertilize hay fields and pastures (Sloan et al., 1996). In a study conducted in 1995, researchers projected that in Alabama where almost 2 million tons of litter is produced, if properly handled and utilized, the nutrients in this manure could fertilize every acre of corn, wheat, and sorghum produced in the state, or 323,748 hectares (800,00 acres) of bermudagrass sod production (Mitchell et al., 1995).

Handling systems for poultry litter encompass all the operations for removing manure from the poultry houses, pre-treating, and transporting the manure to the field where it will be spread by spreading equipment (Moore et al., 1996). Upon removal from the poultry house, poultry litter may be immediately spread or temporarily stored; both posing environmental hazards. When spread on agricultural land, poultry litter is usually applied based solely on nitrogen content. Poultry litter nitrogen (N) to phosphorus (P) concentration is roughly 2:1, and long term applications to land can cause an accumulation of phosphorous. In one study, less than one half of the phosphorus contained in poultry litter was removed by Bermuda grass sod (Brink et al., 2004). Over long periods of repeated application there have been pH increases in soil and high phosphorus concentrations, regardless of the crops efficiency to use phosphorus (Grichar et al., 2005).

Over-application of poultry litter can lead to accumulation of nutrients in water bodies. Phosphorus is usually the limiting nutrient for eutrophication in fresh water bodies, rivers, lakes, and streams (Moore and Edwards, 2005). In 1996, the Environmental Protection Agency suggested that eutrophication was the main cause of impaired water sources. In northwestern Arkansas and northeastern Oklahoma, researchers studied several river systems experiencing problems due to excess phosphorus and nitrogen pollution from point and non-point sources from over use of manure as agronomic fertilizer. Another problem accentuated by over application of poultry litter near water bodies is algal blooms. Algal blooms cause taste and odor problems in drinking water and can be potentially harmful to one’s health. Increased aquatic plant growth can have many negative environmental impacts, resulting in fish kills, water pH problems (Moore and Edwards, 2005). Excessive application of poultry litter in cropping systems can also result in nitrate ($N0_3$) contamination of groundwater. High levels of $N0_3$ in drinking water have been found to cause methaemoglobinaemia (blue baby syndrome), cancers, and respiratory illnesses in humans and fetal abortions in livestock (Bitzer and Simms, 1998; Stevenson, 1986). Another concern with land application of poultry litter is the potential spread of dangerous pathogens and bacteria (Kelleher et al., 2002). Regulatory mandates have increased the demand for Best Management Practices (BMP's) that will reduce nutrient leaching on water sheds affected by excess leaching of phosphorus and nitrogen from manure holding and storage areas, and after field application (Veitor et al., 2001). Disposal of organic waste products such as poultry litter has become more and more difficult for poultry producers because of increased awareness of the potentially harmful effects that these manures can have on ground and surface water supplies (Allen et al., 1994).

Due to increased environmental awareness, poultry litter is coming under strict new state and federal regulations concerning disposal methods with respect to non-point source pollution and other environmental concerns. In 1972, the United States passed the Clean Water Act (CWA), which placed restrictions on the amount of litter and other pollutants that could be land applied. The CWA established the basic structure for regulating discharges of pollutants into the waters of the United States and placed regulating quality standards for surface waters. Initially, the CWA had little impact on poultry producers and placed few limitations on disposal practices. However, in 2003 the

EPA implemented new stricter regulations that would force large operations to manage their manure according to a nutrient management plan. Farmers with the largest operations are forced to acquire permits and new limits were placed on the amount of litter that could be spread via land application (EPA, 2003). Finding ways to properly manage the litter and dispose of it properly is essential so that the valuable nutrients in the litter can be utilized without causing negative environmental impacts.

Poultry manure contains a significant concentration of organic nitrogen due to the presence of high levels of protein and amino acids. Of the nitrogen in fresh manure, 60-80% is typically in organic form, such as urea and protein. Depending on environmental conditions, a large percentage of this organic nitrogen (40-90%) is converted to ammonia within a year. Ammonia exists as either gas (NH_3) or in an ionized state (NH_4) which is water soluable. NH_3 gas can be lost to the atmosphere while NH_4 can be transformed by microorganisms to nitrate (process called nitrification). During anaerobic digestion of poultry litter, the concentration of ammonia-nitrogen rises. Some of the anaerobic microorganisms can use ammonium ions, but an excess of ammonium can inhibit the destruction of organic compounds. Therefore, the presence of ammonium ions contributes to high pH and leads to handling, storage, and disposal issues. Minimization of ammonia content is desired for any treatment of poultry litter. Proper composting can eliminate some of these concerns and decrease ammonia content (Kelleher et al., 2002).

Poultry litter is sometimes composted before incorporation into potting mixes, landscape beds, or spreading it on crop lands and pastures. Composting is the aerobic degradation of biodegradable organic waste and is an effective and inexpensive way to stabilize organic matter (Kelleher et al., 2002; Tiquia and Tam, 2000). Composting methods include in-vessel composting with the use of rotating drums, turned windrows, forced aeration piles, static piles, and other means (Brymer, 2008). Organic materials are decomposed in an accelerated aerobic process through oxidation of carbon by microbial activity (Fritsch and Collins, 1993). The end result is a stable organic product which has been reported to improve soil quality, reduces bulk density, increases soil cation exchange capacity, and enhances populations of soil microorganisms (Fritsch and Collins, 1993). After manure has been composted, it has a more stable form of nutrients and is easier to transport and spread. Composted poultry litter is generally odorless, pathogen free, and fine-textured with a low moisture content making it easier to handle and can be used as an organic fertilizer in most situations (Kelleher et al, 2002). The main disadvantage of composting poultry litter is a decrease in total nitrogen and other nutrients during composting. Nitrification and de-nitrification, which poultry litter undergoes during composting, has been found to result in losses of 21 to 77% of the nitrogen nutrient concentration of the litter after composting (Tiquia and Tam, 2000). Equipment costs associated with composting such as windrow turners, in-vessel digesters, etc., increased labor costs, odor problems, and available land needed to store the poultry litter until composting can be completed are also cited as disadvantages (Sweeten, 1988). While nutrient losses will occur with composting, the ease of handling, odor-reduction, stabilization of nutrients, improvements in storage and handling, as well as pathogen reduction, make composted poultry litter a more desirable product in almost all situations.

Brymer (2008) evaluated composting methods of poultry litter for use in the green industry. In-vessel composting was compared to windrow composting in respect to bacteria levels, container leachate, weed germination, and plant growth. Both methods of composting resulted in compost with safe bacteria levels for human use. In one study *Impatiens wallerana* 'Fanfare' was grown in substrates containing equal amounts of either in-vessel composted poultry litter (IVPL) or windrow composted poultry litter (WRPL). Results indicate that WRPL outperformed the IVPL in plant dry weights and growth indices. Substrate leachates from WRPL were also more suitable for growing containerized crops than IVPL. In an additional study, Brymer evaluated *Hemerocallis spp*. 'Pardon Me' when grown in either IVPL or WRPL. Again, WRPL outperformed IVPL based upon plant growth indices and dry weights. Results also indicate that both methods are equally suited at eradicating potential weed seed present during the composting process (Brymer, 2008). Furthermore, based upon results from these studies, IVPL may not be suitable for production of ornamental crops without pre-plant leaching of salts.

For many years poultry farmers predominately disposed of their manure and waste by spreading it on crop and pastureland. Producers could sell their manure to area farmers as an inexpensive fertilizer source ($8 per ton, or at the cost of hauling in some instances). New regulations are placing limits on this practice but a fair amount of litter can still be applied; however, management of available lands for application is now becoming a problem. As populations continue to grow, rural areas are declining in size as cities are expanding to meet population needs. As a result, there are fewer acres of agricultural land for spreading this manure (Wolfe and Humphries, 2007). Expansion of cities and population increases could present a new avenue for poultry litter disposal in the landscape and soilless potting media industry. The horticulture industry is now a fast growing sector in agriculture, with more and more landscape and nursery operations in business, poultry producers are turning to the green industry as a means of disposing excess manure. Currently research is being conducted to find alternative uses for composted poultry litter in these different agricultural sectors and to establish in what areas poultry litter could provide the best economic and environmental benefit.

Considering the high nutrient content of poultry litter and the accessibility of the product, especially in the intense production areas of the southeastern United States, horticulture professionals, farmers, and turfgrass managers are turning to poultry litter and other organic sources as an alternative to costly inorganic fertilizer sources. The cost of inorganic fertilizers is ever increasing while U.S. fertilizer production is decreasing. Because natural gas is the primary raw material used to produce ammonia, the rise in U.S. gas prices has led to a 35% decline in U.S. ammonia production capacity and a 44% decrease in output between years 2000 and 2006. National average fertilizer prices increased 113% between 2000 and 2007 due to increases in nitrogen costs. During this seven year period, the price of ammonia, the main source of nitrogen in fertilizer production, increased 130% and the price of urea, the primary solid nitrogen fertilizer used in the U.S. rose 127% (Wen-yuan, 2007). Due to the increases in inorganic fertilizer sources, the nutrients in poultry litter are more valuable than ever.

There is a great potential for the use of organic manure type products in the landscape and homeowner sector. Increased awareness of environmental impacts from the use and manufacture of inorganic fertilizer sources has caused many homeowners to seek more environmentally friendly products. Recent trends such as "Going Green" have made the use of organic products more desirable. In a report of Georgia nurseries and landscape firms, 73% of landscape managers polled said they currently do not use composted or manure products as a fertilizer. The majority of the landscapers surveyed said however, that they do use some sort of manure based product for amending landscape beds used for annual and perennial bedding plants. No nursery polled reported using any manure-based products. About one-third of the nurseries and landscapers said they would use a manure type product if it were available and cost effective (Wolfe and Humphries, 2007). Little research has been done in the areas of using poultry litter as a primary nutrient source for landscape and nursery operations, partially due to the limited availability of the products in some areas and also the limited awareness of the cost benefits of organic fertilizers.

The majority of research with poultry litter use is concentrated on the effects of amending row cropping systems, perennial grass fields and pastureland with poultry litter. Growers of corn, wheat, sorghum, soybeans, cotton, and turfgrass systems all utilize poultry litter as a cheap and effective source of fertilizer (Evers, 1998). Application in large fields is easier with current equipment. These large field operations are usually in closer vicinity to the poultry houses, which greatly decreases the farmers shipping costs, which is the most expensive and limiting factor in the widespread use of poultry litter as a fertilizer. There is an abundance of research in this area, particularly in regard to application of poultry litter to row crop lands. Research has shown that poultry litter benefits soils by alleviating soil compaction problems. Researchers reported that the application of organic amendments to compacted soils may minimize the negative impacts of soil compaction by increasing nitrogen mineralization and availability for crops in agricultural soil by promoting better conditions for soil microorganisms to thrive (Pengthamkerrati et al., 2005).

In 1995 research began in south central Texas to evaluate poultry litter effects on coastal bermuda grass growth and development. Tests focused on the amount of nutrient infiltration into the soil profile at various depths, evaluating nutrient leaching potential. In the first two years of the study, plots fertilized with commercial inorganic type fertilizers outperformed the plots fertilized with poultry litter. In the following two years when no fertilizer was applied, plots amended with poultry litter outperformed the commercial fertilizer plots, indicating a slow release of nitrogen overtime from the poultry litter (Grichar et al., 2005). In another study by Evers in 1998, results indicated that an application rate of 3.6 metric tons per 0.4 hectare (4 tons per acre) greatly improved bermuda grass production without causing buildup of unutilized nutrients such as phosphorus (which is usually a major concern). A rate of 3.6 metric tons per 0.4 hectare (4 tons per acre) was the nutrient equivalent of applying 6.8 kg N(15 lb), 6.8 kg P (15 lb) and 13.2 kg K(30 lb) of commercial fertilizer on the same area (Evers, 1998). Because of the N-P-K ratio found in most poultry litter, nitrogen becomes the limiting nutrient for grass production, which allows the buildup of other available nutrients.

Therefore after the initial application of poultry litter, supplemental nitrogen may need to be added via commercial fertilizers or from symbiotic fixation by legumes to utilize excess nutrients in the poultry litters (Evers, 1998).

The most basic and obvious problem when reviewing research concerning poultry litter is that authors often fail to mention the nutritional content of the manure source being used, as it often varies widely from source to source. Often unreported is whether the manure was cage layer, broiler litter or poultry litter, the type and amount of bedding material used, whether the product was raw, composted, liquid, etc. all of which have an enormous impact on the physical characteristics and nutritional value of the litter. Raw manure may have a N-P-K nutritional value of 3-2-2 while after composting that same litter may have a N-P-K ratio of 1.5-3-1 (Mitchell and Tu, 2005). This difference in nitrogen concentrations will have an enormous impact on crop performance in any cropping system and should always be reported. There are also many inconsistencies in fertilizer application rates found in the literature. Some researchers state that it is safe in assuming a 0.45 kg of nitrogen per 92.9 square meters (1 lb of nitrogen per 1,000 ft^2), recommendations for inorganic fertilizer could also be used as a pound per square foot recommendation for poultry litter and other organic sources. However, different nutrient release times, and the fact that it is safer to apply higher rates of organic fertilizers than inorganic fertilizers, due to the decrease in plant damage potential, can dramatically impact proper poultry litter application rates. These problems need to be addressed and discussed when researching poultry litter.

Currently, research is aimed at the development of a sustainable poultry litter management practice to allow producers and farmers a set of guidelines for storing, composting, and applying poultry litter at a rate beneficial to the crop being grown while still protecting the areas water quality and eliminating odor and pathogen problems. Since 2004 researchers at Iowa State University have been conducting a six year study to determine the impact of poultry litter applications on nutrient uptake by crops and on surface and ground water quality. Key results so far indicate that poultry litter applied at a rate of 68 kg per 0.4 hectares (150 lbs per acre) results in lower nitrate, phosphate, and bacteria concentrations in subsurface drainage water when compared to the equivalent application rates of commercial fertilizers (Kanwar, 2004).

Another study indicates that application of aluminum sulfate or aluminum to litter has been found to decrease nutrient runoff, the main concern during long term storage and application (Moore et al., 1999). Also, application of zeolites, minerals with a micro-porous structure, has been shown to reduce odor and gas emissions from poultry operations, increasing marketablity of the manure (McCrory and Hobbs, 2001).

While there is an abundance of research dealing with poultry litter as a fertilizer for agronomic/row cropping systems, little research was found on using poultry litter commercially as a landscape fertilizer or as a nursery potting media amendment. Broiler litter was evaluated as a soil amendment in landscape perennial and annual bedding plants (Reeder et al., 1992). Use of broiler litter incorporated into annual beds as a soil amendment resulted in plants equal to or larger than plants grown with traditional fertilizers (Reeder et al., 1992). Researchers discovered that broiler litter application was adequate to produce quality plants and while the nutrient levels of the manure may not completely replace traditional inorganic fertilizer sources, it can be an inexpensive alternative and reduce inorganic fertilizer requirements while providing an outlet for broiler litter disposal (Reeder et al., 1992). Broiler litter compost ratios to peat and perlite were evaluated and a 1:3:4 ratio of broiler litter compost: peat: perlite produced the best annual and perennial plants from nursery grower's standpoint (Allen et al., 1994). Consumer perceptions of composted broiler litter were also studied by Behe et al. (1991). Consumers were polled on their thoughts and concerns with using composted broiler litter as a soilless potting mix and asked if they would be willing to use a product that contained mostly composted broiler litter. They were later given three different potting mixes and rated the plants being grown in each mix on factors including water needed, foliar color, unpleasant odor, and overall plant health. Participants in the study rated the potting mixes with composted broiler litter as high or higher than 2 commercially available potting mixes based on perceived water holding capacity, plant foliar color, absence of unpleasant odor, and general plant health. Results indicated that a potting mix comprised of predominately composted broiler litter does not appear to have an odor problem, but it was more of a perceived odor problem by the consumers (Behe et al., 1991). Composted poultry litter has also been shown to improve growth in roses planted in the landscape (Warren and Safly, 1990).

Altland (2002) evaluated fertilization practices for landscape bedding plants. Fertilizer treatments were applied to landscape bedding plants in raised beds simulating an urban landscape. Fertilizers evaluated included: Osmocote 14-14-14 and 17-7-12 controlled release fertilizers (CRF's), 13-13-13 and 15-0-15 granular water-soluble (GWS), and industry practice treatment (IP) of incorporating a CRF preplant and topdressing a GWS fertilizer postplant, and an organically-based fertilizer (OBF) composed of recycled newspaper and raw chicken manure. Data collected included foliar color ratings, growth index, foliar nitrogen (% of dry weight), shoot dry weight, and inorganic N recovered in soil solution from suction-cup lysimeters. Results indicate that CRF's generally improved foliar color and plant size compared to GWS fertilizers, while reducing total-N recovered in soil-water. OGFs containing poultry litter generally resulted in larger, more attractive (higher foliar color ratings) plants than those fertilized with any inorganic fertilizer tested. While plants were larger and more attractive when fertilized with OGF, high salt levels from poultry litter caused wilting and/or mortality in some plants early in experiments and resulted in high levels of total-N recovered from soil-water. One possible way to alleviate these problems is composting the litter prior to use in the landscape.

Composted poultry litter has high potential in the container nursery industry, and in particular, as an amendment with high wood containing nursery container potting substrates or as a sphagnum peat moss replacement. Turkey litter has shown to be a beneficial component in nursery production. Tyler et al. (1993a, 1993b, 1993c) evaluated turkey poultry litter chemical, physical and thermal properties when used in combination with pinebark as a substrate and how it affected plant growth. Results indicate that substrates were favorable when poultry litter was incorporated in low volumes. Results by Fulcher et al (2002) also indicated that substrates containing composted poultry litter at low volumes were generally beneficial to plant growth. Poultry litter provides macro and micronutrients needed for plant growth, which makes it a viable option for use in container substrates. While results are generally favorable, poultry litter has characteristically high soluble salt levels, which can damage sensitive crops (Allen et al., 1994). Testing is needed prior to amending any substrate with composted poultry litter to ensure a biologically stable compost, and fresh manure is never recommended due to high ammonia and salt levels, as well as the presence of pathogens and diseases (Midcap, 1995).

Container substrate components have been the focus of much research since the large expansion in the industry in the 1950's (Davidson et al., 2000). Prior to the 1960's, field soil and peat were the primary components used in container-plant production. However, undesirable physical properties and potential pathogen and disease problems associated with the use of field soil led researchers to evaluate pinebark as a potential new substrate component (Lunt and Kohl, 1956; Scott and Bearce, 1972). Pinebark is removed from trees prior to lumber processing and in the past was stockpiled at lumber facilities. Lumber facilities needed a means for bark disposal when pinebark began to accumulate. In the 1970's researchers discovered that bark had ideal physical and chemical properties, was inexpensive, readily available, pathogen free, and was ideal for horticultural applications (Airhart et al., 1978; Brown and Pokorny, 1975; Cotter and Gomez, 1977; Natarella, 1976; Pokorny and Delaney, 1976). Today nursery and greenhouse substrates in the U.S. are composed primarily of aged pinebark and Canadian sphagnum peat moss. Pinebark and peat moss are ideal because they are largely inert, pathogen free, and have been readily available in the past (Boyer, 2008).

In recent years however there has been a consistent decline in availability of pinebark. Due to reduced domestic forestry production, increased importation of logs (with no bark), increased in-field harvesting (leaving bark on the forest floor rather than at the mill), and the use of pinebark as a source of fuel, what was once a forestry waste product is now a valuable commodity (Lu et al., 2006). This reduction in pinebark supplies along with increased shipping costs has made pinebark hard to find for some growers. Costs associated with shipping peat from Canada or Europe could make peat a cost-prohibitive component of greenhouse substrates. Shipping to the U.S. from Canada can cause peat moss to be more than half the cost of total growing material (Boyer, 2008).

Another problem associated with the use of peat moss is that peat is a slowly renewable resource. Some peat bogs in Canada and Europe will be closed within the next decade due to over-harvesting (Carlile, 2004). As a result of these major changes in the industry, researchers continue to seek new possible alternatives that could replace pinebark and peat as the main components for nursery and greenhouse production.

Recent research has identified Clean Chip Residual (CCR) as a potential substrate substitute for pinebark and peatmoss (Boyer et al., 2008). CCR is a by-product of forestry production process of thinning pine plantings using mobile in-field equipment when a plantation reaches 10-15 years in age. In-field harvesting results in two products Clean Chips (used for making paper products) and CCR (everything else, including wood, needles, and bark). CCR is comprised of approximately 50% wood, 40% bark, and 10% needles and is either sold for boiler fuel or left in the field and spread across the harvesting area. When sold as fuel, CCR is valued at \$18-24/ton (\$3 to \$4/yd^3). When compared to the cost of pinebark (\$12 to 20/yd^3) and the cost of peat (around \$70/yd^3), CCR has the potential to provide significant savings to producers (Boyer, 2008). Studies by Boyer et al. (2008) indicate plants grown in CCR grew as well or better than plants grown in standard pinebark peatmoss combinations.

Another potential substrate material is *WholeTree. WholeTree* (WT) is composed of the entire shoot portion of the tree and contains around 80% wood fiber depending on the age of the tree harvested. *WholeTree* can be obtained from low-value biomass that is acquired during pine plantation thinning, much like CCR, or in some instances, when a pine plantation is clear cut in order to replant (Boyer, 2008). Studies by Fain and Gilliam (2006) indicate that annual vinca (*Catharanthus roseus*) grown in WT had similar growth to plants grown in PB. Fain et al. (2008) reported WT composed of three species of pine could each be successfully used as a growth substrate for annual vinca. Fain et al. (2006) evaluated WT in the production of herbaceous greenhouse crops (marigold, *Tagetes patula* 'Little Hero Yellow'; lantana, *Lantana camara* 'Lucky Red Hot Improved'; and petunia *Petunia x hybrida* 'Dreams Pink'). Plants were grown in 100% WT and ground with a hammermill to three different screen sizes and mixed on a v:v basis with peat moss and compared to nursery standard peat moss blends. In general, plants grown in WT substrates were smaller than plants grown in standard blends, but plants increased in size with increasing peat moss percentage.

Wright and Browder (2005) demonstrated that with proper nutrition and irrigation, ground pine logs are comparable to pinebark as a container substrate. In this study root growth of Japanese holly (*Ilex crenata* ‘Chesapeake’), azalea (*Rhododendron obtusum* ‘Karen’) and marigold (*Tagetes erecta* ‘Indica Gold’) was more extensive in ground pine wood chips than in aged pinebark. Results also show that these high wood substrates exhibited acceptable pH ranges, had no toxic nutrient levels, and no excessive shrinkage was observed.

One major concern associated with the use of a wood based substrate is the initial immobilization of nitrogen. Reports indicate that substrates containing high wood content often require higher fertilizer applications to achieve similar plant growth as standard substrates (Wright et al., 2008). Use of composted poultry litter in high wood based substrates could potentially balance the initial nitrogen immobilization. Composted poultry litter also has potential to provide growers with a peat moss alternative. Poultry litter co-composted with sawdust was shown to grow the largest marigold (*Tagetes patula* 'Bonanza Yellow') and provide a favorable alternative to peatmoss (Freeman and Cawthon, 1999). Results from this study also indicated that composted poultry litter has similar physical properties to peat moss. Boyer et al. (2006) tested substrates composed up 50% to 100% whole pine trees (*Pinus taeda*) for the production of container grown lantana (*Lantana camara*) in combinations with peat and poultry litter compared to a pinebark:sand substrate. Results indicate that the poultry litter treatments with high wood content were statistically similar to the wood: peat and pinebark: sand combinations.

Based upon current and past research, poultry litter could become a valuable commodity in the horticulture industry. Poultry litter has benefits when used in the landscape and in soilless container substrates, but it also has limitations. Transportation costs are the main problem is mass marketing poultry manure nationally because moving manure long distances results in high transportation costs, and the cost-saving advantages of using poultry litter become mute (Grichar et al., 2005). In areas of intense poultry production, such as the southeastern U.S., litter could be attained at a low cost in most situations. Transportation costs would be negligible considering the close proximity of poultry operations in these areas. An additional problem is the variability in nutrient content from source to source and the temporary odor and pathogen problems during storage or after application make it a less desirable nutrient source for some homeowners. Composting eliminates most odor and pathogen problems, and generally provides a nutritionally stable product. Even after composting, nutritional analysis is needed before use in the landscape or in a container substrate. Most authors conclude that while poultry litter will never replace commercial fertilizers as a whole, it can be a cost effective source of fertilizer for plants while providing an outlet for poultry farmers to dispose of poultry waste. The problem with current disposal methods such as mass application to farm and pasturelands, is the potential for negative environmental effects that large quantities of manure have on local ground and surface water supplies. When managed properly, poultry litter is the most valuable of all animal manures, having the highest concentrations of essential nutrients needed for plant growth.

Due to the excess of poultry litter production and the inevitable expansion of the poultry industry, research is needed to develop environmentally sound disposal methods, while still providing crops an efficient and economical nutrient source. Based upon past and current research, the production of nursery and greenhouse crops in alternative substrates and amendments such as composted poultry litter could be a viable option. Research also indicates that composted poultry litter can be used effectively in the landscape and provide landscapers and homeowners with an inexpensive, environmentally friendly supplement or alternative to costly inorganic fertilizers. Slight changes in production practices are needed, but these changes should be minimal. Composted poultry litter has the potential to provide a positive economic benefit to the horticulture industry by providing a fertilizer source, landscape amendment, and container substrate alternative that is locally produced, sustainable, and environmentally sound.

Research is needed to determine what areas of the horticulture industry that composted poultry litter can be most beneficial. The objective of this research was to determine how composted poultry litter can be used beneficially in the landscape and container nursery industries while providing poultry producers an environmentally sound means of waste disposal. Results from these studies indicate that composted poultry litter may have potential as a valuable alternative to inorganic fertilizers and provide a suitable substrate supplement in containerized ornamental crop production.

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CHAPTER II

Evaluation of Composted Poultry Litter as a Substrate Amendment for Whole Tree, Clean Chip Residual, and Pinebark for Container Grown Woody Nursery Crops

Abstract

Whole Tree (WT) and Clean Chip Residual (CCR) are potential new nursery substrates that are by-products of the forestry industry containing high wood content. Initial immobilization of nitrogen is one limitation of these new substrates; however the addition of composted poultry litter (CPL) to substrates containing high wood content could balance initial nitrogen immobilization and provide an inexpensive fertilizer source for growers. This study evaluated five woody nursery crops being grown in WT, CCR, and pinebark (PB) with the addition of CPL or peat as a substrate amendment. Results indicate that woody nursery crops can be grown successfully in WT and CCR substrates 6:1 (v:v) with CPL. Use of CPL in WT and CCR substrates may provide an alternative to traditional PB plus peat based combinations in container plant production while providing poultry producers an environmentally sound means of waste disposal.

Introduction

Pinebark (PB) and PB plus peat combinations are the predominant substrate components for container plant production in the southeastern United States (Boyer et al., 2008). Reduced forestry production in the United States paired with the increased use of

PB as a fuel source is reducing the availability of PB (Lu et al, 2006). The growing concern over future availability of PB, high shipping costs associated with peat and the argument that peat is a relatively non-renewable resource, has led to the exploration for alternatives to these two commonly used substrate components (Boyer et al., 2008; Fain et al., 2008).

Whole Tree (WT) consists of entire pine trees (*Pinus taeda* L.) which are harvested from pine plantations at the thinning stage, chipped whole and later hammermilled through specific screen sizes based upon crop specification (Fain et al., 2008). Whole Tree (90% wood fiber) is made up of wood, bark, limbs, needles, cones, and is used fresh after grinding. Studies suggest WT can be used successfully in production of greenhouse crops (Fain et al., 2007; Fain et al., 2008).

Mobile field equipment is now being used for in-field pine tree harvesting operations which process trees into ‘clean chips’ for pulp mills, leaving behind a residual material composed of about 50% wood, 40% bark, and 10% needles (Boyer et al., 2008). This material, referred to as ‘clean chip residual’ (CCR) is either sold as boiler fuel or spread across the harvesting area. CCR accounts for about 25% of the total biomass harvested. With millions of acres in the southeast in forestry production, CCR has the potential to provide an economical and sustainable substrate alternative for the nursery industry (Boyer et al., 2008).

The major concern associated with the use of a wood based substrate is the initial immobilization of nitrogen. Reports indicate that substrates containing high wood content require higher fertilizer applications to achieve similar plant growth as standard bark or peat based substrates (Gruda et al., 2000; Jackson et al., 2006; Wright et al., 2008). Use of CPL in wood based substrates could balance the initial nitrogen immobilization while providing poultry farmers a new outlet for the growing problem of waste disposal.

One of the problems in modern agricultural operations is the large amount of waste generated by intense animal production in concentrated areas. Historically, land application was the preferred method of poultry waste disposal with almost 90% of all poultry litter being applied to agricultural land (Daniel et al., 1995). EPA regulations now require larger poultry operations (> 100,000 birds) or operations within close proximity to lakes, streams, rivers, ground-water supplies, etc., to obtain permits and dispose of manure according to a nutrient management plan (NMP) (EPA, 2008). For example, the average livestock operation in the Mid-Atlantic states would have to increase the amount of land used for spreading animal manures from 28 to 161 hectares (69 to 398 acres) in order to meet a nitrogen-based application standard (McBride and Key, 2003). In areas where poultry production is intense and concentrated, such as in the southeastern United States, excess manure still exists and limits placed on the amount of litter that can be land applied on an annual basis leaves poultry producers in need of new economical ways to safely dispose of this waste. Typical poultry litter will have the following nutrient ranges: Nitrogen from 2.1 to 6%, Phosphorus from 1.4 to 9%, Potassium from 0.8 to 6.2%, Calcium from 0.8 to 6.1%, Magnesium from 0.2 to 2.1%, and Sulfur from 0.1 to 0.8%, on a dry-weight basis (Mitchell et al., 1995). Nutrients present in poultry manure can provide an economical alternative to costly inorganic fertilizers and soil amendments. Fuel costs associated with importing peat from Canada are decreasing grower's profit margins (Fain et al., 2007). As fuel costs increase fertilizer becomes more expensive. Fertilizer prices rise with the cost of natural gas which is the primary raw material used to produce ammonium nitrate (Wen-yuan, 2007). National composite fertilizer prices increased 113% between 2000 and 2007 due to increases in nitrogen costs. During this seven-year period the price of ammonium nitrate, the main source of nitrogen in fertilizer production, increased 130% and the price of urea, the primary solid nitrogen fertilizer used in the US, rose 127% (Wen-yuan, 2007). The USDA Economic Research Service reported a 20% rise in national fertilizer prices in 2007 and an 18% increase at the end of 2008. As fertilizer prices continue to rise, it is important to search for cost saving alternatives to conventional fertilizers. Poultry litter has higher concentrations of nutrients than other animal wastes, is relatively dry (easily mixed with substrates), and is totally collectable (Stephenson et al., 1990). Adding CPL to PB, WT, or CCR substrate could provide the nursery industry with a valuable substrate component and a low cost nutrient supplement while providing poultry producers with an environmentally friendly means of waste disposal. Research has shown that composted organic material has the potential to improve the physical and chemical properties of container substrates (Hemphill et al., 1984; Tyler et al 1993a). In studies by Bilderback and Fonteno (1991), growth of *Cotoneaster dammeri* were improved when grown in a substrate composed of PB, rockwool, and CPL when compared to plants grown in substrates containing only PB. In a study by Tyler et al. (1993b) *Cotoneaster dammeri* C.K. Schneid. 'Skogholm' and *Hermerocallis* sp. 'Red Magic' grew as well in substrates amended with composted turkey litter as plants grown in a 100% pinebark substrate.

The objective of this study was to evaluate WT, CCR and PB with the addition of CPL as a substrate for production of container-grown nursery crops.

Materials and Methods

Experiment 1

Experiment 1 was conducted at the Auburn University Ornamental Horticulture Research Center, located in Mobile, Al. Five species (*Rhododendron* x 'Iveryana' (azalea), *Buxus sempervirens* L. (boxwood), *Ilex crenata* Thunb. 'Compacta' (holly), *Loropetalum chinense* Oliv. 'Chang's Ruby' (loropetalum), and *Ternstroemia gymnanthera* Thunb. (ternstroemia)) were transplanted from cell pack liners (72, 48, 38, 50, and 50 cell pack liners, respectively) into #1 containers on 31 May 2007, placed in full sun and over-head irrigated as needed. Treatments consisted of nine substrates composed of varying ratios of PB, WT, CCR, and CPL (Table 1). Treatments included WT and CPL (6:1 v:v) (WT:CPL), CCR and CPL (6:1 v:v) (CCR:CPL), PB:CPL (6:1 v:v) (PB:CPL), 100% WT, 100% CCR, 100% PB, WT:Peat (6:1 v:v) (WT:Peat), CCR:Peat (6:1 v:v) (CCR:Peat), and PB:Peat (6:1 v:v) (PB:Peat). Whole Tree and CCR used in this study were processed to pass a 0.64 cm (0.25 in) and 0.95 cm (0.375 in) screen, respectively using a swinging hammer mill (No. 30 C.S. Bell, Tifton, OH). Fresh poultry litter used was obtained from Greenville, AL and was composted in an in-vessel rotating drum digester (BW Organics, Inc. Sulphur Springs, TX) for two weeks until temperature fluctuations indicated that the material was fully composted. Nutrient content of CPL based on analysis by Brookeside Laboratories Inc. (New Knoxville, OH) was 2.5% nitrogen, 1.4% phosphorous, and 2.3% potassium on a wet weight (as is) basis.

Each substrate treatment was pre-plant incorporated with Harrell's (Harrell's Fertilizer Inc., Sylacauga, AL) 18N-2.6P-9.9K (15-6-12) (8 to 9 month formulation) at 10.7 kg/m^3 (18 lb/yd^3), 1.2 kg/m^2 (2 lb/yd^3) gypsum and 0.9 kg/m^2 (1.5 lb/yd^3) Micromax (The Scotts Co., Maryville, OH). Plants were arranged by species in a randomized complete block design with eight single plant replications.

Pour-through extractions were conducted at 7, 15, 30, 60, 90, 120 and 180 days after transplanting (DAT) and analyzed for pH and electrical conductivity (EC) using the Virginia Tech pour-through technique (Wright, 1986). Subjective foliar color ratings were taken at 60 and 120 DAT on a scale of 1 to 5 where 1 = severe chlorosis, 2 = moderate chlorosis, 3 = slight chlorosis, 4 = light green, and 5 = dark green. Growth indices [(height + width1 + width2)/3] were taken at 120 and 340 DAT, and shrinkage measurements (measured in cm from the media surface to the top of the pot) were taken on boxwood at 120 DAT and 340 DAT. Root ratings were taken by rating root coverage of the outer surface of the root ball at 340 DAT on a scale of 1 to 5 with 1 = no visible roots, 2 = 25% of surface covered with roots, 3 = 50% root coverage, 4 = 75% coverage, and 5 = 100% coverage.

Recently matured, current season terminal shoots (5.1 to 7.6 cm (2-3 in)) (11) were sampled from ternstroemia at 340 DAT. Foliar samples (four replications per treatment) were analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), sodium (Na), Copper (Cu), and zinc (Zn). Foliar N was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Data were analyzed using Duncan's Multiple Range test ($P \leq 0.05$) using a statistical software package (SAS Institute version 9.1, Cary, NC).

Experiment 2

Experiment 2 was conducted at the Auburn University Ornamental Horticulture Research Center, in Mobile, Al. Materials and methods for experiment 2 were similar to experiment 1 with the following exceptions. Five species (*Rhododendron* x 'Amelia rose' (azalea), *Buxus sempervirens* L. (boxwood), *Ilex crenata* Thunb. 'Compacta' (holly), *Loropetalum chinense* Oliv. 'Chang's Ruby' (loropetalum), and *Ternstroemia gymnanthera* 'Bronze Beauty' Thunb. (ternstroemia)) were transplanted from cell pack liners (72, 48, 38, 50, and 50 cell pack liners, respectively) into #1 containers on 17 April 2008, placed in full sun and over-head irrigated as needed. Substrate treatments were similar to experiment 1. Fresh poultry litter used was obtained from Greenville, AL and was composted in an in-vessel rotating drum digester (BW Organics, Inc. Sulphur Springs, TX) for two weeks until temperature fluctuations indicated that the material was fully composted. CPL was analyzed by Brookside Laboratories Inc. (New Knoxville, OH) and analysis showed 2.3% nitrogen, 1.5% phosphorous, and 2.3% potassium on a wet weight (as is) basis.

Substrate air space (AS), container capacity (CC), and total porosity (TP) were determined following procedures described by Bilderback et al. (1982). Substrate bulk density (BD) (measured in grams per cubic centimeter) was determined from 374.5 cm^3 samples dried in a 105° C forced air oven for 48 h. Substrates were analyzed for particle size distribution (PSD) 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 0.11mm sieve collected in a pan. 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).

Pour-through extractions were conducted at 7, 30, 60, 90, 120, 285, and 390 days after transplanting (DAT) and analyzed for pH and electrical conductivity (EC) using the pour through technique (Wright, 1986). Subjective foliar color ratings were taken at 60 and 120, and 390 DAT on a scale of 1 to 5 where 1 = severe chlorosis, 2 = moderate chlorosis, 3 = slight chlorosis, 4 = light green, and 5 = dark green. Growth indices [(height + width1 + width2)/3] were taken at 60 and 390 DAT, and shrinkage measurements (measured in cm from the media surface to the top of the pot) were taken on boxwood at 7, 30, 60, and 390 DAT. Root ratings were taken by rating root coverage of the outer surface of the root ball at 390 DAT on a scale of 0 to 10, 0 = 0% of surface covered with roots, 10 = 100% of the rootball surface covered with roots. Data were analyzed using Duncan's Multiple Range Test ($P \leq 0.05$) using a statistical software package (SAS Institute version 9.1, Cary, NC).

Results

Experiment 1

pH and EC. Addition of CPL tended to increase pH while peat caused a decline in pH (Table 1.1). Initial data at 7 DAT showed that pH levels for PB (3.8), CCR (4.7), and WT (5.2) were increased to pH levels of 5.8, 6.7, and 6.9 respectively when CPL was added to the respective substrates. Conversely, addition of peat tended to lower pH for PB (3.8 to 3.7), CCR (4.7 to 4.2) and WT (5.2 to 4.3). pH levels for all substrates amended with CPL declined over time; however pH levels at the end of the study were within the desired range (4.5 to 6.5) (Yeager et al., 2007). However, substrates with peat added or 100% WT, CCR, or PB had unacceptable pH levels at 180 DAT (less than 4.5).

Electrical conductivity (EC) levels were initially high (7 DAT) in WT, CCR, and PB substrates amended with CPL (1.3, 1.2, and 1.6 dS/m respectively) (Table 1.1). However by 30 DAT all CPL treatments were within the recommended range (0.5 to 1.0 dS/m) with the exception of PB:CPL which remained slightly higher (Yeager et al., 2007). At 60 DAT all CPL treatments had acceptable EC levels and remained within an acceptable range for the duration of the study. Substrates amended with peat had slightly higher EC levels than 100% substrates (WT, CCR, and PB) which had acceptable EC levels throughout the study. In general, CPL treatments had the highest pH and the highest EC throughout the study. pH levels of substrates amended with CPL were more favorable for plant growth than 100% WT, CCR, and PB or substrates containing peat which remained very acidic throughout the study. While high EC levels may be a concern for more sensitive crops, the majority of woody nursery crops would not be affected by the EC levels exhibited in CPL treatments which peaked at 1.6 dS/m and declined quickly.

Growth Indices (GI). Growth indices data [(height + width1 + width2)/3] at 120 DAT indicated that hollies were larger when grown in CCR:CPL, PB:CPL, 100% WT, 100% CCR, or CCR:Peat (Table 1.2). At 340 DAT hollies grown in 100% WT, CCR, or PB as well as CCR:Peat grew the largest; however growth was statistically similar to all other treatments except WT:CPL and PB:Peat which were smaller (Table 1.2). At 120 DAT boxwood gown in CCR:CPL were larger than plants in all other substrates, a trend that continued at 340 DAT. The least growth in boxwood occurred in substrates containing 100% PB or PB:Peat which may be attributed to low pH levels. Loropetalum were larger in substrates containing 100% CCR or CCR:Peat at 120 and 340 DAT while the least growth occurred in WT:CPL. Azaleas grown in substrates containing 100% CCR were the largest at 120 DAT; however, by 340 DAT growth indices of plants grown in 100% CCR were statistically similar to WT:Peat and CCR:Peat. No differences were observed in the growth of ternstroemia in any substrate throughout the study.

Foliar Color Ratings (FCR). Foliar color ratings (FCR) were similar among all treatments in holly at 60 and 120 DAT (Table 1.3). At 60 DAT, boxwood grown in WT:CPL, CCR:CPL, PB:CPL, 100% WT, 100% CCR, WT:Peat, and CCR:Peat had slightly higher FCR than other treatments, however at 120 DAT, no significant differences existed. Loropetalum FCR were highest in 100% CCR at 60 DAT; however by 120 DAT, 100% WT received the highest ratings. Azaleas grown in WT:Peat received the highest FCR at both 60 and 120 DAT. Azaleas had the lowest FCR in treatments containing CPL, possibly due to higher pH levels. Ternstroemia FCR was similar for plants grown in 100% WT, CCR, PB, PB:Peat, and CCR:Peat and this trend continued at 120 DAT.

Root Ratings. Hollies grown in substrates containing CPL had the lowest root ratings and root ratings were statistically similar among all other treatments (Table 1.4). Boxwood root ratings were highest in CCR:CPL and the lowest root rating occurred in substrates containing PB:Peat. Root ratings in loropetalum, azalea, and ternstroemia were all lowest in WT:CPL; however, all other treatments had root ratings similar to the traditional PB:Peat substrate.

Shrinkage. Shrinkage measurements were all similar with the exception of WT:CPL and CCR:CPL which had more shrinkage than any other treatment at 340 DAT (Table 1.4) possibly due to further decomposition of the WT and CCR. Interestingly, PB:CPL substrates had the least shrinkage of any treatment, even less than PB:Peat combination (3.6 to 4.3). High wood substrates (WT and CCR) had more shrinkage in general than treatments containing PB. However, similarities between 100% WT, CCR, and PB indicate that the use of high wood substrates alone does not increase media settling due to wood decomposition.

Tissue Nutrient Content. Tissue nutrient content of ternstroemia was similar among treatments for K, Fe, Cu, and Zn (Table 1.5). In general, all treatments contained nutrient contents higher than or equal to the sufficiency range for each nutrient level tested. Foliar N tended to be highest in 100% WT, 100% CCR, and 100% PB, as well as in WT:Peat and CCR:Peat. Treatments containing CPL also tended to have the lowest foliar N. Foliar P levels were highest in PB:CPL and CCR:Peat, however CCR:Peat P levels were similar to other treatments.

Experiment 2

Physical Properties. All substrates had acceptable air space (AS) except substrates containing PB, which had a higher than recommended AS (10-30%) (Table 2.1). AS tended to increase with increasing particle size. Container Capacity (CC) of all substrates were in the acceptable ranges (45-65%) (Yeager et al., 2007) except for PB:CPL and 100% PB which were slightly lower. Total porosity results were within acceptable ranges for all substrates tested. Bulk density (BD) results indicated that all substrates had acceptable BD with the exception of CCR:Peat, which was slightly lower than the recommended range (0.19 to 0.70 g/cm^3) (Yeager et al., 2007).

Particle Size Analysis. Substrates containing PB had a higher component of large particles and fewer medium and fine particles than any of the other substrates (Table 2.2). 100% CCR had the largest percentage of medium particles. WT:Peat had a higher percentage of fine particles than other substrates, but were similar to 100% WT and CCR. In general, 100% WT and CCR substrates had predominately medium sized particles.

pH and EC. Similar to experiment 1, addition of CPL tended to increase pH while the addition of peat to substrates tended to decrease pH (Table 2.3). At 7 DAT the addition of CPL increased pH levels of WT (5.5 to 7.4), CCR (4.8 to 7.4) and PB (4.2 to 6.9). Conversely, peat decreased pH in WT, CCR, and PB substrates to levels of 4.6, 4.1, and 4.0, respectively. pH levels generally tended to decrease in all substrates over time, and by 60 DAT, most substrates were within the desired range for container-grown nursery crops (4.5 to 6.5) (Yeager et al., 2007). Substrates were within acceptable ranges until 285 DAT when all substrates without CPL dropped below desired levels, a trend that continued at 390 DAT.

As in experiment 1, at 7 DAT EC levels were initially high in substrates containing CPL (Table 2.3). However, by 30 DAT, all EC levels were within desired ranges (0.5 to 1.0) (Yeager et al., 2007) with the exception of PB:CPL which remained slightly higher. After 60 DAT, EC began to gradually decline in all substrates, possibly due to depletion of fertilizer. While all EC levels declined over time, substrates containing CPL generally had the highest EC levels all of substrates until 285 DAT when almost all substrate EC levels leveled off.

Growth indices (GI). At 60 DAT, GI indicated that hollies grown in PB:CPL were larger than hollies grown in all other treatments, while hollies grown in WT:CPL had the lowest GI (Table 2.4). By 390 DAT, hollies grown in PB:CPL substrate continued to be larger than hollies grown in all other substrates. GI of boxwood at 60 DAT were generally similar among all substrates. By 390 DAT, boxwood grown in WT:CPL and CCR:CPL had a higher GI than boxwood grown in all other substrates, possibly due to the higher pH levels of these substrates. Loropetalum showed little difference in growth at 60 DAT, however WT:CPL, 100% WT, 100% PB and all substrates containing peat tended to have higher GI. By 390 DAT, substrates containing CPL along with 100% PB and PB:Peat substrate had higher GI than most other substrates. Azalea GIs at 60 DAT indicated that 100% WT, 100% PB, and all substrates containing peat were largest, possibly due to the lower pH of these substrates. By 390 DAT, 100% PB, 100% WT, and all substrates containing peat grew larger azaleas than any other treatment, while azaleas grown in substrates containing CPL had the lowest GI. Few statistical differences were observed in ternstroemia at 60 DAT, however at 390 DAT ternstroemia were largest in 100% WT and all substrates containing peat. Ternstroemia in substrates containing CPL tended to have the lowest GI, with the exception of PB:CPL which was similar to the PB:Peat nursery standard.

Foliar Color Ratings (FCR). No differences were observed in FCR of holly at 60 or 120 DAT (Table 2.5). Only slight differences occurred at 390 DAT, with WT:CPL, WT:Peat, and PB:Peat having slightly lower FCR than other treatments, however all substrates generally performed similarly. Small differences were observed in boxwood FCR at 60 DAT, however by 120 DAT, there were no differences in FCR among boxwoods in any substrate. By 390 DAT, again few differences were observed. Generally boxwoods grown in substrates containing CPL tended to have a higher FCR than boxwoods grown in other substrates, however these differences were minimal. At 60 and 120 DAT loropetalum tended to have higher FCR in substrates containing peat, however by 390 DAT there were no differences in FCR among any substrate. Azaleas had the highest FCR in 100% PB and WT:Peat substrates at 60 DAT, but were similar to other treatments. At 120 DAT, azaleas tended to have the highest FCR when grown in substrates containing peat, but again at 390 DAT there were no differences in FCR among azaleas in any substrate. Ternstroemia had the lowest FCR when grown in CPL at 60 DAT, a trend that continued at 120 DAT. By 390 DAT, 100% WT and 100% CCR had the highest FCR, but FCR was similar to other treatments. Little difference was observed in ternstroemia grown in any substrate.

Root Ratings (RR). Holly had the highest RR in 100% WT, however RR were similar in PB:CPL, 100% CCR, 100% PB, WT:Peat, CCR:Peat, and PB:Peat (Table 2.6). Holly had significantly less roots in WT:CPL than in any other treatment. In contrast, boxwood RR were highest in WT:CPL, and had similar root growth in CCR:CPL. Loropetalum grown in 100% PB had highest RR, however PB:CPL, 100% CCR, and PB:Peat were similar. As in experiment 1, azaleas had lowest RR in WT:CPL. While ternstroemia in experiment 1 had significantly higher RR in WT:CPL, in experiment 2 WT:CPL along with CCR:CPL had the significantly lower RR than all other treatments.

Shrinkage. At 7 DAT substrate shrinkage was greatest in treatments containing WT, specifically WT:CPL, 100% WT, and WT:P. PB:CPL and CCR:Peat had less shrinkage than any other treatment (Table 2.7). This trend continued at 30 DAT. By 60 DAT, WT:CPL and CCR:CPL treatments had significantly more shrinkage than any other treatment, possibly due to further decomposition of WT and CCR. At the conclusion of the study WT:CPL had more shrinkage than any other treatment (6.4). PB:Peat had less shrinkage than any other treatment, however shrinkage was similar to PB:CPL, 100% PB, and CCR:Peat.

Discussion

In summary, similarities among substrates in these studies amended with peat or CPL indicate that CPL could be an economically viable and sustainable substrate amendment for container plant production. In both experiments, CPL tended to raise pH and peat tended to lower pH, particularly in the first 2 months. At the conclusion of each experiment, treatments containing CPL were closer to the BMP suggested pH levels than any other treatments.

CPL increased EC levels in both studies, more dramatically in experiment 2 than in experiment 1. However, in each study, EC levels quickly declined and were within recommended levels by 30 DAT.

While growth differences did occur with individual species throughout these studies, at the end of both studies all five species grown in high wood substrates (100%) had growth similar to plants grown in the PB:Peat commercial standard substrate. FCR were also similar among treatments for most species throughout these studies. RR results were again species specific concerning the use of CPL. Similarly, in a study by Tyler et al. (1993b) results indicated that high EC levels resulting from incorporation of composted turkey litter may inhibit root growth of cotoneaster (*Cotoneaster dammeri* 'Skogholm') and daylily (*Hemerocallis sp.* 'Red Magic'). However, in both studies all species grown in alternative wood based substrates had root coverage comparative to the grower standard PB:P. WT:CPL had the most shrinkage in both studies, possibly due to further decomposition from the WT. The smaller particle size of the WT used in comparison with CCR and PB also contributed to the high shrinkage of this substrate, especially when CPL was added to WT. It is important to note, that when WT was used at 100%, or in combination with peat, shrinkage was similar to 100% PB and PB:Peat in experiment 1.

Use of CPL in container production could possibly balance initial nitrogen immobilization which is often a concern when using substrates with high wood content. CPL could also be used as a peat substitute while growing non-sensitive crops. As PB supplies decline and fertilizer prices continue to increase, growers must look to the future for economically sustainable substrates. These results show high wood substrates with or without CPL (depending on crop) have potential to address future industry needs.

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Table 1.1 Experiment 1. Solution pH and electrical conductivity (EC) of substrates[Z].

	7 DAT[Y]		30 DAT		60 DAT		120 DAT		180 DAT	
Treatment	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)
6:1 WT[X]:CPL[W]	6.9 a[T]	1.3 a	6.6 a	0.3 e	6.3 a	0.4 b	5.9 a	0.3 a	5.3 b	0.24 a
6:1 CCR[V]:CPL	6.7 b	1.2 a	6.4 b	0.5 cde	5.9 a	0.8 a	6.0 a	0.2 a	5.8 a	0.15 bc
6:1 PB[U]:CPL	5.8 c	1.6 a	5.6 c	1.2 a	5.5 b	0.5 ab	5.2 ab	0.2 a	4.9 b	0.13 c
100% WT	5.2 d	0.4 b	4.9 d	0.4 de	5.1 c	0.4 b	3.8 c	0.3 a	3.4 c	0.2 ab
100% CCR	4.7 e	0.4 b	4.6 e	0.8 b	4.6 ed	0.6 ab	4.5 bc	0.3 a	3.4 c	0.18 abc
100% PB	3.8 g	0.4 b	3.8 g	0.7 bc	4.3 e	0.5 ab	3.5 c	0.2 a	3.3 c	0.21 ab
6:1 WT:Peat	4.3 f	0.6 b	4.4 f	0.4 de	4.7 d	0.4 b	4.6 bc	0.2 a	3.5 c	0.2 abc
6:1 CCR:Peat	4.2 f	0.6 b	4.3 f	0.6 bcd	4.4 ed	0.5 b	3.7 c	0.2 a	3.7 c	0.18 abc
6:1 PB:Peat	3.7 h	0.6 b	3.7 g	0.8 b	4.3 e	0.4 b	3.8 c	0.3 a	3.5 c	0.19 abc

[Z] pH and EC of solution obtained by the pour through method.

[Y] Days after transplanting.

[X] WT = Whole Tree.

[W] CPL = Composted poultry litter.

[V] CCR = Clean chip residual.

[U] PB = Pinebark.

[T] Means separated within column by Duncan's Multiple Range Test at *P* = 0.05.

Table 1.2 Experiment 1. Influence of substrate composition on growth indices[Z] at 120 and 340 days after transplanting.

	Holly		Boxwood		Loropetalum		Azalea		Ternstroemia	
Substrate	120 DAT[U]	340 DAT	120 DAT	340 DAT	120 DAT	340 DAT	120 DAT	340 DAT	120 DAT	340 DAT
6:1 WT[Y]:CPL[X]	27.0 bcd[T]	32.8 b	15.3 b	25.2 b	34.4 e	39.5 c	20.5 d	29.1 c	20.0 a	31.3 a
6:1 CCR[W]:CPL	32.3 a	35.8 ab	20.6 a	30.2 a	45.8 bc	46.4 b	19.8 d	31.6 bc	24.7 a	35.6 a
6:1 PB[V]:CPL	31.1 ab	36.2 ab	17.4 b	23.7 bc	37.3 de	40.7 c	21.1 cd	29.6 c	25.3 a	32.3 a
100% WT	28.8 abcd	36.7 a	14.7 cb	21.7 cd	45.1 c	46.4 b	23.0 bcd	33.7 b	25.6 a	35.1 a
100% CCR	29.4 abc	37.4 a	14.8 cb	19.2 de	53.3 a	53.2 a	27.3 a	39.4 a	25.6 a	35.9 a
100% PB	28.1 bcd	36.2 ab	12.4 c	16.5 e	41.8 cd	43.2 bc	24.8 ab	33.4 b	24.8 a	33.5 a
6:1 WT:Peat	26.0 cd	34.5 ab	15.1 bc	20.4 d	41.9 cd	42.6 bc	20.7 d	38.9 a	20.7 a	32.3 a
6:1 CCR:Peat	28.3 abcd	36.7 a	14.8 bc	19.5 de	51.2 ab	51.6 a	24.0 bc	37.9 a	24.6 a	32.4 a
6:1 PB:Peat	24.7 d	32.8 b	12.5 c	17.0 e	42.6 cd	44.1 bc	20.4 d	31.9 bc	24.2 a	41.0 a

[Z] Growth Indices = [(height + width1 + width2)/3]

[Y] WT = Whole Tree.

[X] CPL = Composted Poultry Litter.

[W] CCR = Clean chip residual.

[V] PB = Pinebark.

[U] DAT = Days after transplanting.

[T] Means separated using Duncan's Multiple Range Test at $P = 0.05$.

Table 1.3 Experiment 1. Influence of substrate composition on foliar color ratings^{Z} at 60 and 120 DAT^{Y}.

	Holly		Boxwood		Loropetalum		Azalea		Ternstroemia	
Treatment	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT
6:1 WT^{X}:CPL^{W}	4.0 a^{T}	4.0 a	3.9 ab	4.0 a	3.1 d	3.8 d	3.4 c	3.6 d	3.7 c	3.6 c
6:1 CCR^{V}:CPL	4.0 a	4.0 a	4.0 a	4.0 a	3.8 bc	4.3 ab	3.5 c	3.8 d	3.8 bc	3.1 d
6:1 PB^{U}:CPL	4.0 a	4.0 a	3.8 ab	4.0 a	3.9 b	4.3 ab	3.9 ab	3.8 d	3.8 bc	3.8 bc
100% WT	4.0 a	4.0 a	3.9 ab	4.0 a	3.8 bc	4.5 a	3.9 ab	4.2 bc	4.1 ab	4.4 a
100% CCR	4.0 a	4.0 a	3.9 ab	4.0 a	4.4 a	4.1 bc	4.2 a	4.5 ab	4.0 abc	4.0 abc
100% PB	4.0 a	4.0 a	3.4 c	4.0 a	3.6 c	3.9 cd	3.9 ab	3.9 cd	4.1 ab	4.1 ab
6:1 WT:Peat	4.0 a	4.0 a	3.9 a	4.0 a	3.6 c	4.1 bcd	4.1 a	4.8 a	3.8 bc	3.9 bc
6:1 CCR:Peat	4.0 a	4.0 a	3.9 ab	4.0 a	4.3 a	4.1 bcd	3.9 ab	4.2 bc	3.9 abc	3.9 bc
6:1 PB:Peat	4.0 a	4.0 a	3.6 bc	4.0 a	3.8 bc	3.4 e	3.9 ab	3.9 cd	4.2 a	4.0 abc

[Z] Foliar color rated on a scale of 1 to 5, 1 = severe chlorosis, 5 = dark green.

[Y] DAT = Days after transplanting.

[X] WT = Whole Tree.

[W] CPL = Composted poultry litter.

[V] CCR = Clean chip residual.

[U] PB = Pinebark.

[T] Means separated using Duncan's Multiple Range Test at *P* = 0.05.

Table 1.4 Experiment 1. Influence of substrate composition on root rating[Z] and shrinkage [Y].

	Root Ratings					Shrinkage	
Treatment	Holly	Boxwood	Loropetalum	Azalea	Ternstroemia	120 DAT[T]	340 DAT
6:1 WT[X]:CPL[W]	3.1 b[S]	2.8 bc	2.2 d	1.3 e	2.3 c	5.7 a	7.35 a
6:1 CCR[V]:CPL	3.7 b	3.8 a	2.6 c	2.2 d	3.1 bc	4.9 b	6.5 b
6:1 PB[U]:CPL	3.6 b	3.1 b	3.3 b	2.3 d	3.8 bc	3.1 e	3.6 e
100% WT	4.6 a	2.4 c	3.6 ab	3.4 c	4.2 a	3.7 cd	4.5 cd
100% CCR	4.8 a	2.7 bc	3.9 a	4.3 ab	4.0 ab	4.0 c	4.5 cd
100% PB	4.6 a	1.6 d	3.6 ab	4.1 b	3.3 b	3.4 de	4.1 de
6:1 WT:Peat	4.3 a	2.3 c	3.4 ab	4.1 b	3.2 bc	4.1 c	4.8 c
6:1 CCR:Peat	4.7 a	1.8 d	3.6 ab	4.6 a	3.6 ab	3.7 cd	4.3 cd
6:1 PB:Peat	4.3 a	1.4 d	2.9 c	3.8 b	4.0 ab	3.7 cd	4.3 cd

[Z] Root rating scale of 1 to 5, 1 = very poor root system, 5 = very strong root system.

[Y] Shrinkage = measure (cm) from media surface to the top of pot.

[X] WT = Whole tree.

[W] CPL = Composted poultry litter.

[V] CCR = Clean chip residual.

[U] PB = Pinebark.

[T] DAT = Days after transplanting.

[S] Means separated within column by Duncan's Multiple Range Test at $P = 0.05$.

Table 1.5 Experiment 1. Tissue nutrient content of *Ternstroemia gymnanthera* .

Treatment	**Tissue Nutrient Content**[Z]											
	N (%)	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**	**Al (ppm)**	**B (ppm)**	**Fe (ppm)**	**Mn (ppm)**	**Na (ppm)**	**Cu (ppm)**	**Zn (ppm)**
6:1 WT[Y]:CPL[X]	1.5 bcde[U]	0.18 bc	1.1 a	1.3 ab	0.34 ab	52.5 e	30.2 ab	36.2 a	27.6 c	438.8 abc	9.5 a	17.6 a
6:1 CCR[W]:CPL	1.3 de	0.17 bc	0.9 a	1.5 ab	0.34 ab	74.1 de	26.4 ab	54.8 a	29.2 c	448.4 abc	6.6 a	12.7 a
6:1 PB[V]:CPL	1.4 cde	0.23 a	1.0 a	1.7 ab	0.38 a	113.4 cd	37.5 a	54.8 a	55.3 ab	506.1 ab	11.7 a	22.9 a
100% WT	1.6 a	0.14 bc	1.0 a	1.2 b	0.33 ab	102.7 cd	20.7 b	41.3 a	37.0 bc	394.7 c	3.8 a	11.7 a
100% CCR	1.5 abc	0.12 bc	1.1 a	1.4 ab	0.34 ab	129.5 bc	22.2 b	34.9 a	54.0 ab	390.3 c	0.1 a	10.1 a
100% PB	1.4 abcd	0.17 bc	1.1 a	2.0 a	0.32 b	198.7 a	30.4 ab	49.9 a	54.6 ab	523.3 a	11.4 a	20.4 a
6:1 WT:Peat	1.6 ab	0.13 bc	1.0 a	1.6 ab	0.32 b	124.0 bc	23.4 b	38.9 a	34.9 c	459.5 abc	3.6 a	12.3 a
6:1 CCR:P	1.6 ab	0.20 ab	1.2 a	1.9 ab	0.30 b	166.1 ab	30.6 ab	44.9 a	59.8 a	514.7 ab	8.5 a	15.8 a
6:1 PB:P	1.3 e	0.11 c	0.9 a	1.6 ab	0.30 b	158.5 ab	21.0 b	44.4 a	36.3 bc	426.3 bc	22.5 a	12.4 a
Suffienciency range[T]	*1.43 - 1.90*	*0.10 - 0.13*	*0.40 - 0.52*	*2.0 - 2.9*	*0.13 - 0.15*	***[S]	*55-126*	*58-69*	*15-35*	***	*4-6*	*7-10*

[Z] Tissue analysis performed on 10 terminal shoots (5.1 cm - 7.6 cm or 2-3 in of most recently matured leaves) per plant; N = nitrogen, P = phosphorus,

K = potassium, Ca = Calcium, Mg = magnesium, Al = aluminum, B = boron, Fe = iron, Mn = manganese, Zn = zinc.

[Y] WT = WholeTree.

[X] CPL = Composted poultry litter.

[W] CCR = Clean chip residual.

[V] PB = Pinebark.

[U] Means separated within column by Duncan's Multiple Range Test (*P* = 0.05).

[T] Sufficiency range published by Mills and Jones (1996).

Table 2.1 Physical properties of whole tree, pinebark, and clean chip residual based substrates^{Z}.

Treatments^{Y}	**Air Space**^{X}	**Container capacity**^{W} (% Vol)	**Total porosity**^{V}	**Bulk density**^{U} (g-cm^{3})
6:1 WT:CPL	21 f^{T}	56 a	77 e	0.23 b
6:1 CCR:CPL	28 de	51 b	80 c	0.24 ab
6:1 PB:CPL	37 b	38 e	75 f	0.25 a
100% WT	26 e	55 a	80 bc	0.20 d
100% CCR	35 bc	47 c	82 b	0.20 d
100% PB	42 a	41 d	83 a	0.22 c
6:1 WT:Peat	27 de	57 a	83 a	0.20 d
6:1 CCR:Peat	29 d	45 c	74 f	0.17 e
6:1 PB:Peat	33 c	45 c	78 d	0.23 bc
Recommended range^{S}	*30-Oct*	*45 - 65*	*50 - 85*	*0.19 - 0.70*

[Z] Analysis performed using the North Carolina State University porometer.

[Y] WT = WholeTree, CCR=Clean chip residual, PB= pinebark, CPL=composted poultry litter.

[X] Air space is volume of water drained from the sample divided by volume of the sample.

[W] Container capacity is (wet weight - oven dry weight) divided by volume of the sample.

[V] Total porosity is container capacity + air space.

[U] Bulk density after forced-air drying at 105º C (221.0º F) for 48 h; 1 g cm3 = 62.4274 lb/ft3.

[T] Means separated within column by Duncan's Multiple Range Test at $P = 0.05$ (n=3).

[S] Recommended ranges as reported by Yeager et al., 2007. Best Management Practices Guide for producing Container-Grown Plants.

Table 2.2 Experiment 2. Particle size analysis of substrates.

U.S. standard sieve no.	Sieve opening (mm)[Z]	Substrates[Y]								
		6:1 WT:CPL	6:1 CCR[W]:CPL	6:1 PB:CPL	100% WT	100% CCR	100% PB	6:1 WT:Peat	6:1 CCR:Peat	6:1 PB:Peat
1/2	12.5	0.0 c[X]	0.0 c	2.8 b	0.0 c	0.0 c	5.0 a	0.0 c	0.0 c	5.6 a
3/8	9.5	0.0 c	0.0 c	3.8 b	0.0 c	0.0 c	3.8 b	0.0 c	0.1 c	6.1 a
1/4	6.35	1.6 c	1.9 c	9.2 b	0.4 c	0.3 c	11.3 a	0.8 c	1.1 c	10.2 ab
6	3.35	15.0 c	17.8 bc	20.2 ab	10.8 d	16.5 c	21.6 a	20.4 ab	16.7 c	21.0 ab
8	2.36	18.8 b	19.5 b	12.5 c	19.5 b	20.7 b	12.7 c	25.4 a	18.4 b	10.6 c
10	2	6.9 c	7.7 bc	4.5 d	10.1 a	9.0 ab	4.4 d	75 bc	7.2 c	3.6 d
14	1.4	17.0 bc	19.7 a	11.5 d	18.8 ab	18.4 ab	11.0 d	16.7 bc	15.5 c	8.9 e
18	1	12.8 a	12.0 ab	9.5 c	12.3 ab	13.1 a	8.3 c	11.1 b	11.9 ab	6.9 d
35	0.5	15.0 ab	12.0 bc	14.8 ab	13.5 abc	13.0 abc	12.6 abc	10.7 c	15.6 a	11.9 bc
60	0.25	7.0 ab	5.2 ab	6.7 ab	5.6 ab	5.2 ab	6.4 ab	4.6 b	8.1 ab	8.8 a
140	0.11	3.1 ab	2.3 b	2.1 b	3.3 ab	1.9 b	2.1 b	1.6 b	3.7 ab	5.1 a
270	0.05	1.0 ab	0.87 ab	0.50 b	0.70 ab	0.40 b	0.50 b	0.43 b	0.80 ab	1.3 a
pan	0	0.43 ab	0.50 a	0.37 ab	0.23 ab	0.13 b	0.37 ab	0.47 a	0.33 ab	0.43 ab
Texture[W]										
Coarse		16.6 c	19.7 c	36.0 b	11.2 d	16.9 c	41.6 a	21.2 c	17.9 c	42.6 a
Medium		55.6 bc	58.8 ab	38.0 d	60.8 ab	61.2 a	36.4 d	60.7 ab	53.0 c	30.0 e
Fine		58.6 c	62.8 bc	43.0 d	66.8 ab	68.2 ab	44.4 d	69.7 a	63.0 bc	41.0 d

[Z] 1 mm = 0.0394 in.

[Y] WT= Whole Tree, CPL = Composted poultry litter, CCR = Clean Chip Residual, PB = Pinebark.

[X] Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Duncan's Multiple Range Test at (*P* = 0.05).

[W] Coarse = 3.35-12.5 mm; Medium = 1.00-2.36 mm; Fine = 0.00-0.50 mm.

Table 2.3. Experiment 2. Solution pH and electrical conductivity (EC) of substrates[Z].

	7 DAT[Y]		30 DAT		60 DAT		90 DAT		120 DAT		285 DAT		390 DAT	
Treatment	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)
6:1 WT[X]:CPL[W]	7.4 a[T]	3.9 a	7.3 a	0.8 b	6.6 a	0.7 cd	6.8 a	0.46 bc	6.5 a	0.28 a	5.7 a	0.16 b	5.5 a	0.14 c
6:1 CCR[V]:CPL	7.4 a	2.9 b	7.1 a	0.7 b	6.5 a	0.9 bc	6.3 b	0.73 a	6.3 a	0.24 ab	6.0 a	0.12 cd	5.2 b	0.14 c
6:1 PB[U]:CPL	6.9 b	2.8 b	6.5 b	1.3 a	5.8 bc	1.3 a	5.7 c	0.48 b	5.3 b	0.21 abc	5.0 b	0.16 b	4.1 c	0.21 ab
100% WT	5.5 c	1.0 cd	6.3 c	0.5 cd	6.0 b	0.6 cd	5.1 de	0.37 bcd	4.5 bc	0.18 bcd	3.3 d	0.16 bc	3.1 e	0.23 ab
100% CCR	4.8 d	0.7 cd	5.8 d	0.3 d	5.9 b	0.4 d	5.2 d	0.27 d	4.3 c	0.17 bcd	3.4 d	0.16 bc	3.0 e	0.26 a
100% PB	4.2 f	0.5 d	4.8 f	0.5 cd	5.3 cd	0.7 bcd	4.8 e	0.28 d	4.3 c	0.14 cd	3.5 cd	0.17 b	3.3 de	0.22 ab
6:1 WT:Peat	4.6 e	0.9 cd	5.8 d	0.3 d	5.7 bc	0.4 d	5.6 c	0.22 d	5.2 b	0.11 d	3.8 c	0.12 d	3.5 d	0.18 bc
6:1 CCR:Peat	4.1 fg	1.2 c	5.5 e	0.5 c	5.5 bcd	0.9 bc	4.8 e	0.31 cd	4.5 c	0.17 bcd	3.3 d	0.22 a	3.2 de	0.23 ab
6:1 PB:Peat	4.0 g	0.9 cd	4.6 f	0.5 c	5.1 d	1.0 ab	5.0 de	0.37 bcd	4.4 c	0.13 cd	3.7 cd	0.15 bcd	3.3 de	0.23 ab

[Z] pH and EC of solution obtained by the pour through method.

[Y] Days after transplanting.

[X] WT = Whole Tree.

[W] CPL = Composted poultry litter.

[V] CCR = Clean chip residual.

[U] PB = Pinebark.

[T] Means separated within column by Duncan's Multiple Range Test at $P = 0.05$.

Table 2.4 Experiment 2. Influence of substrate composition on growth indices[Z] at 60 and 390 days after transplanting.

	Holly		Boxwood		Loropetalum		Azalea		Ternstroemia	
Substrate	60 DAT[U]	390 DAT	60 DAT	390 DAT	60 DAT	390 DAT	60 DAT	390 DAT	60 DAT	390 DAT
6:1 WT[Y]:CPL[X]	26.0 c[1]	40.3 c	18.5 ab	31.1 a	42.4 ab	50.0 a	24.8 bc	33.3 d	30.4 abc	39.2 dc
6:1 CCR[W]:CPL	30.4 b	43.5 bc	17.2 ab	30.4 a	38.1 b	54.4 a	25.5 bc	34.2 d	26.5 c	37.6 d
6:1 PB[V]:CPL	35.8 a	48.6 a	18.8 ab	27.5 b	37.9 b	52.7 a	26.7 bc	37.8 c	30.5 abc	45.3 bc
100% WT	32.3 b	45.1 b	18.5 ab	26.5 b	43.5 ab	37.7 bc	29.2 ab	45.9 a	29.5 bc	47.2 ab
100% CCR	32.2 b	43.4 bc	16.9 b	23.6 cd	37.8 b	36.2 bc	23.5 c	42.0 b	27.7 c	44.1 bc
100% PB	31.1 b	41.7 bc	18.0 ab	23.0 d	47.6 a	50.4 a	31.0 a	45.5 ab	30.6 abc	45.5 bc
6:1 WT:Peat	29.3 b	41.1 c	18.6 ab	26.0 bc	43.7 ab	41.4 b	31.0 a	46.6 a	34.3 a	52.3 a
6:1 CCR:Peat	29.2 b	44.2 bc	25.7 a	24.0 cd	41.6 ab	34.9 c	27.5 abc	43.7 ab	31.1 abc	47.6 ab
6:1 PB:Peat	31.8 b	40.3 c	17.9 ab	23.4 cd	48.0 a	49.2 a	31.1 a	44.1 ab	33.2 ab	50.1 ab

[Z] Growth Indices = [(height + width1 + width2)/3]

[Y] WT = Whole Tree.

[X] CPL = Composted Poultry Litter.

[W] CCR = Clean chip residual.

[V] PB = Pinebark.

[U] DAT = Days after transplanting.

[1] Means separated using Duncan's Multiple Range Test at $P = 0.05$.

Table 2.5. Influence of substrate compositition on foliar color ratings[Z] at 60, 120, and 390 DAT[Y].

	Holly			Boxwood			Loropetalum			Azalea			Ternstroemia		
Treatment	60 DAT	120 DAT	390 DAT	60 DAT	120 DAT	390 DAT	60 DAT	120 DAT	390 DAT	60 DAT	120 DAT	390 DAT	60 DAT	120 DAT	390 DAT
6:1 WT[X]:CPL[W]	4.0 a[T]	4.0 a	4.1 bc	3.3 abc	3.9 a	3.9 ab	3.3 cd	4.1 c	3.9 a	3.3 bc	3.3 cd	4.0 a	3.6 b	3.1 c	3.8 c
6:1 CCR[V]:CPL	4.0 a	4.0 a	4.4 a	3.0 c	4.0 a	4.0 a	3.1 d	4.2 c	2.9 a	3.1 c	3.1 d	4.0 a	3.6 b	3.0 c	4.1 abc
6:1 PB[U]:CPL	4.0 a	4.0 a	4.3 ab	3.6 a	4.0 a	3.7 a	3.9 bc	4.6 abc	3.1 a	4.0 ab	3.8 bcd	4.0 a	3.6 b	3.8 b	3.9 bc
100% WT	4.0 a	4.0 a	4.4 a	3.5 ab	4.0 a	3.8 ab	4.4 ab	5.0 a	2.8 a	3.6 abc	4.4 ab	4.0 a	3.9 a	4.0 a	4.4 a
100% CCR	4.0 a	4.0 a	4.4 a	3.2 bc	3.9 a	3.7 ab	3.7 cd	4.9 ab	3.4 a	3.2 c	3.8 abc	3.5 a	3.9 a	4.1 a	4.4 a
100% PB	4.0 a	4.0 a	4.4 a	3.7 a	4.0 a	3.8 ab	4.6 a	4.3 bc	2.8 a	4.3 a	4.5 a	4.0 a	4.2 a	4.0 a	3.9 bc
6:1 WT:Peat	4.0 a	4.0 a	4.3 abc	3.4 abc	3.9 a	3.7 ab	4.6 a	5.0 a	3.0 a	4.3 a	4.6 a	4.0 a	4.2 a	4.1 a	4.2 ab
6:1 CCR:Peat	4.0 a	4.0 a	4.5 a	3.5 ab	4.0 a	3.6 b	4.6 a	5.0 a	2.6 a	3.8 abc	4.6 a	4.0 a	4.1 a	4.0 a	4.0 bc
6:1 PB:Peat	4.0 a	4.0 a	4.1 c	3.2 bc	4.0 a	3.6 b	4.6 a	5.0 a	3.3 a	3.8 abc	4.6 a	4.0 a	4.1 a	4.0 a	4.1 abc

[Z] Foliar color rated on a scale of 1 to 5, 1 = severe chlorosis, 5 = dark green.

[Y] DAT = Days after transplanting.

[X] WT = Whole Tree.

[W] CPL = Composted poultry litter.

[V] CCR = Clean chip residual.

[U] PB = Pinebark.

[T] Means separated using Duncan's Multiple Range Test at *P* = 0.05.

Table 2.6 Experiment 2 Influence of substrate composition on root ratings[Z].

	Root Rating				
Treatment	Holly	Boxwood	Loropetalum	Azalea	Ternstroemia
6:1 WT[Y]:CPL[X]	3.8 c[T]	7.1 a	2.5 e	1.0 d	2.4 e
6:1 CCR[V]:CPL	6.3 b	6.1 ab	3.3 de	0.9 d	2.0 e
6:1 PB[V]:CPL	7.6 ab	5.5 bc	5.1 ab	3.4 c	4.5 d
100% WT	9.1 a	5.0 c	4.3 bcd	7.9 a	7.3 abc
100% CCR	8.8 a	3.6 de	4.8 abc	5.9 b	7.5 ab
100% PB	8.1 a	2.9 ef	6.0 a	7.4 a	6.0 c
6:1 WT:P[U]	7.8 ab	4.6 cd	3.8 cde	6.6 ab	8.1 a
6:1 CCR:P	7.6 ab	3.8 de	3.3 de	7.5 a	7.9 ab
6:1 PB:P	8.1 a	2.3 f	4.9 abc	7.9 a	6.6 bc

[Z] Root rating on scale of 0-10, 0 = 0% root coverage of rootball, 10 = 100% root coverage of rootball at 409 after transplanting.

[Y] WT = Whole tree.

[X] CPL = Composted poultry litter.

[W] CCR = Clean chip residual.

[V] PB = Pinebark.

[U] P = Peat.

[T] Means separated using Duncan's Multiple Range Test at $P = 0.05$

Table 2.7 Experiment 2. Influence of substrate composition on shrinkage[Z].

	Shrinkage (cm)			
Treatment	7 DAT[U]	30 DAT	60 DAT	390 DAT
6:1 WT[Y]:CPL[X]	2.5 ab[T]	3.3 a	4.9 a	6.4 a
6:1 CCR[V]:CPL	2.1 cd	3.0 ab	4.6 a	5.7 b
6:1 PB[V]:CPL	1.9 e	2.2 c	2.9 d	2.9 f
100% WT	2.6 a	3.0 ab	3.7 b	4.6 c
100% CCR	2.3 cd	2.5 cd	3.3 bcd	3.5 de
100% PB	2.3 bc	2.5 bc	3.1 cd	3.0 ef
6:1 WT:Peat	2.5 ab	3.2 a	3.6 bc	3.8 d
6:1 CCR:Peat	1.8 e	2.3 c	3.0 d	3.3 def
6:1 PB:Peat	2.0 de	2.4 bc	3.0 d	2.8 f

[Z] Shrinkage = measure (cm) from media surface to the top of pot.

[Y] WT = Whole tree.

[X] CPL = Composted poultry litter.

[W] CCR = Clean chip residual.

[V] PB = Pinebark.

[U] DAT = Days after transplanting.

[T] Means separated using Duncan's Multiple Range Test at *P* = 0.05.

CHAPTER III

Application of Composted Poultry Litter as a Fertilizer for Landscape Use

Abstract

Each year, over 16 million tons of poultry litter is produced in the U.S. and poultry farmers face the challenge of storing and disposing of poultry litter due to new federal and state regulations that limit the amount of poultry litter than can be land-applied each year. As a result, poultry farmers are looking for new avenues to dispose of this waste. In this study, three experiments were conducted to evaluate use of composted poultry litter (CPL) as fertilizer for landscape annual bedding plants. In experiments 1 and 2, ‘Celebrity Red’ petunia and ‘Quartz Scarlet’ verbena were planted in raised beds simulating an urban landscape. Prior to planting, 10 fertilizer or CPL treatments were incorporated into the raised beds including**:** Peafowl® brand garden grade fertilizer 13N-5.6P-10.9K (13-13-13) at rates of 4.9 g N/m^2 (1 lb N/1000 ft^2) and 9.8 g N/m^2 (2 lb N/1000 ft^2), Polyon® 13N-5.6P-10.9K (13-13-13) at rates of 4.9 g N/m^2 (1 lb N/1000 ft^2) and 9.8 g N/m^2 (2 lb N/1000 ft^2) and composted poultry litter at rates of 4.9 g N/m^2 (1 lb N/1000 ft^2), 9.8 g N/m^2 (2 lb N/1000 ft^2), 19.6 g N/m^2 (4 lb N/1000 ft^2), 29.4 g N/m^2 (6 lb N/1000 ft^2), 39.2 g N/m^2 (8 lb N/1000 ft^2), and 49 g N/m^2 (10 lb N/1000 ft^2). Experiment 3 was similar to experiments 1 and 2: however in experiment 3, Dusty Miller (*Senecio cineria*) was substituted for ‘Quartz Scarlet’ verbena. Use of CPL incorporated into

landscape planting beds as a fertilizer source resulted in plants equal to or larger than plants grown with conventional inorganic fertilizers. Nitrate and ammonia levels in leachates from plots amended with CPL were comparable with plots amended with commercial inorganic fertilizers and nitrogen (N) levels were in most cases less in plots fertilized with CPL when compared to inorganic fertilizers when the same N rate was applied. CPL may not be able to replace inorganic fertilizers completely in all landscape situations, but it can reduce fertilizer requirements, and provide an economically and environmentally sound alternative to poultry waste disposal while providing beneficial aspects for plant growth in annual bedding plants.

Introduction

The U.S. poultry and egg industry is valued at billions of dollars in gross farm receipts and employs hundreds of thousands of people. In Alabama alone, the poultry industry generates over $2 billion in gross farm receipts and employs over 78,000 people (USDA, 2008). Over the past several decades the poultry industry has expanded exponentially. Increasing demand for low cholesterol meat products along with the recent cost saving changes in the farming industry from small family farms to large commercial farming practices have attributed to this expansion (Moore et al., 1996).

Historically, poultry wastes have been used as a source of fertilizer and soil amendment in agronomic row cropping systems. Poultry litter is often desired over other animal manures due to its high nutrient content in comparison with other animal manures. Typical poultry litter will have the following nutrient ranges: Nitrogen from 2.1 to 6%, Phosphorus from 1.4 to 9%, Potassium from 0.8 to 6.2%, Calcium from 0.8 to 6.1%

Magnesium from 0.2 to 2.1%, and Sulfur from 0.1 to 0.8%, on a dry-weight basis (Mitchell et al., 1995).

While land application was the predominate disposal method for poultry litter in the past, due to increased environmental awareness, poultry litter is now under strict new state and federal regulations concerning disposal methods with respect to non-point source pollution and other environmental concerns**.** In 1974 Congress passed the Safe Drinking Water Act which requires EPA to determine safe levels of chemicals in drinking water which do or may cause health problems. These safe levels of contaminates are based solely on possible health risks and exposure, and are called Maximum Contaminant Level Goals (MCLGs). The MCLG for NO_3 has been set at 10 mg/L (10 ppm) and the MCLG for NH_4 at 0.5 mg/L (0.5 ppm) (EPA, 1972). Based upon these MCLGs, EPA has set an enforceable standard called a Maximum Contaminant Level (MCL). Beginning in 1993, EPA requires water suppliers to collect water samples at least once a year and determine if NO_3 or NH_4 water levels are present above 50 percent of their MCLs. If N levels are present above these levels, the system must continue to monitor the contaminant every three months, and consequently take steps to reduce the amount of N in water supplies. Approximately 44% of Alabamians obtain drinking water from ground-water supplies (Hairston and Stribling, 1995). Because leached nitrate-N from landscape fertilization programs can contaminate drinking water, it is important to identify landscape fertilization practices that provide excellent plant growth while minimizing N lost to leaching.

While new regulations are placing limits on land application of poultry litter, a fair amount of poultry litter can still be land applied; however, management of available lands for application is now becoming a problem. As populations continue to grow, rural areas are declining in size as cities are expanding to meet population needs. As a result, there are fewer acres of agricultural land for spreading manure (Wolfe and Humphries, 2007). Expansion of cities and population increases could present a new avenue for poultry litter disposal in the landscape and soilless potting media industry. In Alabama, greenhouse, nursery, and landscape operations employed 44,000 people and had a $2.89 billion economic impact in the state in 2008 (J. Harwell, pers. comm.). The horticulture industry is now the fastest growing sector in agriculture in Alabama and with more and more landscape and nursery operations in business, poultry producers are turning to the green industry as a means of disposing excess manure. Research is underway to find alternative uses for composted poultry litter in different agricultural sectors and to establish areas where poultry litter could provide the best economic and environmental benefit.

Considering the high nutrient content of poultry litter and the accessibility of the product, especially in the intense production areas of the southeastern United States, horticulture professionals, farmers, and turfgrass managers are turning to poultry litter and other organic sources as an alternative to costly inorganic fertilizer sources. Inorganic fertilizer cost is increasing while U.S. fertilizer production is decreasing. Because natural gas is the primary raw material used to produce ammonia, the rise in U.S. gas prices has led to a 35% decline in U.S. ammonia production capacity and a 44% decrease in output between years 2000 and 2006. National average fertilizer prices increased 113% between 2000 and 2007 due to increases in nitrogen costs. During this seven year period, the price of ammonia, the main source of nitrogen in fertilizer production, increased 130% and the price of urea, the primary solid nitrogen fertilizer used in the U.S. rose 127% (Wen-yuan, 2007). Due to the increases in inorganic fertilizer sources, the nutrients in poultry litter are more valuable than ever.

There is a great potential for the use of organic manure type products in the landscape and homeowner sector. Increased awareness of environmental impacts from the use and manufacture of inorganic fertilizer sources has caused many homeowners to seek more environmentally friendly products. Organically based products are becoming more popular, especially with urban consumers. Recent trends such as "Going Green" have made the use of organic products more desirable and marketable.

Many studies have been conducted showing the benefits of poultry litter application as a fertilizer in row cropping systems (Burmester et al., 1991; Porch et al., 1990). Poultry litter has also been shown to improve growth in roses, woody ornamentals, annuals, and bermuda grass production (Feagley et al., 2005; Reeder et al., 1992; Warren and Safley, 1990). In two studies by Altland (2002) growth of 'Magestic Giants White' pansy (*Viola* x *wittrockiana*) and Telstar Purple dianthus (*Dianthus chinensis*) was compared when fertilized with granular water soluble fertilizers (GWS), controlled release fertilizers (CRF), and an organically based fertilizer (OBF) composed of recycled newspaper amended with poultry litter at similar rates. In experiment 1, the OBF resulted in plants having adequate foliar color and plant size, with less total nitrogen leaching recovered from soil water samples. In experiment 2, plants fertilized with OBF in general had superior foliar color and size compared to all other treatments, but also caused elevated levels of total nitrogen in soil water. However, composting poultry litter prior to application could reduce nitrogen leaching. Use of poultry litter in the landscape industry could provide an environmentally sound means of disposal for poultry producers as well as an economical alternative to increasingly expensive fertilizers.

Research is needed to understand how the type of fertilizer used will affect plant growth and nutrient leaching. The objective of this study was to evaluate composted poultry litter as a fertilizer source for bedding plants at various rates in comparison with commercially available inorganic fertilizers for three commonly used landscape annual bedding species, ‘Quartz Scarlet’ verbena, ‘Celebrity Red’ petunia, and Dusty Miller (*Senecio cineraria*) in regards to plant growth and nutrient leaching. In order to evaluate consecutive applications of CPL to the same area, each plot received the same fertilizer in each of the three experiments.

Materials and Methods

Experiment 1

A fallow site was chosen which had not received any fertilizer in several years. Plots were tilled to a 10.2 cm (4 in) depth and raised beds were developed using a Kenco bed maker (Kenco Corp., Ligonier Valley, PA) with each experimental unit being 3.05 m by 0.46 m (10 ft by 1.5 ft). Before planting 10 treatments were applied: Peafowl® brand (Piedmont Fertilizer Co., Opelika, AL) garden grade fertilizer 13N-5.6P-10.9K (13-13-13) at rates of 4.9 g N/m^2 (1 lb N/1000 ft^2) and 9.8 g N/m^2 (2 lb N/1000 ft^2), Polyon® (Agrium Advanced Technologies, Sylacauga, AL) 13N-5.6P-10.9K (13-13-13) at rates of 4.9 g N/m^2 (1 lb N/1000 ft^2) and 9.8 g N/m^2 (2 lb N/1000 ft^2) and composted poultry litter (CPL) at rates of 4.9 g N/m^2 (1 lb N/1000 ft^2), 9.8 g N/m^2 (2 lb N/1000 ft^2), 19.6 g N/m^2

(4 lb N/1000 ft^2), 29.4 g N/m^2 (6 lb N/1000 ft^2), 39.2 g N/m^2 (8 lb N/1000 ft^2), and 49 g N/m^2 (10 lb N/1000 ft^2). A control receiving no fertilizer was also maintained for comparison. Treatments were top-dressed on the prepared landscape beds and lightly tilled in prior to planting. Poultry litter used in this experiment was obtained from Greenville, AL. and was composted in an in-vessel rotating drum digester (BW Organics, Sulphur Springs, TX) for two weeks and stored under a tarp for 30 days until installation of the study. Poultry litter was analyzed by Brookside Laboratories Inc. (New Knoxville, OH). Composted poultry litter analysis showed 2.5% nitrogen, 1.4% phosphorous, and 2.3% potassium on a wet weight (as is) basis. On August 17, 2007 fertilizer treatments were applied to the raised beds and *Petunia spp*. 'Celebrity Red' and *Verbena hybrida* 'Quartz Scarlet' were transplanted from 36 cell-pack liners into the prepared landscape beds. In each plot, 12 plants of one species were planted 0.3 m (1 ft) on center. Plants were arranged by species in a randomized complete block design. Soil water leachates were collected using suction cup lysimeters 0.6 m (2 ft) long and 5.1 cm (2 in) in diameter with a ceramic cap 7.6 cm (3 in) long and 5.1 cm (2 in) wide. Lysimeters were installed at a 45º angle to the ground to minimize preferential water flow down the side of the lysimeter at a depth of 25.4 cm (10 in). The hole for the lysimeter was formed using a soil core remover. A mud slurry using soil from the hole was poured back into the hole before insertion of the lysimeter to ensure soil contact with the ceramic cap. A hand pump was used to create a suction of 60 centibars (8.82 psi) within the lysimeter.

Data collected included growth indices [(height +width1 + width 2)/3(cm)] at 4, 8, and 12 weeks after planting (WAP). Leaf chlorophyll content (LCC) was quantified using a SPAD-502 Chlorophyll Meter (Minolta, Inc.) at 4, 8, and 12 WAP. Plants were harvested at 12 WAP to avoid potential frost injury. Leachates were collected using lysimters at 2, 4, 8, 12, and 16 WAP. Soil water collected from lysimeters was analyzed using a colorimetric procedure to determine N as NO_3 and NH_4. Water was also analyzed for pH, electrical conductivity (dS/m). Fresh and dry weights were taken 12 WAP. Foliar samples (most recently matured leaves) (Mills and Jones, 1996) were collected and analyzed for nutrient content at 12 WAP. Foliar samples were analyzed for nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), aluminum (Al), cadmium (Cd), chromium (Cr), sodium (Na), nickel (Ni), lead (Pb), and carbon (C). Foliar N was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Data were analyzed using Duncan's Multiple Range Test ($P \leq 0.05$) using a statistical software package (SAS® Institute version 9.1, Cary, NC).

Experiment 2

Experiment 2 was similar to experiment 1 with the following exceptions: On May 19, 2008, fertilizer treatments were applied to the raised landscape beds as mentioned in experiment 1. Poultry litter used experiment 2 was obtained from Greenville, AL. and was composted in an in-vessel rotating drum digester (BW Organics, Sulphur Springs, TX) for two weeks. Poultry litter was analyzed by Brookside Laboratories Inc. (New Knoxville, OH). Composted poultry litter analysis showed 2.3% nitrogen, 1.5%

phosphorous, and 2.3% potassium on a wet weight (as is) basis. *Petunia spp*. 'Celebrity Red' and *Verbena hybrida* 'Quartz Scarlet' were transplanted from 36 cell-pack liners into the prepared landscape beds on May 19, 2008, similarly to experiment 1. Eight plants of either petunia or verbena were planted per plot and each species analyzed separately. Leachates were collected using lysimters at 1, 2, 4, 8, and 12 WAP. Soil water collected from lysimeters was analyzed using a colorimetric procedure to determine N as NO_3 and NH_4. Water was also analyzed for pH, electrical conductivity (dS/m). Fresh and dry weights were taken 12 WAP. Foliar samples (most recently matured leaves) (Mills and Jones, 1996) were collected and analyzed for nutrient content at 12 WAP. Foliar samples were analyzed for nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), aluminum (Al), and sodium (Na). Foliar N was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Data were analyzed as in experiment 1.

Experiment 3

Experiment 3 was similar to experiments 1 and 2 with the following exceptions: On August 21, 2008, fertilizer treatments were applied to raised landscape beds as mentioned in experiment and *Petunia spp*. 'Celebrity Red' and *Senecio cineria* (Dusty Miller) were transplanted from 36 cell-packs into the prepared landscape beds. Eight plants petunia and dusty miller were planted per plot and each species analyzed separately. CPL was taken from the same source as CPL used in experiment 2 and nutrient analysis of CPL was the same as in experiment 2. Data was taken and analyzed as in experiments 1 and 2.

Results

Experiment 1

Growth indices (GI) and Dry weights (DW). At 4 WAP, petunia growth was similar among the Peafowl brand (9.8 g N/m^2), Polyon (9.8 g N/m^2), CPL (9.8 g N/m^2), CPL (19.6 g N/m^2), CPL (29.4 g N/m^2), CPL (39.2 g N/m^2), and CPL (49.0 g N/m^2) (Table 1.1). By 8 WAP CPL (29.4 g N/m^2), CPL (39.2 g N/m^2), CPL (49.0 g N/m^2) and Peafowl brand (9.8 g N/m^2) had the highest GI, however Peafowl (9.8 g N/m^2) and CPL (29.4 g N/m^2), and CPL (49.0 g N/m^2) were similar to other treatments, except Peafowl and Polyon (at 4.9 g N/m^2) and the non-fertilized control. At 12 WAP CPL treatments (29.4, 39.2, and 30.7 g N/m^2) along with Polyon (9.8 g N/m^2) had the largest GI. The increased growth in beds with Polyon fertilizer treatment at 12 WAP may be due to the extended release of the product over time. In addition, when CPL was compared with either Peafowl or Polyon fertilizer at the same fertilizer rate, CPL grew petunias as large as or larger than the inorganic fertilizers at all dates GI was taken.

Petunia dry weights (DW) generally increased as fertilizer rate increased (Table 1.1). As expected, petunia DW revealed that petunias grown in CPL plots had similar DW to petunias grown with Peafowl or Polyon fertilizers when the same N rate of fertilizer was applied.

Verbena GI revealed little differences in GI at 4 WAP and 8 WAP (Table 1.1). However, by 12 WAP, Peafowl (9.8 g N/m^2) and both Polyon rates along with CPL treatments (29.4, 39.2, and 49.0 g N/m^2) had the largest GI. Again, growth of verbena was statistically similar in plots treated with CPL and inorganic fertilizers at the same N rate. Verbena DW generally increased as fertilizer rate increased (Table 1.1) with the exception of Polyon treatments, and verbena fertilized with CPL at 4.9 g N/m^2 had higher DW than verbena fertilized with CPL at 9.8 g N/m^2, however these two treatments were statistically similar. While the higher rates of CPL (39.2 and 49.0 g N/m^2) had the higher verbena DW, these DWs were statistically similar to other treatments. Again, when the same N rate of fertilizer was used, plants grown with CPL were similar to plants grown with inorganic fertilizers.

Leaf chlorophyll content (LCC). At 4 WAP there were no differences in leaf chlorophyll content (LCC) of petunia in any treatment (Table 1.2). At 8 WAP, plants in CPL (49.0 g N/m^2) had the highest LCC, however LCC was statistically similar for plants in both rates of Peafowl brand, both rates of Polyon, as well as CPL at 39.2 g N/m^2. By 12 WAP, there were very few differences in LCC among treatments. Peafowl (9.8 g N/m^2), Polyon (4.9 g N/m^2), along with CPL at rates of 29.4, 39.2, and 49.0 g N/m^2 were slightly higher than other treatments, however plants in these treatments were still statistically similar to most other treatments.

At 4 WAP, there were no differences in LCC of verbena. At 8 WAP, plants in CPL treatments 4.9 g N/m^2, 9.8 g N/m^2, and 19.6 g N/m^2 had slightly lower LCC than other treatments, however by 12 WAP no differences were observed.

Tissue Nutrient Content. In general, petunia tissue nutrient content was similar among all treatments for N, with Peafowl (4.9 g N/m^2) having slightly less foliar N and Polyon (9.8 g N/m^2) having slightly more (Table 1.3). P tended to be highest in CPL treatments (29.4, 39.2, and 49.0 g N/m^2). No differences were observed in K among any treatment. All other essential nutrients were equal to or above sufficiency ranges, with the exception of B, which was slightly less than the sufficiency range, and Cd and Cr were higher in CPL at 19.6 g N/m^2 than any other treatments (Mills and Jones, 1996).

There were no differences in foliar N content of verbena (Table 1.4). Again, P tended to be highest in treatments fertilized with CPL at rates of 39.2 and 49.0 g N/m^2. K content was highest in verbena fertilized with Peafowl fertilizer (4.9 g N/m^2), however foliar K content was similar to both rates of poly and CPL at 9.8, 29.4, 39.2, and 49.0 g N/m^2). All other essential nutrients were within or above sufficiency levels (Mills and Jones, 1996). As in petunia, verbena Cd and Cr levels were highest in CPL at 19.6 g N/m^2 than in any other treatment.

N levels in soil-water as NO_3 - N and NH_4 – N. At 2 WAP, NO_3 and NH_4 were high for all treatments (Table 1.5). No treatment was less than 6 times the EPA recommended level for NO_3 in drinking supplies (10 mg/L or 10 ppm) and only the non-fertilized control was close to having an acceptable NH_4 level of 0.5 mg/L (0.5 ppm) (EPA, 1972). At 4 WAP NO_3 levels remained high; NH_4 levels began to drop and no differences were observed among any treatment with the exception of Peafowl (9.8 g N/m^2) which was significantly higher than all other treatments, a trend that continued at 8 WAP. NO_3 at 8 weeks, however, dropped significantly from previous levels and all treatments were within acceptable levels with the exception of the Peafowl fertilizer at both treatments which remained high. By 12 WAP, NO_3 and NH_4 levels were within recommended levels and remained within these recommended levels for the duration of the study. While all treatments were within recommended levels, Polyon at the 9.8 g N/m^2 had higher NO_3 levels at 12 and 16 WAP than other treatments, possibly because it is a controlled released fertilizer (CRF). This indicates that while CRF may have lower N levels in soil water after initial application, it may continue to leach more N than other fertilizer sources over time.

Water pH and EC. There were no differences in soil solution pH among any treatment throughout the study (Table 1.6). EC level of Peafowl fertilizer (9.8 g N/m^2) was significantly higher than all other treatments at 2 WAP (Table 1.6). At 4 WAP, Peafowl (9.8 g N/m^2), and CPL at 19.6, 29.4, 39.2, and 49.0 g N/m^2 had the highest EC levels. By 8 WAP Peafowl (9.8 g N/m^2) and CPL (49.0 g N/m^2) had the highest EC levels among any treatment, however CPL (49.0 g N/m^2) was statistically similar to other treatments. At 12 WAP, CPL (39.2 g N/m^2) had the highest EC level; however EC levels were similar to both rates of Peafowl fertilizer, Polyon at 9.8 g N/m^2, and CPL at 19.6 and 49.0 g N/m^2. At the conclusion of the study (16 WAP) there were minor differences in EC levels among treatments.

Experiement 2

Growth indices (GI) and Dry weights (DW). Petunia GI at 4 WAP indicated that Peafowl fertilizer at both rates (4.9 and 9.8 g N/m^2) along with CPL at rates of 19.6, 29.4, 39.2, and 49.0 g N/m^2 grew the largest plants, a trend that continued at 8 WAP (Table 2.1). By 12 WAP petunias were largest when fertilized with Peafowl (4.9 g N/m^2) and CPL at rates of 19.6, 29.4, 39.2, and 49.0 g N/m^2. As in experiment 1, petunia DW indicated that plants fertilized with CPL were statistically similar to plants fertilized with inorganic fertilizers at the same rate.

At 4 WAP, Peafowl (9.8 g N/m^2) along with CPL at rates of 19.6, 29.4, 39.2, and 49.0 g N/m^2 grew the largest verbena according to plant GI (Table 2.1). By 12 WAP Polyon (9.8 g N/m^2) along with all CPL treatments had the highest GI. While verbena GI indicated that CPL grew plants equal to or smaller than the inorganic fertilizers in experiment 1, experiment 2 results show that CPL treatments out-performed Peafowl fertilizer when the same N rate was used. Also, when verbena were fertilized with equal N rates of Polyon and CPL, CPL grew plants larger than or equal in size to those fertilized with Polyon. However, plant DW indicated that the highest rates of CPL (29.4, 39.2, and 49.0 g N/m^2) grew plants statistically similar to, or smaller than inorganic (Peafowl and Polyon) fertilizer treatments. This could be due to the higher N rates in CPL treatments causing plants to become “leggy” and therefore rendering 12 WAP GI inaccurate in respect to true plant size. Little visible differences were observed among verbena for any fertilized treatment at 12 WAP.

Leaf chlorophyll content (LCC). LCC of petunia was generally similar for petunia throughout the study, however small differences did occur (Table 2.2). At 4 WAP, plants in Peafowl fertilizer at both rates along with CPL at 29.4 and 49.0 g N/m^2 had slightly higher LCC than other treatments. LCC was again very similar among most treatments at

8 WAP, however by 12 WAP CPL treatment (4.9 g N/m^2) had a statistically higher LCC than all other treatments except for the highest rates of CPL (39.2 and 49.0 g N/m^2).

Similarly to petunia, verbena LCC at 4 WAP showed little differences between treatments (Table 2.2). However by 8 WAP Peafowl (9.8 g N/m^2), Polyon (4.9 and 9.8 g N/m^2) as well as CPL at 19.6 g N/m^2 had slightly higher LCC. By 12 WAP, verbena fertilized with Polyon (9.8 g N/m^2) had significantly higher LCC than all other treatments.

Tissue Nutrient Content. In general, petunia N and P nutrient content was similar among all treatments, and no differences were observed in leaf K content (Table 2.3). N, P, and K were within recommended ranges (Mills and Jones, 1996). No treatment yielded leaves containing sufficient ranges of Ca or B, however all other nutrients were present in adequate amounts.

Similar to petunia tissue nutrient content, little difference was observed in verbena N levels and all were above sufficiency range (1.43 to 1.90, Mills and Jones, 1996) (Table 2.4). The highest level of CPL (49.0 g N/m^2) had higher leaf P content than all other treatments with the exception of CPL at 39.2 g/N m^2, which was similar to other CPL treatments. Verbena K content was above sufficient levels in all treatments. All other required nutrients were present at equal to or above the sufficiency range, with the exception of Ca and B, which were slightly lower. Only minor differences occurred in micronutrient content with the exception of Mn which decreased as the level of CPL increased.

N levels in soil-water as NO_3 - N and NH_4 – N. At 1 WAP, there were minor differences in NO_3 levels in water, and all treatments were equal to or less than the non-fertilized control (Table 2.5). NH_4 levels were also similar among all treatments, and the only significant difference occurred among Polyon (4.9 g N/m^2) and CPL (9.8 g N/m^2) in which Polyon fertilized plots had significantly higher water NH_4 levels than the CPL (9.8 g N/m^2) plots. At 2 WAP however, Peafowl (4.9 g N/m^2) had significantly higher NO_3 levels in water than any other treatment, similar to results in experiment 1. No differences were observed in water NH_4 at 2 WAP. At 4 WAP Peafowl (4.9 g N/m^2) again had the highest levels of NO_3 in soil water (14.9 ppm) and was the only treatment with NO_3 levels exceeding the recommended range (10 ppm, EPA, 1972). While Peafowl (4.9 g N/m^2) levels were high, levels were similar to Peafowl (9.8 g N/m^2) and CPL (39.2 g N/m^2). Again, no differences were observed in NH_4 at 4 WAP. By 8 WAP all NO_3 levels were within acceptable ranges and all treatments had NO_3 levels similar to the non-fertilized control, a trend that continued at 12 WAP. NH_4 levels at 8 WAP indicated no difference among any treatment, however by 12 WAP CPL (29.4 g N/m^2) again had very high NH_4 levels exceeding recommended levels, however NH_4 levels of CPL at 29.4 g N/m^2 were similar to CPL at rates of 9.8, 19.6, and 29.4 g N/m^2.

Water pH and EC. No differences were observed in water pH among any treatment until 8 WAP when CPL (39.2 g N/m^2) became only significantly higher than CPL at 4.9 g N/m^2 and the non-fertilized control (Table 2.6). At 12 WAP water pH was highest in CPL treatments 19.6, 39.2, and 49.0 g N/m^2.

Water EC levels were similar among most treatments at 1 WAP (Table 2.6). The only difference observed in water EC levels was among CPL (19.6 g N/m^2) and CPL 9.8, 29.4, and 39.2 g N/m^2. At 2 WAP the only difference observed was that CPL (49.0 g N/m^2) was significantly higher than both rates of Polyon, as well as CPL at 4.9 and 9.8 g N/m^2. By 8 WAP EC levels began to level off, and only CPL (39.2 g N/m^2) and Polyon (9.8 g N/m^2) were different. At 12 WAP, and CPL (39.2 g N/m^2) had slightly higher EC levels than all other treatments with the exception of Peafowl (4.9 g N/m^2) and CPL (19.6 g N/m^2) which were statistically similar.

Experiment 3

Growth indices (GI) and Dry weights (DW). At 4 WAP plant GI indicated that petunias fertilized with CPL at 29.4 g N/m^2 were largest, however GIs were similar to petunias fertilized with Peafowl fertilizer (9.8 g N/m^2), and CPL at 4.9, 39.2, and 49.0 g N/m^2 (Table 3.1) At 8 WAP petunias were largest when grown in CPL at 29.4, 39.2, and 49.0 g N/m^2; however petunias were statistically similar to petunias fertilized with Peafowl (9.8 g N/m^2), Polyon (4.9 g N/m^2), and CPL at 4.9 g N/m^2. By 12 WAP petunias were largest when fertilized with CPL at a rate of 49.0 g N/m^2; however petunias were equally as large when fertilized with Peafowl (9.8 g N/m^2) and CPL at rates of 29.4 and 39.2 g N/m^2. As in experiments 1 and 2, petunias grew as well in CPL treatments compared with inorganic fertilizers when the same N rate was applied. Dry weights tended to increase as N rate increased (Table 3.1). The largest difference observed among petunia DW in fertilized plots was between CPL (49.0 g N/m^2) and Peafowl (4.9 g N/m^2). In general, all other treatments had similar DW. In addition, as in the previous two experiments, petunia DW were statistically similar among plants fertilized with CPL and Peafowl or Polyon at the same N rate.

At 4 WAP dusty miller fertilized with Peafowl (9.8 g N/m^2) were significantly larger than all other treatments (Table 3.1). By 12 WAP dusty miller fertilized with Polyon (9.8 g N/m^2) were larger than all other treatments with the exception of Peafowl (9.8 g N/m^2) which were statistically similar. As expected, dusty miller DW fertilized with Polyon (9.8 g N/m^2) were larger than all other treatments, however differences were not significant with the exception of CPL at 29.4 and 39.2 g N/m^2) which had significantly less plant DW.

Leaf chlorophyll content (LCC). As in experiments 1 and 2, at 4 WAP petunias showed only minor differences in LCC. At 8 WAP differences became more pronounced as Polyon (9.8 g N/m^2) had significantly higher LCC than all other treatments. This trend continued at 12 WAP, however by 12 WAP Polyon (4.9 g N/m^2) and CPL (49.0 g N/m^2) were statistically similar.

Dusty miller LCC were in general fairly similar among most treatments at 4 WAP and by 8 WAP no differences were observed. At 12 WAP Polyon treatments at both rates grew dusty miller with the highest LCC, however LCC was similar to Peafowl brand (9.8 g N/m^2), and CPL at rates of 4.9, 19.6, 39.2, and 49.0 g N/m^2.

Tissue Nutrient Content. Petunias fertilized with Polyon (either rate) along with CPL (49.0 g N/m^2) had higher foliar N content than other treatments (Table 3.3). P content was highest in petunias fertilized with CPL at 39.2 and 49.0 g N/m^2. K was also highest in petunias grown in CPL. All other essential nutrients were within sufficiency ranges (Mills and Jones, 1996) with the exception of Ca and B which were slightly less. Mn decreased while Na tended to increase as the rate of CPL increased.

Dusty miller foliar N content was highest in Polyon (4.9 g N/m^2), however N levels were similar to Polyon at 9.8 g N/m^2, and CPL at 39.2 and 49.0 g N/m^2 (Table 3.4). P content was highest in treatments fertilized with CPL, and P content tended to increase as the rate of CPL increased. Again, all nutrients were present within the sufficiency ranges with the exception of Ca and B which were slightly less. As in petunia, Mn tended to decrease as the rate of CPL increased.

N levels in soil-water as NO_3 - N and NH_4 – N. At 1 WAP NO_3 levels were similar and only Polyon (9.8 g N/m^2) and CPL (29.4 g N/m^2) were significantly different (Table 3.5). NH_4 levels were highest in CPL (29.4 g N/m^2) at 1 WAP, however no treatment was within EPA recommended levels. At 2 WAP, NO_3 levels were highest in CPL (29.4 g N/m^2), however NO_3 levels were similar in plots fertilized with CPL (39.2), Peafowl brand (9.8 g N/m^2), and Polyon (4.9 g N/m^2). No differences were observed in water NH_4 levels at 2 WAP. At 4 WAP, again, CPL (29.4 g N/m^2) had higher NO_3 levels than all other treatments, and NH_4 levels were similar among all treatments. Similarly to experiment 2, by 8 WAP, no differences occurred in water NO_3 and NH_4, a trend that continued throughout the duration of experiment 3.

Water pH and EC. At 1 WAP, soil solution pH was highest in CPL (49.0 g N/m^2), however pH levels of plots fertilized with Peafowl (4.9 g N/m^2), Polyon (4.9 and 9.8 g

N/m^2), as well as CPL (rates of 4.9, 9.8, 19.6, and 39.2 g N/m^2) were similar (Table 3.6). At 2 WAP pH levels were generally similar among all treatments with the exception of Polyon (4.9 g N/m^2) and the non-fertilized control which were significantly more alkaline than Peafowl brand (9.8 g N/m^2). At 4 WAP no differences were observed in water pH. Small differences occurred at 8 WAP, however by 12 WAP all treatments were statistically similar.

EC levels were similar at 1 WAP, and only CPL (29.4 g N/m^2) had a significantly higher EC level than Peafowl (9.8 g N/m^2), Polyon (9.8 g N/m^2), CPL (4.9 g N/m^2), and the non-fertilized control. By 2 WAP EC levels began to increase as the rate of CPL increased and by 4 WAP CPL (49.0 g N/m^2) had a significantly higher EC level than all other treatments with the exception of CPL at 39.2 g N/m^2, which was statistically similar, a trend that continued at 8 WAP. By 12 WAP, the two highest CPL rates still had the highest EC levels, but where now statistically similar to Peafowl brand (4.9 g N/m^2), Polyon (9.8 g N/m^2), and CPL treatments 9.8, 19.6, 29.4, and 39.2 g N/m^2.

Discussion

Similarities among treatments in these studies indicate that use of CPL as a fertilizer for landscape annual bedding plants could produce plants equal to or larger than plants fertilized with traditional commercially available inorganic fertilizers. Final plant GI and DW in all three experiments indicate that petunias grew as large or larger when fertilized with CPL compared to an inorganic fertilizer at the same rate. Verbena GI and DW in experiment 1 also demonstrate that verbena grew similarly when fertilized with equal rates of CPL compared to inorganic fertilizers, and in experiment 2, plants fertilized with CPL grew better than when fertilized with inorganic fertilizers. In experiment 3, dusty miller also grew as large in CPL treatments in comparison to inorganic fertilizer treatments. Both petunia and verbena growth tended to increase in size as the rate of CPL increased.

Comparatively, a study by Altland (2002) evaluated the growth of ‘Peppermint Cooler’ vinca (*Catharanthus roseus* (L.) G. Don ‘Peppermint Cooler’), ‘Bonanza Yellow’ marigold (*Tagetes patula* L. ‘Bonanza Yellow’), and ‘Hawaii Blue’ ageratum (*Ageratum houstonianum* Mill. ‘Hawaii Blue’) when fertilized with different fertilizer formulations, methods of application, and frequencies. Fertilizer treatments were applied to landscape bedding plants in raised beds simulating an urban landscape. Fertilizers evaluated included: Osmocote 14-14-14 and 17-7-12 controlled release fertilizers (CRF’s), 13-13-13 and 15-0-15 granular water-soluble (GWS), and industry practice treatment (IP) of incorporating a CRF preplant and topdressing a GWS fertilizer postplant, and an organically-based fertilizer (OBF) composed of recycled newspaper and raw chicken manure. Results from this study indicate the organically based fertilizer resulted in larger, more attractive (higher foliar color ratings) plants than inorganic fertilizers. Our study had similar results in that CPL treatments generally grew plants as large as or larger than the inorganic fertilizers; however in some cases the CPL treatment had a much higher N rate than the inorganic treatments.

There were few differences in LCC of petunia or verbena in experiment 1. In experiment 1 at 12 WAP, petunias did have the highest LCC when fertilized with CPL (49.0 g N/m^2), however LCC were similar to Peafowl (9.8 g N/m^2), Polyon (4.9 g N/m^2), and CPL at both 29.4 and 39.2 g N/m^2. In the same experiment, verbena LCC were similar among all treatments at 12 WAP with the exception of the non-fertilized control, which had significantly less LCC than all other treatments except the lowest rate of CPL. At the conclusion of experiment 2, petunias had the highest LCC when fertilized with CPL at 4.9 g N/m^2, while verbena had the highest LCC when fertilized with Polyon at the 9.8 g N/m^2 rate. In experiment 3, petunias had the lower LCC when fertilized with CPL in comparison with the inorganic equivalent. Dusty miller also had the highest LCC when fertilized with either rate of Polyon, however LCC were similar to Peafowl brand (9.8 g N/m^2), and CPL at rates of 4.9, 19.6, 39.2, and 49.0 g N/m^2. While few differences did occur over the course of the three experiments, visual differences in foliar color were non-existent.

Tissue nutrient content also yielded very few differences among treatments, and all fertilized plants had sufficient levels of most required nutrients.

NO_3 and NH_4 levels in experiment 1 were extremely high in comparison with results from experiments 2 and 3, and levels remained high in most treatments until 8 WAP. This is possibly due to drought conditions for the initial portion of the study, which slowed N leaching. In all three experiments, N leaching (NO_3 and NH_4) from CPL was less than or equal to N leaching compared to inorganic fertilizers at the same N rate.

A similar sequence of studies was conducted by Altland (2002) in which organically based fertilizers (OBF) (fresh cage layer poultry manure + recycled newspapers) were compared with commonly used inorganic fertilizer formulations. Altland reported that the OBF had higher total soil-water N ($NO_3 + NH_4$) in comparison with the inorganic formulations in the majority of experiments conducted. However, Atland's studies evaluated fresh poultry manure, while our experiments used fully composted poultry litter. While composting litter prior to application will result in the loss of some nutrients, it may be beneficial in terms of reducing odor and non-point source pollution from N leaching.

In experiment 1, Peafowl (9.8 g N/m^2) had the highest NH_4 levels at 2, 4, and 8 WAP and the highest NO_3 levels at 4 and 8 WAP. N leaching in experiment 1 from the inorganic fertilizers was similar to CPL N leaching, even when 5 times the fertilizer rate was applied using CPL. In experiment 2, NO_3 and NH_4 leaching from CPL treatments was equal to or less than N leaching from inorganic treatments, with an exception of samples taken at 8 WAP, when CPL (39.2 g N/m^2) NO_3 water levels were significantly higher than either Peafowl or Polyon brand fertilizers; however a much higher N rate was applied via CPL. At 12 WAP NH_4 water levels were also higher in CPL treatments. Experiment 3 water samples indicate NH_4 levels were also highest at 1 WAP in CPL (29.4 g N/m^2), however no other differences occurred throughout the duration of the study. NO_3 levels were also highest in CPL (29.4 g N/m^2) at 2 and 4 WAP, however by 8 WAP no other differences in water NO_3 levels occurred.

In experiment 1, NO_3 and NH_4 levels were consistently higher than recommended levels until 8 WAP. While total N leaching was less in experiments 2 and 3, especially in earlier weeks, NO_3 and NH_4 levels exceeded recommended levels throughout the studies. A similar situation was reported by Timmons and Holt (1977) where mean annual flow-weighted concentration of inorganic N (NH_4 + NO_3) in surface runoff from unfertilized native prairie was 1.3 mg/L, with a maximum value of 13.6 mg/L observed during a 5 year study. In addition, Sharpley et al., (1983) reported NH_4 in runoff from unfertilized pasture (0.9 mg/L) and NO_3 levels consistently higher than the critical values associated with accelerated eutrophication (0.3 mg/L). Consequently, Sharpley (et al., 1983) reported that it appears to be unrealistic to attempt to attain or maintain NH_4 or NO_3 concentration in surface runoff from fertilized agricultural land, below the recommended levels.

The liming effects of poultry litter have been well documented (Hue, 1992; Kingery et al., 1993) and the EPA has set guidelines stating that soil solution pH levels should remain between 6.5 and 8.5. If pH becomes acidic (below 6.5), drinking water can have a bitter metallic taste and corrosion of pipes and other plumbing can occur. If pH rises above 8.5, the water can have a “slippery” feel and can cause deposits in certain materials (EPA, 2009). In our study, no differences occurred in soil solution pH levels in experiment 1, however pH was slightly more acidic at all dates than recommended (EPA, 1972). In experiment 2, all treatments had similar pH levels until 8 WAP, but only CPL (39.2 g N/m^2) and CPL (4.9 g N/m^2) were significantly higher. By 12 WAP in experiment 2, the higher rates of CPL tended to have higher pH, which was expected. Soil solution pH remained within acceptable levels throughout the duration of experiment 2. Differences did occur in water pH in experiment 3, however at the conclusion of the study no differences were observed, and CPL did not raise pH above acceptable levels (8.5) (EPA, 1972).

EC levels were highest in treatments having the highest NO_3 and NH_4 levels. Throughout all three experiments, only Peafowl (9.8 g N/m^2) in experiment 1 at 2 WAP had an EC level of 4.9, which could be damaging to more sensitive crops; however, these levels dissipated quickly, and no negatives effects occurred in this experiment.

In summary, results from these experiments demonstrate that CPL can be used successfully as a fertilizer for annual bedding plants. In most cases, plants grew as well or better when equal rates of fertilizer were applied either using CPL or commercially available inorganic fertilizer formulations. In respect to non-point source pollution, these experiments also indicate that composted poultry litter could be used at much higher rates of N than inorganic fertilizers resulting in plants with greater size while minimizing negative environmental impacts. As fertilizer prices continue to rise, landscapers and homeowners will begin to look for alternatives to expensive inorganic fertilizer sources. CPL could provide nutritional requirements needed for healthy plant growth, and the use of CPL in the landscape will provide poultry producers an outlet for their poultry waste that is environmentally friendly. While CPL and other organic fertilizer sources may never fully replace the need for inorganic fertilizers, CPL can supplement other fertilizer sources while minimizing negative environmental impacts.

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Table 1.1 Effect of fertilizers on growth indices^{Z} and shoot dry weights^{Y} of 'Celebrity Red' petunia and 'Quartz Scarlet' verbena.

Treatment	Rate	'Celebrity Red' Petunia				'Quartz Scarlet' Verbena			
	(g N/m^2)	4 WAP^X	8 WAP	12 WAP	Dry Wt.	4 WAP	8 WAP	12 WAP	Dry Wt.
13-13-13 Peafowl®	4.9	13.5 bc^W	18.6 cd	26.1 cde	123.8 abc	17.1 ab	21.0 bc	22.9 cd	93.6 bc
13-13-13 Peafowl®	9.8	15.3 ab	22.2 ab	28.1 bcd	150.4 a	18.7 a	22.7 ab	25.4 abcd	113.2 ab
13-13-13 Polyon®	4.9	12.5 cd	16.8 d	24.5 de	92.1 bc	16.1 b	22.3 abc	26.0 ab	111.0 ab
13-13-13 Polyon®	9.8	13.6 abc	20.8 bc	30.2 ab	127.3 ab	16.6 ab	23.1 ab	25.5 abc	109.7 ab
CPL^V	4.9	13.4 bc	20.6 bc	26.9 bcd	109.2 bc	15.6 b	22.6 ab	24.6 bcd	107.7 ab
CPL	9.8	14.2 abc	21.6 bc	27.8 bcd	121.9 abc	15.4 b	22.8 ab	24.4 bcd	94.0 bc
CPL	19.6	15.5 a	20.8 bc	28.9 bc	126.9 ab	16.1 b	23.2 ab	24.2 bcd	117.1 ab
CPL	29.4	14.4 ab	23.6 ab	30.4 ab	147.6 a	17.1 ab	22.9 ab	25.5 abc	112.5 ab
CPL	39.2	15.1 ab	25.0 a	33.2 a	150.2 a	17.7 ab	23.7 ab	27.6 a	122.5 ab
CPL	49	13.8 abc	22.9 ab	30.7 ab	156.5 a	16.3 b	24.1 a	26.2 ab	126.1 a
Non-fertilized control	***	11.3 d	16.0 d	22.8 e	90.1 c	15.7 b	19.8 c	22.7 d	78.6 c

[Z] Growth indices = [(height + width1 + width2)/3]

[Y] Dry weights measured in grams, taken from average dry weight of 5 plants per plot from each replication.

[X] WAP = Weeks after planting.

[W] Means separated within columns using Duncan's Mutliple Range Test (alpha = 0.05).

[V] CPL = Composted poultry litter.

Table 1.2 Effect of fertilizers on leaf chlorophyll content[Z] of 'Celebrity Red' petunia and 'Quartz Scarlet' verbena.

Treatment	Rate	'Celebrity Red' Petunia			Quartz Scarlet' Verbena		
	(g N/m^2)	4 WAP[Y]	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
13-13-13 Peafowl®	4.9	48.8 a[X]	49.0 abc	38.1 c	45.6 a	44.7 a	43.0 a
13-13-13 Peafowl®	9.8	48.4 a	48.9 abc	43.5 ab	49.0 a	44.4 a	42.9 a
13-13-13 Polyon®	4.9	46.9 a	48.2 abc	42.7 ab	46.6 a	46.0 a	45.2 a
13-13-13 Polyon®	9.8	48.9 a	49.5 ab	42.0 bc	47.8 a	46.4 a	42.5 a
CPL[W]	4.9	46.5 a	44.4 C	40.4 bc	45.2 a	43.0ab	40.4 ab
CPL	9.8	49.2 a	46.9 bc	41.8 bc	45.1 a	41.5 ab	44.3 a
CPL	19.6	46.6 a	46.3 bc	40.5 bc	44.2 a	43.2 ab	42.4 a
CPL	29.4	48.0 a	46.2 bc	44.1 ab	45.0 a	45.3 a	43.3 a
CPL	39.2	47.9 a	47.5 abc	44.2 ab	47.5 a	45.8 a	42.0 a
CPL	49	49.8 a	51.9 a	46.7 a	46.4 a	47.2 a	44.7 a
Non-fertilized control	***	47.2 a	46.0 bc	41.9 bc	45.0 a	38.3 b	36.2 b

[Z] Leaf chlorophyll content quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) (average of 5 leaves per plant).

[Y] WAP = Weeks after planting.

[X] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test. (alpha = 0.05).

[W] CPL = Composted poultry litter.

Table 1.3 Effect of fertilizer on tissue nutrient content of *Petunia spp.* 'Celebrity Red', Experiment 1.

	Rate	Tissue Nutrient Content^{Z}																
Treatment	(g N/m^{2})	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)	Cd (ppm)	Cr (ppm)	Na (ppm)	Ni (ppm)	Pb (ppm)	C (%)
13-13-13 Peafowl®	4.9	2.0 b^{Y}	0.25 d	4.8 a	0.85 ab	0.27 ab	24.8 ab	350.6 ab	110.4 ab	11.6 abc	88.0 ab	509.0 ab	2.4 b	1.3 b	637.8 e	2.0 ab	8.3 ab	40.3 d
13-13-13 Peafowl®	9.8	2.2 ab	0.27 cd	4.8 a	0.87 ab	0.28 ab	23.0 b	293.2 ab	118.0 a	9.8 c	92.0 ab	410.2 ab	0.14 b	0.0 b	813.4 de	0.66 b	5.4 b	40.6 bcd
13-13-13 Polyon®	4.9	2.1 ab	0.25 d	4.4 a	0.91 ab	0.28 ab	21.8 b	402.2 a	111.2 ab	17.2 ab	88.8 ab	592.0 a	0.34 b	0.10 b	565.4 e	0.34 b	6.6 b	40.5 cd
13-13-13 Polyon®	9.8	2.4 a	0.27 cd	4.7 a	0.91 ab	0.30 a	22.6 b	329.6 ab	104.0 abc	11.1 abc	85.4 ab	440.6 ab	0.16 b	0.12 b	680.8 e	0.48 b	12.0 ab	41.1 abcd
CPL^{X}	4.9	2.0 ab	0.26 d	4.4 a	0.87 ab	0.27 ab	22.0 b	410.2 a	110.0 ab	17.6 a	83.2 ab	621.2 a	0.20 b	0.0 b	785.0 de	1.1 b	12.4 ab	41.0 abcd
CPL	9.8	2.1 ab	0.26 d	4.2 a	0.88 ab	0.26 b	21.2 b	330.6 ab	93.0 bc	12.8 abc	80.4 ab	491.6 ab	0.22 b	0.0 b	1128.8 d	0.0 b	11.1 ab	41.4 abc
CPL	19.6	2.1 ab	0.29 bc	4.5 a	0.90 ab	0.27 ab	29.2 a	381.6 ab	102.0 abc	17.6 a	87.2 ab	566.2 ab	7.5 a	6.8 a	1617.8 c	6.1 a	15.8 a	41.4 abc
CPL	29.4	2.1 ab	0.30 ab	4.4 a	0.88 ab	0.26 b	21.8 b	296.4 ab	107.4 abc	11.8 abc	79.2 ab	422.8 ab	0.2 b	0.08 b	2007.8 bc	0.0 b	7.3 b	41.4 abc
CPL	39.2	2.1 ab	0.32 ab	4.7 a	0.88 ab	0.28 ab	22.2 b	251.8 b	97.6 abc	9.9 c	82.8 ab	371.2 b	0.18 b	0.34 b	2336.0 b	0.0 b	6.1 b	41.9 a
CPL	49	2.2 ab	0.33 a	4.8 a	0.79 b	0.26 b	21.4 b	371.2 ab	87.2 c	9.5 c	76.6 b	543.2 ab	0.24 b	0.0 b	2987.8 a	0.42 b	8.6 ab	41.5 ab
Non-fertilized control	***	2.0 ab	0.26 d	4.9 a	0.99 a	0.29 ab	22.5 b	418.0 a	108.5 ab	10.6 bc	96.0 a	600.8 a	0.25 b	0.10 b	657.5 e	0.70 b	9.4 ab	41.6 a
Sufficiency range^{V}		*1.43 - 1.90*	*0.10 - 0.13*	*0.40 - 0.52*	*2.0 - 2.9*	*0.13 - 0.15*	*55 - 126*	*58 - 69*	*15 - 35*	*4 - 6*	*7 - 10*	*N/A*^{U}	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*

[Z] Tissue analysis performed on 20 terminal shoots (5.1 cm - 7.6 cm or 2-3 in of most recently mature leaves) per plant; N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum, Cd = cadmium, Cr = chromium, Na = sodium, Ni = nickle, Pb = lead, C = carbon.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

[V] Sufficiency range published by Mills and Jones (1996).

[U] N/A = Not applicable.

Table 1.4 Effect of fertilizer on tissue nutrient content of *Verbena hybrida*. 'Quartz Scarlet', Experiment 1.

	Rate	Tissue Nutrient Content[Z]																
Treatment	(g N/m^2)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)	Cd (ppm)	Cr (ppm)	Na (ppm)	Ni (ppm)	Pb (ppm)	C (%)
13-13-13 Peafowl®	4.9	1.9 a	0.25 e	3.1 a	1.2 a	0.47 abc	28.2 b	330.8 b	290.0 a	12.3 ab	118.0 a	461.8 b	1.4 b	1.4 b	179.6 bcde	3.3 a	3.7 b	42.5 a
13-13-13 Peafowl®	9.8	2.0 a	0.25 de	2.6 c	1.2 a	0.47 abc	27.8 b	1760.2 a	261.4 a	9.5 ab	95.8 bcd	2042.8 a	0.0 b	2.2 ab	153.2 e	3.4 a	5.1 b	41.1 a
13-13-13 Polyon®	4.9	1.9 a	0.27 de	2.8 abc	1.1 a	0.48 ab	26.4 b	332.8 b	211.4 b	12.2 ab	94.6 bcd	496.2 b	0.0 b	0.0 b	155.6 de	2.6 a	0.5 b	42.3 a
13-13-13 Polyon®	9.8	2.0 a	0.27 de	2.9 abc	1.1 a	0.51 a	26.4 b	341.0 b	202.8 bc	12.1 ab	100.8 abc	480.0 b	0.0 b	0.3 b	197.6 abcd	2.3 a	1.6 b	43.4 a
CPL[X]	4.9	1.9 a	0.29 cd	2.7 c	1.2 a	0.49 ab	27.4 b	282.2 b	182.6 bc	9.3 ab	96.0 bcd	432.2 b	0.0 b	0.1 b	151.0 e	1.9 a	4.4 b	43.3 a
CPL	9.8	1.9 a	0.30 cd	2.8 abc	1.1 a	0.50 a	27.6 b	295.2 b	186.6 bc	6.5 b	88.2 bcde	440.8 b	0.0 b	0.0 b	158.0 cde	2.3 a	0.6 b	42.4 a
CPL	19.6	1.9 a	0.34 bc	2.8 bc	1.1 a	0.48 ab	33.2 a	279.2 b	181.0 bc	14.0 a	99.0 abc	406.8 b	5.3 a	5.2 a	167.6 cde	6.3 a	10.7 a	43.2 a
CPL	29.4	1.9 a	0.32 c	2.9 abc	0.9 b	0.39 d	24.0 b	229.2 b	161.8 c	7.6 ab	75.0 ed	312.8 b	0.0 b	0.0 b	215.2 ab	1.3 a	0.7 b	42.3 a
CPL	39.2	1.9 a	0.37 ab	2.9 abc	1.1 ab	0.44 bcd	26.8 b	721.0 ab	164.0 c	8.7 ab	72.8 e	473.0 b	0.1 b	0.4 b	201.0 abc	1.9 a	1.8 b	43.3 a
CPL	49	2.0 a	0.40 a	3.0 ab	1.1 ab	0.42 cd	26.2 b	358.6 b	182.2 bc	11.0 ab	80.6 cde	528.4 b	0.0 b	0.7 b	232.8 a	1.9 a	2.5 b	43.0 a
Non-fertilized control	***	1.7 a	0.33 bc	2.7 c	1.2 a	0.51 a	26.4 b	436.6 b	255.4 a	13.8 a	105.8 ab	662.0 b	0.2 b	0.0 b	158.0 cde	3.1 a	0.7 b	42.6 a
Sufficiency range[V]		*1.43 - 1.90*	*0.10 - 0.13*	*0.40 - 0.52*	*2.0 - 2.9*	*0.13 - 0.15*	*55 - 126*	*58 - 69*	*15 - 35*	*4 - 6*	*7 - 10*	*N/A*[U]	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*

[Z] Tissue analysis performed on 20 terminal shoots (5.1 cm - 7.6 cm or 2-3 in of most recently mature leaves) per plant; N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum, Cd = cadmium, Cr = chromium, Na = sodium, Ni = nickle, Pb = lead, C = carbon.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

[V] Sufficiency range published by Mills and Jones (1996).

[U] N/A = Not applicable.

Table 1.5 Effect of fertilizers on N in soil water, experiment 1.

Treatment	Rate	2 WAP[Z]		4 WAP		8 WAP		12 WAP		16 WAP	
	(g N/m^2)	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4
13-13-13 Peafowl®	4.9	121.0 ab	27.1 a[Y]	111.3 bcd	3.9 b	22.9 b	0.87 b	0.87 b	0.10 ab	0.27 b	0.17 a
13-13-13 Peafowl®	9.8	76.4 bcd	5.3 b	141.6 abc	44.7 a	87.1 a	11.3 a	1.73 b	0.17 a	0.50 b	0.10 a
13-13-13 Polyon®	4.9	62.5 d	4.0 b	74.9 cd	0.4 b	0.93 b	0.07 b	0.20 b	0.03 b	0.23 b	0.07 a
13-13-13 Polyon®	9.8	90.5 abcd	12.9 ab	95.3 bcd	0.9 b	8.9 b	0.10 b	3.27 a	0.17 a	2.4 a	0.10 a
CPL[X]	4.9	103.2 abcd	3.0 b	54.9 d	0.4 b	0.80 b	0.17 b	0.83 b	0.03 b	0.20 b	0.17 a
CPL	9.8	73.8 cd	9.3 ab	102.6 bcd	0.7 b	6.0 b	0.13 b	0.30 b	0.0 b	0.13 b	0.10 a
CPL	19.6	118.2 abc	7.4 ab	194.4 a	2.8 b	2.9 b	0.17 b	0.63 b	0.03 b	1.0 ab	0.27 a
CPL	29.4	79.7 bcd	7.0 ab	104.8 bcd	1.1 b	3.7 b	0.10 b	0.97 b	0.07 ab	0.87 ab	0.13 a
CPL	39.2	128.6 a	5.5 b	129. 0 abcd	1.6 b	1.3 b	0.23 b	0.67 b	0.06 ab	0.37 b	0.13 a
CPL	49	114.1 abc	21.7 ab	165.6 ab	3.1 b	8.8 b	0.27 b	0.17 b	0.0 b	0.53 b	0.20 a
Non-fertilized control	***	68.8 d	0.9 b	77.0 cd	0.2 b	1.3 b	0.17 b	0.50 b	0.0 b	0.53 b	0.10 a

[Z] WAP = Weeks after planting.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

Table 1.6 Effect of fertilizers on pH and electrical conductivity of soil water, experiment 1.

Treatment	Rate	2 WAP^Z		4 WAP		8 WAP		12 WAP		16 WAP	
	(g N/m^2)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)
13-13-13 Peafowl®	4.9	5.4 a	1.3 b	5.7 a	1.3 abcd	5.7 a	0.6 b	6.1 a	0.29 abcd	6.0 a	0.25 ab
13-13-13 Peafowl®	9.8	5.5 a	4.9 a	5.8 a	1.7 ab	5.3 a	1.4 a	5.7 a	0.53 ab	5.6 a	0.33 a
13-13-13 Polyon®	4.9	5.5 a	0.8 b	5.9 a	0.6 d	6.0 a	0.2 b	6.1 a	0.20 bcd	5.7 a	0.16 ab
13-13-13 Polyon®	9.8	6.1 a	1.1 b	6.3 a	0.9 bcd	6.1 a	0.3 b	6.0 a	0.28 abcd	5.9 a	0.25 ab
CPL^X	4.9	6.2 a	1.2 b	6.3 a	0.8 dc	6.1 a	0.3 b	6.2 a	0.21 bcd	5.9 a	0.16 ab
CPL	9.8	6.2 a	1.1 b	6.0 a	1.0 bcd	5.8 a	0.3 b	5.9 a	0.26 bcd	5.8 a	0.18 ab
CPL	19.6	5.7 a	1.8 b	6.1 a	2.0 a	5.9 a	0.7 b	6.2 a	0.30 abcd	5.9 a	0.29 ab
CPL	29.4	5.2 a	1.7 b	5.7 a	1.2 abcd	5.9 a	0.4 b	6.0 a	0.27 bcd	6.2 a	0.20 ab
CPL	39.2	5.9 a	2.2 b	5.6 a	1.5 abc	6.0 a	0.7 b	5.7 a	0.60 a	6.0 a	0.25 ab
CPL	49	5.4 a	1.7 b	5.6 a	1.9 a	6.1 a	0.8 ab	6.2 a	0.49 abc	6.2 a	0.28 ab
Non-fertilized control	***	5.7 a	0.8 b	6.1 a	0.6 dc	6.3 a	0.2 b	6.2 a	0.16 d	6.2 a	0.13 b

[Z] WAP = Weeks after planting.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

Table 2.1 Effect of fertilizers on growth indices^{Z} and shoot dry weights^{Y} of 'Celebrity Red' petunia and 'Quartz Scarlet' verbena.

Treatment	Rate	'Celebrity Red' Petunia				'Quartz Scarlet' Verbena			
	(g N/m^{2})	4 WAP^{X}	8 WAP	12 WAP	Dry Wt.	4 WAP	8 WAP	12 WAP	Dry Wt.
13-13-13 Peafowl®	4.9	24.7 a	38.3 a	40.2 abcd	231.7 ab	14.2 cd	27.1 ab	26.4 c	189.4 abc
13-13-13 Peafowl®	9.8	25.2 a	38.8 a	39.2 bcd	252.8 a	17.0 a	26.9 abc	26.2 c	187.5 abc
13-13-13 Polyon®	4.9	19.2 cd	32.7 b	38.2 d	221.0 ab	12.7 e	26.2 abc	27.0 bc	191.7 abc
13-13-13 Polyon®	9.8	17.8 d	33.3 b	39.1 bcd	233.5 ab	13.4 de	26.7 abc	28.8 ab	233.8 a
CPL^{V}	4.9	19.5 c	32.2 b	38.2 d	215.6 ab	14.2 cd	28.1 a	29.7 a	224.9 ab
CPL	9.8	21.4 b	33.6 b	38.5 cd	226.7 ab	15.2 bc	27.3 ab	29.3 a	207.7 abc
CPL	19.6	24.0 a	38.8 b	41.3 abc	232.2 ab	16.2 ab	27.7 a	29.0 ab	200.7 abc
CPL	29.4	24.4 a	39.0 a	41.6 ab	263.2 a	16.3 ab	26.7 abc	27.8 abc	180.2 bc
CPL	39.2	25.5 a	40.9 a	42.7 a	274.0 a	16.11 ab	25.3 bc	28.7 ab	170.9 c
CPL	49	25.0 a	41.0 a	42.4 a	262.5 a	17.0 a	26.3 abc	30.1 a	176.6 bc
Non-fertilized control	***	18.2 cd	34.5 b	34.8 e	177.9 b	12.6 e	24.7 c	24.0 d	164.9 c

^{Z}Growth indices = [(height + width1 + width2)/3]

^{Y}Dry weights measured in grams, taken from average dry weight of 5 plants per plot from each replication.

^{X}WAP = Weeks after planting.

^{W}Means separated within columns using Duncan's Mutliple Range Test (alpha = 0.05).

^{V}CPL = Composted poultry litter.

Table 2.2 Effect of fertilizers on leaf chlorophyll content^Z of 'Celebrity Red' petunia and 'Quartz Scarlet' verbena.

Treatment	Rate	'Celebrity Red' Petunia			Quartz Scarlet' Verbena		
	(g N/m^2)	4 WAP^Y	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
13-13-13 Peafowl®	4.9	46.0 ab	36.3 bc	32.5 b	53.1 abc	47.5 b	36.2 bcd
13-13-13 Peafowl®	9.8	47.3 a	36.8 abc	32.7 b	53.4 ab	48.7 ab	37.4 bcd
13-13-13 Polyon®	4.9	43.3 bcd	38.7 ab	35.8 b	50.9 abc	48.7 ab	37.4 bcd
13-13-13 Polyon®	9.8	43.7 bc	39.1 a	36.3 b	50.4 bc	51.5 a	45.6 a
CPL^W	4.9	43.2 bcd	39.1 a	51.0 a	51.4 abc	48.4 b	40.1 b
CPL	9.8	42.4 cd	36.9 abc	35.5 b	52.2 abc	46.1 b	38.3 bcd
CPL	19.6	42.6 cd	37.0 abc	33.5 b	49.8 c	49.2 ab	34.4 cd
CPL	29.4	45.4 abc	37.7 abc	36.4 b	51.5 abc	48.3 b	37.4 bcd
CPL	39.2	44.1 bc	36.0 c	37.8 ab	54.3 a	48.2 b	36.2 bcd
CPL	49	44.8 abc	37.1 abc	38.1 ab	53.4 ab	47.5 b	38.5 bc
Non-fertilized control	***	40.5 d	35.4 c	31.0 b	42.9 d	47.6 b	33.7 d

[Z] Leaf chlorophyll content quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) (average of 5 leaves per plant).

[Y] WAP = Weeks after planting.

[X] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test. (alpha = 0.05).

[W] CPL = Composted poultry litter.

Table 2.3 Effect of fertilizer on tissue nutrient content of *Petunia spp.'* Celebrity Red', experiment 2.

	Rate	Tissue Nutrient Content[Z]											
Treatment	(g N/m^2)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)	Na (ppm)
13-13-13 Peafowl®	4.9	2.1 b	0.29 ab	2.0 a	0.80 ab	0.21 ab	29.8 bc	501.6 ab	110.2 a	20.4 bc	137.5 a	533.8 a	996.1 de
13-13-13 Peafowl®	9.8	2.0 b	0.27 b	2.0 a	0.73 b	0.20 ab	29.0 bc	317.1 ab	112.3 a	24.1 abc	142.2 a	258.8 a	1257.3 de
13-13-13 Polyon®	4.9	2.4 ab	0.28 ab	2.0 a	0.80 ab	0.22 a	31.9 ab	320.5 ab	94.7 a	23.7 abc	130.0 a	288.6 a	1269.3 de
13-13-13 Polyon®	9.8	2.4 a	0.28 ab	2.0 a	0.78 ab	0.21 ab	33.3 ab	517.8 ab	105.4 a	26.3 abc	119.8 a	499.0 a	1012.7 de
CPL[X]	4.9	2.3 ab	0.31 ab	2.1 a	0.87 a	0.22 a	32.1 ab	348.8 ab	116.9 a	18.9 bc	131.5 a	325.4 a	1277.9 de
CPL	9.8	2.0 b	0.32 ab	2.1 a	0.82 ab	0.20 ab	28.9 bc	373.6 ab	114.8 a	22.5 bc	136.4 a	351.7 a	1530.4 cd
CPL	19.6	2.2 ab	0.33 ab	2.1 a	0.85 ab	0.20 ab	30.1 abc	689.3 a	125.0 a	35.4 a	121.0 a	580.4 a	1846.7 bc
CPL	29.4	2.3 ab	0.28 ab	2.0 a	0.76 ab	0.20 ab	34.3 a	479.5 ab	91.1 a	31.1 ab	116.0 a	480.3 a	1961.8 bc
CPL	39.2	2.3 ab	0.34 a	2.1 a	0.80 ab	0.20 ab	33.4 ab	269.6 b	99.8 a	17.8 c	130.6 a	237.0 a	2107.6 b
CPL	49	2.1 ab	0.31 ab	2.0 a	0.74 b	0.19 b	29.3 bc	480.3 ab	99.8 a	29.5 abc	124.9 a	450.1 a	2615.8 a
Non-fertilized control	***	2.3 ab	0.27 b	2.0 a	0.77 ab	0.20 ab	26.8 c	338.9 ab	91.8 a	22.8 bc	138.0 a	327.3 a	859.1 e
Sufficiency range[V]		*1.43 - 1.90*	*0.10 - 0.13*	*0.40 - 0.52*	*2.0 - 2.9*	*0.13 - 0.15*	*55 - 126*	*58 - 69*	*15 - 35*	*4 - 6*	*7 - 10*	*N/A*[U]	*N/A*

[Z] Tissue analysis performed on 20 terminal shoots (5.1 cm - 7.6 cm or 2-3 in of most recently mature leaves) per plant; N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum, Na = sodium.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

[V] Sufficiency range published by Mills and Jones (1996).

[U] N/A = Not applicable.

Table 2.4 Effect of fertilizer on tissue nutrient content of *Verbena hybrida.* 'Quartz Scarlet', experiment 2.

	Rate	Tissue Nutrient Content[Z]											
Treatment	(g N/m^2)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)	Na (ppm)
13-13-13 Peafowl®	4.9	2.2 abc	0.25 d	1.6 d	1.2 ab	0.27 b	18.5 c	395.5 a	242.2 a	24.4 a	174.1 ab	410.6 a	198.6 a
13-13-13 Peafowl®	9.8	2.3 abc	0.25 d	1.6 bcd	1.0 b	0.28 ab	21.2 abc	950.3 a	235.2 a	18.1 a	167.4 ab	638.0 a	189.1 a
13-13-13 Polyon®	4.9	2.3 abc	0.26 d	1.6 abcd	1.2 ab	0.28 ab	20.2 abc	278.2 a	235.5 a	20.0 a	172.5 ab	244.9 a	185.2 a
13-13-13 Polyon®	9.8	2.5 a	0.27 d	1.7 ab	1.1 ab	0.27 ab	18.6 c	416.3 a	243.1 a	20.0 a	167.4 ab	228.5 a	166.7 a
CPL[X]	4.9	2.4 ab	0.33 cd	1.7 a	1.2 a	0.29 a	20.4 abc	258.1 a	245.7 a	20.0 a	190.0 a	224.8 a	179.5 a
CPL	9.8	2.2 abc	0.40 bc	1.7 abc	1.3 a	0.28 ab	24.0 a	459.6 a	209.4 abc	25.8 a	163.9 ab	323.6 a	169.8 a
CPL	19.6	2.0 c	0.41 bc	1.6 abcd	1.3 a	0.28 ab	21.6 abc	416.3 a	224.0 ab	23.0 a	167.4 ab	371.7 a	169.5 a
CPL	29.4	2.1 bc	0.42 b	1.6 cd	1.2 ab	0.28 ab	19.8 bc	510.7 a	166.3 c	23.1 a	157.2 ab	485.7 a	172.7 a
CPL	39.2	2.0 bc	0.48 ab	1.7 abcd	1.2 ab	0.29 ab	22.9 ab	314.7 a	186.9 bc	20.5 a	157.2 ab	292.3 a	188.1 a
CPL	49	2.3 abc	0.51 a	1.7 abcd	1.2 ab	0.29 ab	23.5 ab	411.9 a	169.1 c	18.0 a	145.5 b	393.3 a	191.4 a
Non-fertilized control	***	2.2 abc	0.33 cd	1.7 abcd	1.3 a	0.29 a	23.4 ab	255.3 a	251.1 a	25.6 a	173.7 ab	228.9 a	175.5 a
Sufficiency range[V]		*1.43 - 1.90*	*0.10 - 0.13*	*0.40 - 0.52*	*2.0 - 2.9*	*0.13 - 0.15*	*55 - 126*	*58 - 69*	*15 - 35*	*4 - 6*	*7 - 10*	*N/A*[U]	*N/A*

[Z] Tissue analysis performed on 20 terminal shoots (5.1 cm - 7.6 cm or 2-3 in of most recently mature leaves) per plant; N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum, Na = sodium.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

[V] Sufficiency range published by Mills and Jones (1996).

[U] N/A = Not applicable.

Table 2.5 Effect of fertilizers on N in soil water, experiment 2.

Treatment	Rate	1 WAP^Z		2 WAP		4 WAP		8 WAP		12 WAP	
	(g N/m^2)	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4
13-13-13 Peafowl®	4.9	2.7 ab	1.3 ab	12.5 a	3.2 a	14.9 a	1.3 a	1.0 b	1.1 a	1.0 a	1.6 b
13-13-13 Peafowl®	9.8	1.4 ab	0.97 ab	4.7 b	4.1 a	8.4 ab	2.9 a	0.33 b	0.57 a	1.1 a	0.0 b
13-13-13 Polyon®	4.9	0.80 ab	1.6 a	0.43 b	0.90 a	0.43 b	1.4 a	1.2 b	1.0 a	1.1 a	1.3 b
13-13-13 Polyon®	9.8	1.4 ab	1.1 ab	0.40 b	0.53 a	0.50 b	0.70 a	0.43 b	0.67 a	0.87 a	0.40 b
CPL^X	4.9	1.7 ab	0.83 ab	0.63 b	0.47 a	0.53 b	0.67 a	1.4 ab	1.3 a	0.73 a	0.67 b
CPL	9.8	0.10 b	0.30 b	0.53 b	0.83 a	0.43 b	1.0 a	1.5 ab	0.47 a	1.4 a	2.3 ab
CPL	19.6	3.5 a	0.87 ab	0.87 b	0.83 a	0.73 b	1.8 a	1.8 ab	1.7 a	2.8 a	2.7 ab
CPL	29.4	0.67 ab	0.93 ab	6.3 b	1.0 a	0.70 b	1.2 a	1.0 b	2.0 a	3.3 a	2.1 ab
CPL	39.2	0.97 ab	1.4 ab	5.3 b	2.4 a	3.1 ab	3.6 a	6.4 a	1.1 a	0.83 a	10.3 a
CPL	49	2.0 ab	1.2 ab	8.0 b	1.9 a	0.90 b	1.8 a	2.2 ab	0.47 a	0.90 a	0.13 b
Non-fertilized control	***	2.4 ab	0.80 ab	0.53 b	0.83 a	0.43 b	1.2 a	3.4 ab	0.77 a	0.57 a	0.83 b

^{Z}WAP = Weeks after planting.

^{Y}Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

^{X}CPL = Composted poultry litter.

Table 2.6 Effect of fertilizers on pH and electrical conductivity of soil water, experiment 2.

Treatment	Rate	1 WAP^Z		2 WAP		4 WAP		8 WAP		12 WAP	
	(g N/m^2)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)
13-13-13 Peafowl®	4.9	6.6 a	0.23 ab	6.5 a	0.63 ab	7.2 a	0.52 abc	7.3 ab	0.31 ab	6.9 bc	0.39 ab
13-13-13 Peafowl®	9.8	6.8 a	0.25 ab	6.5 a	0.60 ab	6.9 a	0.60 ab	7.3 ab	0.30 ab	6.8 c	0.32 b
13-13-13 Polyon®	4.9	6.9 a	0.23 ab	7.2 a	0.31 b	7.3 a	0.28 bc	7.4 ab	0.22 ab	7.0 bc	0.31 b
13-13-13 Polyon®	9.8	7.2 a	0.25 ab	7.2 a	0.26 b	6.9 a	0.25 c	7.4 ab	0.20 b	6.8 c	0.27 b
CPL^X	4.9	6.8 a	0.22 ab	7.2 a	0.29 b	7.2 a	0.25 c	7.2 b	0.24 ab	6.9 bc	0.30 b
CPL	9.8	6.6 a	0.18 b	7.2 a	0.34 b	7.3 a	0.31 abc	7.6 ab	0.26 ab	6.8 c	0.36 b
CPL	19.6	6.5 a	0.30 a	7.2 a	0.43 ab	7.2 a	0.37 abc	7.6 ab	0.30 ab	7.2 ab	0.39 ab
CPL	29.4	6.5 a	0.18 b	6.6 a	0.45 ab	7.3 a	0.32 abc	7.4 ab	0.28 ab	6.8 c	0.37 b
CPL	39.2	6.7 a	0.21 b	6.7 a	0.56 ab	7.2 a	0.62 a	8.0 a	0.42 a	7.4 a	0.52 a
CPL	49	6.7 a	0.22 ab	6.4 a	0.78 a	7.3 a	0.47 abc	7.8 ab	0.33 ab	7.1 abc	0.30 b
Non-fertilized control	***	6.8 a	0.23 ab	7.3 a	0.30 b	7.2 a	0.29 bc	7.2 b	0.28 ab	6.8 c	0.31 b

[Z] WAP = Weeks after planting.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

Table 3.1 Effect of fertilizers on growth indices[Z] and shoot dry weights[Y] of 'Celebrity Red' petunia and Dusty Miller.

Treatment	Rate	'Celebrity Red' Petunia				Dusty Miller			
	(g N/m^2)	4 WAP[X]	8 WAP	12 WAP	Dry Wt.	4 WAP	8 WAP	12 WAP	Dry Wt.
13-13-13 Peafowl®	4.9	17.1 bcd	23.3 d	25.3 bcde	56.7 c	16.3 bc	23.1 bcd	23.6 ed	144.4 abc
13-13-13 Peafowl®	9.8	18.2 abc	27.6 abc	26.5 abcd	87.2 abc	18.4 a	25.5 ab	27.5 ab	193.2 ab
13-13-13 Polyon®	4.9	16.5 cd	26.2 abcd	22.8 ef	78.3 abc	16.6 bc	24.6 bc	26.5 bc	181.4 abc
13-13-13 Polyon®	9.8	16.6 cd	25.2 cd	24.6 bcdef	86.4 abc	16.5 bc	27.6 a	29.5 a	223.2 a
CPL[V]	4.9	17.8 abc	26.9 abc	24.8 bcdef	79.6 abc	15.8 c	25.2 abc	26.7 bc	181.5 abc
CPL	9.8	16.5 cd	24.8 cd	24.3 cdef	71.5 bc	16.4 bc	23.1 bcd	24.6 cd	175.7 abc
CPL	19.6	16.9 cd	25.5 bcd	23.6 def	76.9 abc	16.6 bc	22.5 cd	23.3 de	140.2 abc
CPL	29.4	19.1 a	28.9 a	28.0 ab	122.8 a	16.5 bc	21.2 de	22.6 de	125.6 bc
CPL	39.2	18.4 abc	28.5 a	27.7 abc	107.5 ab	15.8 c	23.1 bcd	25.0 bcd	131. 4 bc
CPL	49	19.0 ab	28.9 a	29.5 a	126.3 a	16.4 bc	23.5 bcd	24.7 cd	156.1 abc
Non-fertilized control	***	15.8 d	23.2 d	21.6 f	47.9 c	13.9 d	19.8 e	21.4 e	102.4 c

[Z] Growth indices = [(height + width1 + width2)/3]

[Y] Dry weights measured in grams, taken from average dry weight of 5 plants per plot from each replication.

[X] WAP = Weeks after planting.

[W] Means separated within columns using Duncan's Mutliple Range Test (alpha = 0.05).

[V] CPL = Composted poultry litter.

Table 3.2 Effect of fertilizers on leaf chlorophyll content^{Z} of 'Celebrity Red' petunia and Dusty Miller.

Treatment	Rate	'Celebrity Red' Petunia			Dusty Miller		
	(g N/m^{2})	4 WAP^{Y}	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
13-13-13 Peafowl®	4.9	43.6 bc	39.8 c	36.4 f	66.1 ab	62.0 a	53.5 cd
13-13-13 Peafowl®	9.8	47.1 ab	40.4 bc	37.1 ef	67.7 ab	63.6 a	57.1 abc
13-13-13 Polyon®	4.9	45.3 abc	42.6 b	43.3 abc	65.9 ab	63.7 a	59.4 a
13-13-13 Polyon®	9.8	44.3 abc	45.0 a	46.5 a	69.3 a	64.1 a	59.1 a
CPL^{W}	4.9	44.5 abc	40.6 bc	38.2 def	66.3 ab	64.0 a	56.3 abc
CPL	9.8	42.3 c	40.3 bc	40.6 bcde	65.0 bc	60.4 a	54.3 bcd
CPL	19.6	43.8 bc	40.9 bc	39.3 def	64.5 bc	60.4 a	56.1 abc
CPL	29.4	47.4 ab	41.2 bc	40.2 cde	65.9 ab	60.6 a	54.4 bcd
CPL	39.2	43.0 c	40.9 bc	41.0 bcd	66.4 ab	62.0 a	55.5 abcd
CPL	49	48.2 a	40.2 bc	43.9 ab	65.9 ab	63.4 a	58.3 ab
Non-fertilized control	***	42.2 c	40.1 bc	33.1 g	61.4 c	62.0 a	51.5 d

[Z] Leaf chlorophyll content quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) (average of 5 leaves per plant).

[Y] WAP = Weeks after planting.

[X] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test. (alpha = 0.05).

[W] CPL = Composted poultry litter.

Table 3.3 Effect of fertilizer on tissue nutrient content of *Petunia spp.'* Celebrity Red', experiment 3.

	Rate	Tissue Nutrient Content[Z]											
Treatment	(g N/m^2)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)	Na (ppm)
13-13-13 Peafowl®	4.9	2.1 c	0.33 fg	2.7 e	1.1 abc	0.52 c	25.0 b	544.8 a	142.8 ab	19.6 bc	110.2 a	507.8 ab	1869.2 f
13-13-13 Peafowl®	9.8	2.0 c	0.38 e	2.8 de	1.0 bcd	0.53 c	22.8 bc	352.8 a	149.6 a	16.6 bc	105.2 a	360.6 b	2113.6 ef
13-13-13 Polyon®	4.9	2.5 ab	0.36 ef	2.9 cde	1.2 ab	0.61 ab	25.6 b	409.2 a	126.6 bc	24.2 abc	104.2 a	381.6 b	2677.6 de
13-13-13 Polyon®	9.8	2.7 a	0.47 c	2.9 de	1.1 ab	0.61 ab	20.4 cd	385.6 a	147.0 ab	19.0 bc	95.0 ab	297.2 b	2812.8 de
CPL[X]	4.9	2.1 c	0.36 ef	3.1 bcd	1.0 bcd	0.56 bc	26.0 b	420.4 a	95.6 def	16.4 c	82.6 bc	333.0 b	2273.2 ef
CPL	9.8	2.2 c	0.43 d	3.2 abc	1.1 ab	0.57 abc	24.2 bc	470.2 a	100.0 de	22.0 abc	88.2 b	458.8 ab	2459.0 ef
CPL	19.6	2.3 c	0.53 b	3.3 ab	1.0 bcd	0.57 abc	20.4 cd	461.8 a	83.2 efg	35.2 a	82.0 bc	419.6 ab	3303.6 cd
CPL	29.4	2.2 c	0.54 b	3.4 a	0.86 cde	0.54 c	18.0 d	538.8 a	75.4 fgh	29.6 abc	72.2 cd	512.8 ab	3835.0 bc
CPL	39.2	2.3 bc	0.55 ab	3.4 a	0.85 de	0.56 bc	18.2 d	377.8 a	70.0 gh	23.2 abc	71.6 cd	272.4 b	4270.0 ab
CPL	49	2.6 a	0.58 a	3.4 a	0.72 e	0.55 c	17.8 d	313.3 a	58.8 h	30.3 ab	67.0 d	227.8 b	4781.0 a
Non-fertilized control	***	2.2 c	0.31 g	3.0 cde	1.2 a	0.62 a	30.6 a	742.0 a	112.8 cd	25.4 abc	108.6 a	898.0 a	2320.4 ef
Sufficiency range[V]		*1.43 - 1.90*	*0.10 - 0.13*	*0.40 - 0.52*	*2.0 - 2.9*	*0.13 - 0.15*	*55 - 126*	*58 - 69*	*15 - 35*	*4 - 6*	*7 - 10*	*N/A*[U]	*N/A*

[Z] Tissue analysis performed on 20 terminal shoots (5.1 cm - 7.6 cm or 2-3 in of most recently mature leaves) per plant; N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum, Na = sodium.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

[V] Sufficiency range published by Mills and Jones (1996).

[U] N/A = Not applicable.

Table 3.4 Effect of fertilizer on tissue nutrient content of *Senecio cineraria* (Dusty Miller), experiment 3.

	Rate	Tissue Nutrient Content[Z]											
Treatment	(g N/m^2)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)	Na (ppm)
13-13-13 Peafowl®	4.9	1.3 c	0.21 c	1.7 cde	0.91 ab	0.47 ab	29.3 bc	182.8 a	260.0 a	17.0 b	75.0 a	131.3 ab	2368.5 cd
13-13-13 Peafowl®	9.8	1.3 c	0.22 c	1.7 bcde	0.79 bcd	0.42 c	29.0 bc	132.6 a	241.0 ab	22.4 b	71.6 a	88.8 b	2020.0 d
13-13-13 Polyon®	4.9	1.6 a	0.21 c	1.7 bcde	0.89 abc	0.51 ab	28.4 c	139.8 a	183.8 cd	14.2 b	77.4 a	91.0 b	2774.2 abc
13-13-13 Polyon®	9.8	1.6 ab	0.21 c	1.6 e	0.79 cd	0.46 bc	26.6 c	145.8 a	203.4 bc	41.2 a	78.8 a	101.6 ab	2608.0 bc
CPL[X]	4.9	1.4 c	0.24 c	1.8 abcd	0.87 abc	0.49 ab	34.2 a	137.4 a	181.0 cd	17.6 b	66.2 ab	93.6 b	2768.0 abc
CPL	9.8	1.4 bc	0.28 b	1.8 abc	0.87 abc	0.49 ab	36.0 a	149.0 a	165.0 cde	26.4 ab	73.0 a	111.4 ab	2599.0 bc
CPL	19.6	1.4 c	0.30 ab	1.9 a	0.89 abc	0.51 a	33.5 a	147.8 a	156.5 cde	29.5 ab	64.3 ab	112.8 ab	2819.3 ab
CPL	29.4	1.3 c	0.30 ab	1.8 bcde	0.82 abcd	0.47 ab	29.0 bc	134.8 a	141.6 def	19.8 b	57.8 ab	109.2 ab	2642.0 bc
CPL	39.2	1.4 abc	0.31 ab	1.8 abcd	0.75 de	0.48 ab	27.2 c	173.2 a	113.6 ef	30.4 ab	61.8 ab	142.6 a	2834.8 ab
CPL	49	1.5 abc	0.33 a	1.9 ab	0.68 e	0.47 ab	25.0 c	137.8 a	93.4 f	31.4 ab	48.0 b	100.0 ab	3141.8 a
Non-fertilized control	***	1.3 c	0.21 c	1.6 de	0.94 a	0.49 ab	33.0 ab	173.0 a	172.6 cd	21.2 b	76.6 a	135.4 ab	2724.2 abc
Sufficiency range[V]		*1.43 - 1.90*	*0.10 - 0.13*	*0.40 - 0.52*	*2.0 - 2.9*	*0.13 - 0.15*	*55 - 126*	*58 - 69*	*15 - 35*	*4 - 6*	*7 - 10*	*N/A*[U]	*N/A*

[Z] Tissue analysis performed on 20 terminal shoots (5.1 cm - 7.6 cm or 2-3 in of most recently mature leaves) per plant; N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum, Na = sodium.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

[V] Sufficiency range published by Mills and Jones (1996).

[U] N/A = Not applicable.

Table 3.5 Effect of fertilizers on N in soil water, experiment 3.

Treatment	Rate	1 WAP[Z]		2 WAP		4 WAP		8 WAP		12 WAP	
	(g N/m^2)	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4	$N0_3$	NH_4
13-13-13 Peafowl®	4.9	2.1 ab	0.87 c	0.70 b	4.6 a	1.6 c	5.4 a	4.4 a	0.33 a	2.0 a	0.93 a
13-13-13 Peafowl®	9.8	2.2 ab	3.6 b	5.3 ab	9.3 a	5.9 b	0.60 a	3.6 a	1.4 a	1.0 a	0.57 a
13-13-13 Polyon®	4.9	7.3 a	1.9 bc	6.5 ab	6.9 a	4.4 bc	6.2 a	4.2 a	1.7 a	2.6 a	1.3 a
13-13-13 Polyon®	9.8	1.5 ab	2.0 bc	1.3 b	3.4 a	3.6 bc	2.5 a	3.7 a	0.20 a	1.6 a	0.67 a
CPL[X]	4.9	1.4 ab	2.0 bc	0.93 b	2.9 a	2.5 c	1.5 a	3.0 a	0.03 a	0.93 a	0.37 a
CPL	9.8	3.3 ab	2.0 bc	2.3 b	3.7 a	1.9 c	5.6 a	2.1 a	3.3 a	2.2 a	1.7 a
CPL	19.6	4.2 ab	1.8 bc	1.1 b	8.3 a	3.4 bc	7.1 a	5.9 a	0.73 a	2.4 a	2.2 a
CPL	29.4	0.43 b	15.7 a	9.6 a	2.9 a	9.1 a	0.37 a	5.1 a	0.77 a	3.1 a	2.3 a
CPL	39.2	7.0 ab	4.0 b	4.0 ab	8.1 a	3.9 bc	5.7 a	3.9 a	3.7 a	2.6 a	2.2 a
CPL	49	2.8 ab	1.7 bc	2.0 b	6.2 a	2.4 c	5.5 a	3.3 a	1.3 a	2.8 a	0.37 a
Non-fertilized control	***	1.0 ab	2.2 bc	0.73 b	3.8 a	1.1 c	3.4 a	2.2 a	1.3 a	1.1 a	0.83 a

[Z] WAP = Weeks after planting.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

Table 3.6 Effect of fertilizers on pH and electrical conductivity of soil water, experiment 3.

Treatment	Rate	1 WAP^{Z}		2 WAP		4 WAP		8 WAP		12 WAP	
	(g N/m^{2})	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)
13-13-13 Peafowl®	4.9	7.1 ab	0.42 ab	6.8 ab	0.52 ab	7.3 a	0.45 bc	7.5 ab	0.36 b	7.3 a	0.30 abc
13-13-13 Peafowl®	9.8	6.9 bc	0.32 b	6.3 b	0.80 ab	7.1 a	0.37 c	7.1 bc	0.33 b	7.0 a	0.25 bc
13-13-13 Polyon®	4.9	7.3 a	0.37 ab	7.0 a	0.44 b	7.3 a	0.35 c	7.3 ab	0.28 b	7.1 a	0.25 bc
13-13-13 Polyon®	9.8	7.1 abc	0.31 b	6.5 ab	0.37 b	6.9 a	0.32 c	7.2 ab	0.29 b	7.1 a	0.27 abc
CPL^{X}	4.9	7.2 ab	0.34 b	6.8 ab	0.38 b	7.1 a	0.29 c	7.0 bc	0.27 b	6.9 a	0.24 c
CPL	9.8	7.3 a	0.39 ab	6.7 ab	0.53 ab	7.2 a	0.42 bc	7.7 ab	0.38 b	7.5 a	0.33 abc
CPL	19.6	7.3 a	0.50 ab	6.5 ab	0.60 ab	7.1 a	0.46 bc	7.5 ab	0.39 b	7.4 a	0.34 abc
CPL	29.4	6.8 c	0.68 a	6.6 ab	.067 ab	7.0 a	0.39 bc	6.6 c	0.30 b	7.2 a	0.30 abc
CPL	39.2	7.3 a	0.40 ab	6.6 ab	0.82 ab	7.1 a	0.60 ab	7.8 a	0.56 a	7.4 a	0.42 a
CPL	49	7.4 a	0.43 ab	6.8 ab	0.98 a	7.1 a	0.80 a	7.7 ab	0.56 a	7.3 a	0.41 ab
Non-fertilized control	***	7.2 ab	0.31 b	7.0 a	0.42 b	7.2 a	0.32 c	7.6 ab	0.30 b	7.1 a	0.24 c

[Z] WAP = Weeks after planting.

[Y] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (alpha = 0.05).

[X] CPL = Composted poultry litter.

CHAPTER IV

Final Discussion

The purpose of these studies was to evaluate composted poultry litter (CPL) as a substrate amendment for container plant production, and as an alternative fertilizer for landscape annual bedding plants. Peat moss (PM) is a relatively non-renewable resource and the costs associated with shipping PM from Europe and Canada is continually increasing while Pinebark (PB) supplies are becoming less available. Growers must begin to search for alternatives to these two widely used substrate components and find new, sustainable, economical, and environmentally friendly substrate components for future container plant production. Fertilizer prices also continue to increase and landscapers are searching for cost saving alternatives. CPL has the potential to provide valuable plant nutrients, and where poultry production is concentrated (such as Southeastern U.S.), often at a fraction of the cost of inorganic fertilizers. CPL has potential as a suitable alternative substrate amendment while providing valuable plant nutrients in container plant production or landscape settings, and therefore could increase profit margins for growers and landscapers, while providing poultry producers a new avenue for waste disposal, and alleviate the negative environmental impacts associated with mass land-application of poultry litter.

In chapter 2 we began to evaluate CPL as an amendment for container plant production, more specifically for substrates containing high wood content. In general, most species grew as well or better in substrates containing CPL when compared to the industry standard substrate PB:Peat. Treatment differences did occur among individual species, however all treatments provided commercially acceptable plants. Plants grown in substrates containing WholeTree (WT) and clean chip residual (CCR) both of which contain high wood content, did not appear to suffer from nitrogen immobilization which is often a concern when using a substrate containing a high percentage of wood. Species which grew better in substrates containing CPL, such as boxwood, may have benefitted more from the increased pH levels than the additional N levels in the CPL. Increased EC levels in first week after potting did not appear to have any negative effects on plant growth, and EC levels dissipated quickly. However, plants evaluated in these studies were woody ornamentals, and most would not be considered “sensitive” species. More sensitive crops, or herbaceous annuals or perennials could possibly be negatively impacted by high pH and EC levels resulting from the addition of CPL. In these studies, azaleas grew better in substrates that did not contain CPL, likely due to increased pH levels from the incorporation of CPL. CPL will never fully replace inorganic fertilizer sources for container production, but could possibly supplement these fertilizers while providing beneficial physical properties comparable to peat moss at a fraction of the cost, depending on the grower’s location. Results from these studies indicate that use of CPL in container production could provide growers an economical and sustainable substrate amendment to supplement inorganic fertilizer use, and also provide growers with a peat substitute while growing non-sensitive crops. Before growers begin to implement composted products of any kind into their production cycle, manures and other composts must be tested to provide a known nutrient value of the product, and to ensure a fully composted and stable product that is safe for use in container production.

In chapter 3, we continued to evaluate CPL as a fertilizer in a series of field studies simulating an urban landscape. Petunias, verbena, and dusty miller were planted in raised beds and fertilized with either CPL or a commercially available inorganic fertilizer and were evaluated on growth and leaf chlorophyll content (LCC). Nitrogen leaching (NO_3 and NH_4) into the soil in the weeks following fertilization was also monitored by taking soil water samples using suction cup lysimeters. Similarities among treatments in these studies indicate that CPL could be used effectively in the landscape as a fertilizer for annual bedding plants. In all three experiments, all species grew as large or larger when fertilized with CPL as compared to inorganic fertilizers at the same N rate. Both petunia and verbena tended to increase in size as the rate of CPL increased. LCC was also comparable among all treatments for the three species tested. Soil water samples also indicate that when applied at the same N rate, CPL leaches less N into soil water than inorganic fertilizers. In addition, even when CPL was applied at N rates several times greater than the inorganic fertilizers, little or no difference occurred with respect to N leaching. These results indicate that CPL can be used successfully as an alternative fertilizer source for annual bedding plants. In most cases, the higher rates of N applied via CPL also increased plant growth and LCC, while causing minimal or no difference in nutrient leaching. Based upon these studies, landscapers could apply CPL at much higher rates than inorganic fertilizers, resulting in larger, greener plants while causing N leaching comparable to inorganic fertilizers applied at a fraction of the N rate. Based upon location and proximity to large poultry operations, landscapers could purchase CPL for less than commercially available inorganic fertilizers, and in turn increasing profit margins. While use of CPL in the landscape industry has advantages, problems could possibly arise with use in a landscape setting. While CPL is relatively dry and easier to handle than raw litter, N content usually ranges from 1.5 to 3.0%, meaning large amounts of CPL would have to be applied to provide the same nutrient value as a very small amount of inorganic fertilizers. Composting also reduces most of the odor associated with poultry litter, but some odor will still persist, making CPL undesirable in some homeowner and commercial landscape situations. While homeowners are becoming more environmentally aware and are increasing use of composted organic products, in some sectors there is still a negative stigma associated with spreading animal waste in close proximity to homes or office buildings. Also, CPL would not be economical if the landscape company had to pay fuel costs associated with shipping litter long distances, which restricts use of CPL to areas where poultry production is concentration, such as the Southeastern United States. However, as fertilizer prices continue to rise homeowners and landscapers will begin to look for less expensive fertilizer sources. CPL could provide nutrients essential to plant growth, while providing poultry producers a new avenue for waste disposal, which would hopefully benefit the landscape and poultry industries economically, while minimizing negative impacts on the environment.

In addition to these studies, we also evaluated CPL as a fertilizer for ‘Meyer’ zoysia (*Zoysia japonica* ‘Meyer’ (Z-52)) turf. On June 6, 2007, prior to zoysia sod installation, five fertilizer treatments were applied to 46.5 m^2 (500 ft^2) plots of bare ground (no previous fertilization). Treatments consisted of Osmocote® 13N-5.6P-10.9K (13-13-13) (The Scott’s Co., Marysville, OH) at 12.2 g nitrogen (N)/m^2 (2.5 lb N per 1000 ft^2), composted poultry litter (CPL) at (12.2 g N/m^2 (2.5 lb N per 1000 ft^2), CPL at 24.2 g N/m^2 (5 lb N per 1000 ft^2), and CPL at 36.6 g N/m^2 (7.5 lb N per 1000 ft^2). A non-fertilized control was also maintained for comparison. On June 7, 2007, zoysia sod (Beck’s Turf, Inc., Tuskegee, AL) was laid on the treated plots in full sun and received overhead irrigation as needed. The five treatments were arranged in a completely randomized block design with 3 replications of each treatment. Leaf chlorophyll content (LCC) was taken at 4, 8, 12, 16, and 20 weeks after planting (WAP) using a SPAD-502 Chlorophyll Meter (Minolta, Inc.). On May 23, 2008, zoysia was again reevaluated and final LCC were taken and foliar color ratings (FCR) were taken on a scale of 1 to 5 with 1 = brown foliage, 2 = light brown foliage, 3 = light green foliage, 4 = green foliage, 5 = dark green foliage.

At 4 WAP, there were no differences in LCC of the grass in any of the plots receiving fertilizer, a trend that continued at 8 WAP. At 12 WAP, all fertilizer treatments had similar LCC with the exception of CPL (12.2 g N/m^2) which was significantly higher than osmocote at 12.2 g N/m^2 and CPL at 24.4 g N/m^2. By 16 WAP, the osmocote treatment had the highest LCC, however LCC was similar to CPL at 24.4 and 36.6 g N/m^2. The Osmocote treatment again had the highest LCC at 20 WAP, however all treatments were statistically similar with the exception of the non-fertilized control, which had significantly lower LCC than the fertilized zoysia plots. Zoysia was again re-evaluated on May 23, 2008 and LCC data and FCR indicated no difference among any treatment. LCC were similar among all treatments and all treatments received a FCR of 4, with no visual differences seen.

Results from this study indicate that CPL has the potential to provide turf managers as well as homeowners a fertilizer alternative to expensive inorganic CRFs. Minor differences occurred throughout the study, however all fertilizer treatments resulted in acceptable zoysia growth and color. Turf managers could potentially benefit economically from incorporating CPL into their fertilization program depending on location and proximity to poultry farms. Turf species are in general heavy feeders of nutrients and require numerous applications throughout the growing season. The layout of most sod farms would also make application possible with current spreading equipment. In addition, fast growing turf species would utilize nutrients rapidly; reducing leaching and contamination of near-by water supplies.

In summary, the results from these experiments demonstrate that composted poultry litter could be used successfully as an amendment in container plant production as well as an alternative fertilizer source for landscape annual bedding plants and lawns. In container production, CPL could be used as a substitute for peat for non-sensitive crops, while providing growers a cheap source of nutrients. In a landscape setting, CPL could provide a fertilizer source that performs as well as most commercially available fertilizers at a fraction of the cost. In addition, much higher rates of N could be applied without causing excessive N leaching, resulting in larger, more attractive plants. Incorporating the use of CPL into the horticulture industry could provide economic benefits to growers and landscapers, provide poultry producers a new way to dispose of poultry manure, and help mitigate negative impacts that land application of poultry litter has on the environment.