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The use of summer cover crops and composted broiler litter in fall organic vegetable production

By

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The use of summer cover crops and composted broiler litter in fall organic vegetable production

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Cover crops and composted broiler litter (CBL) are two organic methods used to improve soils and organic vegetable production. The objectives of this study included determining the extent summer cover crops and CBL alter nutrient availability in soil, determining how summer cover crops and CBL influence fall vegetable crops in organic production systems and identifying which cover crops/ CBL combinations improve fall vegetable crop production best. Four cover crops were tested: sunn hemp (*Crotalaria juncea*), sesame (*Sesamum indicum*), sorghum sudan grass (*Sorghum X drummondii*) and a sunn hemp + sesame blend, in combination with four composted broiler litter rates: 0, 2,800, 5,600, 11,200 $kg \cdot ha^{-1}$ for two years. Few differences were seen among cover crop treatments except for the sorghum sudan grass treatment, which had negative effects on fall broccoli production unless combined with CBL. The CBL increased nutrient availability, percent organic matter, pH and broccoli yield as the rate increased.

Key words: cover crops, composted broiler litter, organic

DEDICATION

I would like to dedicate this research to by husband and family for supporting me endlessly and for their help and encouragement along the way.

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NOMENCLATURE

CR	*Sunn- hemp (Crotolaria juncea)*
CS	*Sunn- hemp + Sesame blend*
SE	*Sesame (Sesamum indicum)*
SO	*Sorghum-sudan grass (Sorghum x drummondii)*
1	*0 kg·ha*$^{-1}$ *compost*
2	*2,800 kg·ha*$^{-1}$ *compost*
3	*5,600 kg·ha*$^{-1}$ *compost*
4	*11,200 kg·ha*$^{-1}$ *compost*
N	*Nitrogen*
P	*Phosphorus*
K	*Potassium*
Ca	*Calcium*
Mg	*Magnesium*
Zn	*Zinc*
S	*Sulfur*
Cu	*Copper*
B	*Boron*
Na	*Sodium*
%OM	*Percent organic matter*

ICP	*Inductively coupled plasma photometry*
CBL	*Composted broiler litter*
WHO	*World Health Organization*
NOP	*National Organic Program*
NRCS	*Natural Resources Conservation Service*
lbs./A	*pounds per acre*
USDA	*United States Department of Agriculture*
ERS	*Economic Research Service*
ARS	*Agricultural Research Service*
EPA	*Environmental Protection Agency*

CHAPTER I

INTRODUCTION

Fertile soil deposited from flooding of the Nile and Tigris valleys made Egypt and Mesopotamia the bread baskets of the ancient world, showing since the beginning of recorded history, the importance of soil fertility to agricultural production has been known (Wolman and Fournier, 1987). The key to maintaining maximum production is to understand what crops need from the soil. Plants have many elements required for successful growth and development. As nutrients are depleted, there is a need to replace them, but also replace them in sustainable ways to last the test of time. Practices such as planting cover crops in the summer and using chicken litter compost are useful to improve soils and improve fall vegetable crop production.

Organic Agriculture

Organic agriculture is a system for crop, livestock and fish farming that emphasizes environmental protection and the use of natural farming techniques (Morgera et al., 2012). The efficient use of manures and legumes has been the center of organic farming systems in the past and present (Wolman and Fournier, 1987). Organic agriculture's roots are in traditional practices in small communities around the world where knowledge of effective practices are passed from generation to generation (Morgera et al., 2012). Since organic agriculture began was revived in the 1960's in the

United States, it has become a more organized movement and is now the fastest growing food sector across the world (Morgera et al., 2012). In the late 1980's, countries in the European Union began developing and providing support for producers to transition to organic agriculture (USDA ERS, 2012). Organic agriculture is projected to play a major part in preventing desertification, preserving biodiversity, contributing to sustainable growth and promoting plant and animal health (Morgera et al., 2012). The growing interest in organic products has opened new trade opportunities for developing countries through internationally recognized certification (Morgera et al., 2012). Reasons for organic agriculture according to the United States Department of Agriculture (USDA) National Organic Program (NOP) include: its reliance on renewable resources, support of local economies, building of soil and water quality, promoting environmental stewardship, enhancing biodiversity and innovation, and that it can benefit in all agriculture (AMS, 2012). Organic sales in the United States increased by over 30 billion U.S. dollars from 1990 to 2011 (AMS, 2012).

The U.S. certified organic production uses a system that is managed in accordance with the Organic Food Production Act Provisions' National Organic Program to respond to site-specific conditions by combining cultural, biological, and mechanical practices that promote cycling of resources, maintain ecological balance, and conserve biodiversity (AMS, 2013). The National Organic Standards Board (NOSB), formed by the Secretary of Agriculture, aids in the development of standards for substances to be used in organic production (CFR, 2013). By law, production or handling operations or individual portions of the operations that produce or handle crops, livestock, livestock products, or other agricultural goods planned to be sold, labeled or represented as "100 percent organic,"

"organic," or "made with organic" must be certified and meet all relevant requirements (CFR, 2013). To be labeled or sold as "organic," the product cannot be handled or produced with a) synthetic substances or ingredients, b) nonagricultural substances used in or on processed products, c) nonorganic agricultural substances used in or on processed products, or d) sewage sludge (CFR, 2013). According to the NOP, producers must choose practices that preserve or improve the physical, chemical, and biological condition of soil and minimize soil erosion (CFR, 2013). Producers must manage nutrients and soil fertility through crop rotations, cover crops, and applications of plant and animal materials, but these materials must be managed so that they do not add to contamination of crops, soil, or water by plant nutrients, pathogens, heavy metals, or prohibited residual substances (CFR, 2013).

The International Panel on Climate Change, an international body established by the United Nations Environment Programme, has strongly supported the adoption of sustainable cropping systems like those used on organic farms to cut carbon emissions because organic methods are expected to result in lower carbon emissions (Morgera et al., 2012). High levels of organic matter in organic soils trap carbon, lowering carbon emissions over time (Morgera et al., 2012). Numerous organizations have expanded research on organic agriculture since the 1990's; these include, but are not limited to, the Economic Research Service, National Institute of Food and Agriculture, and USDA's Agricultural Research Service (USDA ERS, 2012). The two main national programs in the U.S. that support and help organic farmers are the national organic program and the cost-share assistance program. (USDA ERS, 2012).

Conventional agriculture makes high yield the priority, which can result in extensive environmental degradation, including water, soil and air pollution; soil erosion; biodiversity loss and desertification (Morgera et al., 2012) because of extensive chemical use. Soil erosion is a main reason for lost yield capacity and fertility (Morgera et al., 2012). Soils that are organically managed often have better moisture-retention capacity than those of conventional farms, key in arid climates to reducing the risk of desertification (Morgera et al., 2012).

Soil conservation is one key concept in organic agriculture (Morgera et al., 2012). Organic farming can increase organic content in the soil and increase its ability to retain water (Morgera et al, 2012). Additional organic materials from applied manures contribute to soil structure synthesis, help in erosion control and reduce needs for inorganic N fertilization, as well as for most other nutrients (Wolman and Fournier, 1987). Like manure, cover crop incorporation can improve soil structure and reduce the need for additional fertilizers (Mutch, 2010). Organic matter, as defined by the NOP, is ‘the remains, residues, or waste products of any organisms (CFR, 2013). In agriculture, water pollution can be due to soil erosion, and nitrate and synthetic products seeping into water supplies (Morgera et al., 2012), but it can also be caused by phosphorus pollution from manures. Cover crops and their incorporation may sustain long-term soil fertility by improving soil organic matter and levels of microbial and enzyme activities (Dinesh et al., 2004). Although worldwide limitations to organic farming include the availability of sufficient amounts of manure and water, and the control of incident pests (Wolman and Fournier, 1987), both cover crops and chicken litter compost can be seen as a benefit for farmers and producers.

Food security is a growing concern. While there is currently enough food in this world to feed everyone, the problem lies in distribution (WHO, 2012). Organic production can increase biodiversity and long- term productivity, and can provide local production and access of food (Morgera et al., 2012). While agriculture is still the top employment sector in developing countries (WHO, 2012), the fastest growing food sector in the world by land use and market size is organic agriculture (Morgera et al., 2012). There may also be improved employment opportunities in rural and local communities since organic farming often entails more manual labor to compensate for not using synthetic fertilizers and pesticides (Mogera et al., 2012).

Cover Crops

In 1955, R. Heddle and J. Herriott stated that cereal cover crops can aid in plant establishment by reducing weed competition. Work by J. Lewis in 1959 suggested that seed yields were not increased by nitrogen application when the plots did not contain a previous cover crop. He also found that sowing a lower rate of seed without a cover crop produced weedy plots (Lewis, 1959). Economic and environmental concerns have fueled the reappearance of cover crop use (Mutch, 2010) and alternatives to conventional fertilizers. Differences in soil chemistry and physical properties combined with wide-ranging climatic and agricultural variability across the United States beckons for research on N availability and use efficiency on a regional scale (Sorensen and Jensen, 1995).

Plant nutrients are lost in the soil through runoff, erosion, leaching, gaseous losses to the atmosphere and crop removal (Bierman and Rosen, 2005). Cover crops are planted to improve soil quality by protecting, improving, and providing nutrients in the soil (Mutch, 2010). Cover crops can capture soil nitrogen that could be lost to leaching, improve pastures, impact insect and disease life cycles, and suppress weed and nematode growth (Mutch, 2010). They may also provide a significant source of nitrogen for crops in the future, and reduce erosion, runoff and associated pollution (Mutch, 2010; Baldwin and Creamer, 1999). Muñoz-Carpena, et al. (2008) found that soil water content decreased quickly in no-cover plots while it was released slowly in cover crop plots, and found that this effect was further amplified in the second season of study for the cover crop soil. Planting cover crops is an efficient tool to reduce nitrogen loss and excessive phosphorus and potassium accumulation in an intensive vegetable cropping system (Gao et al., 2011b). One of the most important benefits, when a legume cover crop is planted, is nitrogen production (Mutch, 2010). Cover crop systems have a higher carbon mineralization capacity compared to a continuous cropping system (Gao et al., 2011a). Cover crops can also suppress weed populations (Ngouajio and Mennan, 2005) by blocking sun light to the soil surface or as mulch. In a 1997 trial by Harrison et al. (2004) broccoli yields were higher in all cover crop mulch treatments than with a bare soil control.

The way most of these characteristics are achieved is by the amount of organic matter cover crops provide in their residues. The greatest source of soil organic matter is the residue from the crops (Nyakatawa et al., 2001). Crop residues, as defined by the NOP, are ‘plant parts remaining in a field after the harvest of a crop, which include stalks, stems, leaves, roots, and weeds’ (CFR, 2013). Organic matter improves soil stability, water infiltration, air diffusion, and reduces soil crusting (Baldwin and Creamer, 1999). Organic matter also increases the soil microbe population, which in turn contributes to efficient nutrient cycling and soil structure, and can increase nutrient retention in the root zone (Baldwin and Creamer, 1999). Cover crops can build and maintain soil organic matter, which is a major factor for sustaining and increasing agricultural productivity (Nolte and Wang, 2010). Dinesh et al. (2004) found that soil organic carbon and total nitrogen levels were enhanced by cover crops, although there was no significant difference in soil pH or Ca and Mg levels.

If providing the following cash crop with readily available nitrogen or enhancing soil organic matter is desired, a legume should be chosen as a cover crop (Nolte and Wang, 2010). The most important gain from legume production is nitrogen because of the symbiotic nitrogen fixation in the crop's root nodules (Wolman and Fournier, 1987) that can be used by subsequent crops (Baldwin and Creamer, 1999) and that can be particularly helpful in organic production systems, where synthetic fertilizers cannot be used (Nolte and Wang, 2010). Bacteria that live in nodules on the legumes' roots convert atmospheric nitrogen into a form that the crop can use (Baldwin and Creamer, 1999). For example, when sunn hemp (*Crotalaria juncea*), a legume, was used as a cover crop, there was a net increase of soil nitrogen (Bosch et al., 2008). Dinesh et al. (2004) found that leguminous cover crops increased total C, total N and organic C levels, thus enhancing soil fertility. Results from a study done by Muñoz-Carpena, et al. (2008) showed that using sunn hemp as a cover crop can improve soil physical conditions by increasing soil water retention resulting in subsequently enhanced crop evapotranspiration and decreased soil drainage. Changes in soil physical properties were seen in corn plots in continuous rotation with a leguminous summer cover crop after three years and these changes were accredited to an increase in organic matter content in the field (Muñoz-Carpena et al., 2008). Work by Muñoz-Carpena et al. (2008) illustrates why cover crops have to be considered as a part of the total fertility system being used. They found that corn N uptake and yields slightly increased in cover crop plots, but N leaching did as well due to the excess of nitrogen available, and fast mineralization and nitrification rates (Muñoz-Carpena et al., 2008).

Using grass or non-legume cover crops helps keep nitrogen in the plant-soil system by trapping residual nitrogen that may otherwise be lost to leaching (Baldwin and Creamer, 1999). Nitrogen is incorporated into the tissue of the cover crop and is subsequently released for the following crop when the cover crop decomposes (Baldwin and Creamer, 1999). Although, Abdul-Baki et al. (1997) found that an increase to broccoli yield from fertilizer N suggested that N provided from the cover crops did not fully meet the need of the broccoli crop.

Legumes and non-legumes are used as cover crops, each providing nitrogen in a different way. How much nitrogen and when it is available for subsequent crops is affected by the ratio of carbon to nitrogen (C:N) in the cover crop biomass (Baldwin and Creamer, 1999). The C:N ratio should be considered when a cover crop is chosen (Nolte and Wang, 2010). Mazzoncini et al. (2011) found that non-legumes and legumes both increased soil organic carbon when compared to no cover crop. The growing period and duration in the field of the cash crop should also be considered in choosing a cover crop (Nolte and Wang, 2010). A mixture of legume and non-legume cover crop species can be planted to achieve the desired C:N ratio when both nitrogen availability and weed suppression are desired (Nolte and Wang, 2010). The competitive ability of each cover crop species should be considered when mixing to avoid one cover crop out-competing another (Nolte and Wang, 2010).

In time to prepare the field for the cash crop, cover crops are cut. In some instances they are left on the soil surface and sometimes they are incorporated into the soil. Murungu et al. (2011) suggested that plant material incorporated into the soil will have a higher rate of decomposition because of the increased surface area exposed to soil microbes, as compared to plant material left on the soil surface. Mazzoncini et al. (2011) found that a no till system had a significantly lower soil bulk density and a significantly higher soil organic carbon concentration than a conventionally tilled system.

Some species are known to have allelopathic effects on others. Allelopathy is defined as a suppression of growth of one species because of a release of toxic substances from another. Sunnhemp (*Crotalaria juncea*) reduced germination percentage and seedling growth of some crop species, including bell pepper, tomato, turnip and onion (Skinner et al., 2012 and Adler and Chase, 2007). Wang et al. (2012) stated that sunn hemp's allelopathic effects can be effective in suppressing nematodes. Sesame was shown to have negative effects on canola (*Brassica napus*) by delaying and decreasing germination rates and germination percentages (Soleymani and Shahrajabian, 2012). A study published in 2009 showed sorghum sudan grass to have varying negative impacts on survival and mortality, transplant biomass, and yield of tomato, lettuce and broccoli plants (Summers et al., 2009). They showed that a later transplant date from the time the sorghum sudan grass is shred allows for more of a chance of the transplants success (Summers et al., 2009). Adler and Chase (2007) stated that using transplants may offer some protection for crop plants in which allelopathy may be a problem.

Besides cover crops, animal manure, notably chicken litter, can be used to provide nutrients to the soil for plant uptake.

Composted Broiler Litter

Benefits of animal droppings in agriculture have been recognized since the dawn of history; for example, manuring of fields is mentioned in Homer's *The Odyssey* (Wolman and Fournier, 1987), written around the 8th century B.C. In 1979, S.R. Wilkinson found that the use of animal manure, including chicken litter, over several years resulted in little or no need for additional phosphorus (P) or potassium (K) and that yields produced from immediately incorporating manure nitrogen (N) were equal to that of conventional fertilizer. Manures can improve soil physical properties and alleviate micronutrient deficiencies (Wilkinson, 1979). He also suggested that the value of waste as a fertilizer can exceed waste management costs, shifting manure from a liability to a resource (Wilkinson, 1979). In 1993, Wood et al. found that the lasting effects of using chicken litter resulted in increased yields in bermudagrass hay fields, making it an admirable choice for a sustainable agricultural practice. Interest in broiler litter N has been increasing as an economical option to commercial fertilizer as the prices for commercial fertilizer N rise (Adeli et al., 2010). While long-term N fertilizer promotes decomposition of soil organic matter and crop residues (Khan et al., 2007), applying broiler litter reduced soil bulk density and improved the stability of soil aggregates (Adeli et al., 2010).

Land application of broiler litter is a common method of disposal because of its value as a synthetic fertilizer substitute, but it presents possible environmental problems because of nutrient runoff (Vervoort and Keeler, 1999). An increase in animal production and increasing environmental concern has led to significant regulatory and political issues surrounding the disposal of animal wastes (Vervoort and Keeler, 1999).

Composting, the process of creating a thermophilic microbial converted product into humus that can be used as a soil amendment (EPA, 2012), is a practice that can lessen the amount of animal manure in local areas (DeLaune et al., 2006). Yard trimmings, food waste, biosolids, animal manure and other organic materials are used in composting (EPA, 2012). Composting becomes more feasible as the land area for application becomes smaller relative to broiler production and as alternative disposal expenses become higher (Vervoort and Keeler, 1999). Animal manures stored appropriately during accumulation can be considered well-balanced fertilizers, having adequate amounts of known essential plant nutrients (Wolman and Fournier, 1987). Manure is bulky and not aesthetically pleasing to handle, which can account for substantial portions being disposed of as a waste product in many developed countries (Wolman and Fournier, 1987). The manure is viewed differently as costs rise for inorganic fertilizer production (Wolman and Fournier, 1987). Increased use of animal manure can help fulfill nutrient requirements of organic crops, but excess nutrients can degrade ecosystems (Preusch et al., 2002). Poultry litter has been applied to land based on crop N requirements, resulting in P application in excess amounts of plant needs, possibly causing degradation of water quality (Preusch et al., 2002), although Nyakatawa et al. (2001) stated that a build-up of P was prevented by crop uptake.

Manure can vary in water and plant nutrient content and can contain a high percentage of carbon (Wilkinson, 1979), therefore it is best to check the nutrient content of the litter before application. Broiler litter is more effective in improving soil properties than conventional fertilizer (Adeli et al., 2010). Adeli et al. (2010) found that increasing litter rate increased soil pH, while inorganic fertilizer N reduced soil pH. Evanylo et al.

(2008) found that all of their high compost rates (agronomic N compost rate) increased soil C and N above all other treatments and reduced soil bulk density; and that after three years of compost applications, even the low compost rates reduced bulk density, showing that even agronomically lower rates of compost continuously applied could improve soil physical properties. Nyakatawa et al. (2001) found a significant effect on soil organic matter after two years of litter application. Chicken litter increases soil total C and microbial biomass C has a larger effect on total soil N (Adeli et al., 2010), and by increasing litter rates, total N uptake increases (Sistani et al., 2010). Sistani et al. (2010) found a 60% availability of manure N after the first year; and Nyakatawa et al. (2001) found up to 40% more NO_3 in treatment plots after the first year, but extractable P and the pH were similar at the end to those at the beginning. Sistani et al. (2010) also found that a higher litter rate (13.2 Mg ha-1) will produce significantly greater dry-mass of the cash crop than conventional fertilizer, although Sumner et al. (2002) found that litter treatments did not significantly influence the yield of marketable corn ears. Composted broiler litter produces significantly less phosphorus runoff than fresh broiler litter (Vervoort and Keeler, 1999).

Compost, as defined by the NOP, is ‘the product of a managed process through which microorganisms break down plant and animal materials into more available forms suitable for application to the soil’ (CFR, 2013). Factors effecting the composition and efficiency of manure use as a fertilizer include: 1) animal species; 2) management; 3) feeding; and 4) storage and transport (Wilkinson, 1979), in turn effecting the quality of the compost. The accessibility and effectiveness of animal manure nitrogen for plants depend on the change of manure organic N to inorganic N, mostly in the form of nitrate

(NO_3^-)-N and ammonium (NH_4^+)-N (Sistani et al., 2010), a process called mineralization. Preusch et al. (2002) found that nitrogen mineralization rates were lower for composted litter than for new litter and that longer composting reduced the amount of extractable N. While there is a loss of more than half of initial N mass in composting, the composted litter contained more stabilized organic matter, making it more valuable (Tiquia and Tam, 2000). Although the nitrogen concentration of the original waste is reduced by composting, the N is transformed into more stable forms (Evanylo et al., 2008). Tiquia and Tam (2000) found that organic matter and total organic carbon mass decreased with composting time. DeLaune et al. (2006) found that without adding a carbon source when composting poultry litter, P concentrations can increase in the final product and in surface runoff. They also found that composting without chemical amendments or bulking agents increased total P concentrations, which decreased N/P ratios with the loss of N during the composting process, showing that chemical amendments may be necessary to supply the equivalent N rates needed and limit soluble P levels in the litter and runoff (DeLaune et al., 2006).

Organic agriculture depends greatly on compost to build soil organic matter (Evanylo et al., 2008). Degraded soil quality decreases agricultural productivity and increases pollution of surface water (Evanylo et al., 2008). While raw litter can be applied directly to farmland, it potentially creates human and animal health risks and can cause surface and ground water pollution (Ogunwande et al., 2008). Raw manure and litter application is not permitted within 90 days of harvest if the edible portion of the product does not come into contact with the ground or within 120 days of harvest if the edible portion does contact the ground under the NOP guidelines (CFR, 2013). Utilizing a soil organic matter enhancing management system, such as using compost in organic farming, can improve degraded soils, decrease surface water pollution and increase agricultural productivity (Evanylo et al., 2008). Understanding the N-cycling process that follows after manuring soil is vital in order to estimate the importance of manure as a N fertilizer (Calderon et al., 2005). To avoid pollution of water by surface run-off or leaching, rates of application will most likely have to be limited (Sumner et al., 2002), although increased rates of composted litter are required to meet the equivalent N rates supplied by fresh litter (DeLaune et al., 2006). Evanylo et al. (2008) found that while soil physical properties were improved with compost applications, positive effects were seen more quickly with higher rates, but low application rates may also improve soil physical properties over time. Nyakatawa et al. (2001) found that significant build ups of nutrients were prevented with crop uptake.

Both cover crops and broiler litter compost can be seen as a benefit for farmers and producers. Using cover crops and/or broiler litter compost is a way to move forward in organic agriculture and toward sustainable practices. They both can improve soils. The objectives of this research were: 1) determine the extent to which summer cover crops and composted broiler litter alter nutrient availability in the soil, 2) determine how summer cover crops and composted broiler litter influence fall vegetable crops in an organic production system and 3) identify which cover crops and/or broiler litter compost combinations improve fall vegetable crop production the most.

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CHAPTER II

INFLUENCE OF SUMMER COVER CROPS AND COMPOSTED BROILER LITTER ON SOILS IN ORGANIC PRODUCTION SYSTEMS

Abstract

Cover crops and composted broiler litter (CBL) are two organic methods used to improve soils and organic vegetable crop production. This research took place at the Truck Crops Experiment Station near Crystal Springs, Mississippi to test the influence of four summer cover crops: sunn hemp (*Crotalaria juncea* L. var. *sun hemp*), sesame (*Sesamum indicum* L. var. *sesame*), sorghum sudan grass (*Sorghum X drummondii* var. *Southland Honey Pasture Hybrid*) and a sunn hemp + sesame blend, in combination with four rates of CBL: 0; 2,800; 5,600; and 11,200 kg·ha^{-1}, on fall broccoli production. The cover crops, in four replicates, were established in the summer, mowed and incorporated into the soil in August. After four weeks the CBL was applied within each subplot and tilled before transplanting broccoli (*Brassica oleracea* L. var. *Italica* Plenck. cv. Marathon) into raised beds. Soil samples were taken pre- and post- cover crop, and after the broccoli were harvested. Representative samples of the cover crops were harvested, weighed for fresh and dry weights, and used in a tissue analysis test. This experiment was done in 2011 and 2012. Few differences were seen across the cover crops, although sorghum sudan grass did have the most nutrient uptake, but the smallest nutrient

concentration. CBL applications increased soil organic matter and nutrient availability, increasing as CBL rates increased.

Introduction

While conventional agriculture makes high yield the priority, it can result in extensive environmental degradation, including water, soil and air pollution; soil erosion; biodiversity loss; and desertification (Morgera et al., 2012). The USDA National Organic Standards require organic farmers to maintain and/or improve soil health while raising crops (CFR, 2013). Soils that are organically managed often have better moisture-retention capacity than those of conventional farms, key in arid climates and to reducing the risk of desertification (Morgera et al., 2012). Organic vegetable growers must also produce high quality crops at a volume sufficient to be profitable. Soil erosion is a main reason for a loss of yield capacity and fertility (Morgera et al., 2012). Differences in soil chemistry and physical properties combined with wide-ranging climatic and agricultural variability across the United States beckons for research on N availability and use efficiency on a regional scale (Sorensen and Jensen, 1995). Two ways to maintain soil quality and add nutrients to the soil are by planting cover crops and applying organic fertilizers such as composted broiler litter.

Cover crops are planted to improve soil quality by protecting, improving, and providing nutrients for soil (Mutch, 2010). Cover crops can also reduce erosion, runoff and associated pollution, capture soil nitrogen that could be lost to leaching, improve pastures, impact insect and disease life cycles, suppress weed and nematode growth, and provide a significant source of nitrogen for crops in the future (Mutch, 2010; Baldwin and Creamer, 1999). Cover crops can build and maintain soil organic matter, which is a major factor for sustaining and increasing agricultural productivity (Nolte and Wang, 2010). Organic matter improves soil stability, water infiltration, air diffusion, and reduces soil crusting (Baldwin and Creamer, 1999). Muñoz-Carpena et al. (2008) found that soil water content depleted quickly in no-cover plots while it was released slowly in cover crop plots, and found that this effect was further amplified in the second season of study for the cover crop soil.

One of the most important benefits of cover crops is that they can enhance nitrogen availability (Mutch, 2010). Legumes and non-legumes used as cover crops provide nitrogen in different ways. If providing a cash crop with readily available nitrogen or enhancing soil organic matter is desired, a legume should be chosen as a cover crop (Nolte and Wang, 2010). For example, when sunn hemp, a legume, was used as a cover crop it created a net increase of soil nitrogen (Bosch et al., 2008). Using grass or non-legume cover crops helps keep nitrogen in the plant-soil system by utilizing residual nitrogen that may otherwise be lost to leaching (Baldwin and Creamer, 1999).

Applying broiler litter reduced soil bulk density and improved the stability of soil aggregates (Adeli et al., 2010). Broiler litter is more effective in improving soil physical property components than conventional fertilizer (Adeli et al., 2010). Evanylo et al. (2008) found that all of their high compost rates (agronomic N compost rate) increased soil C and N above all other treatments and reduced soil bulk density; and that after three years of compost applications, even the low compost rates reduced bulk density, showing that even agronomical lower rates of compost continuously applied could improve soil physical properties. Adeli et al. (2010) found that increasing litter rate increased soil pH, while inorganic fertilizer N reduced soil pH. While soil physical properties are improved with compost applications, positive effects are seen more quickly with higher rates, but the benefits of low application rates may accumulate with time (Evanylo et al., 2008).

Additional organic materials from manures contribute to improved soil structure synthesis and help in erosion control (Wolman and Fournier, 1987); the same is true of cover crop incorporation (Mutch, 2010). Cover crops can build and maintain soil organic matter, which is a major factor for sustaining and increasing agricultural productivity (Nolte and Wang, 2010). This research investigated the use and effects of summer cover crops in combination with composted broiler litter for improvement of soil health. For this research we wanted to determine the extent to which summer cover crops and composted broiler litter alter nutrient availability in the soil.

Materials and Methods

Site description and experimental design

The experiment took place during 2011 and 2012 in a certified organic field in Crystal Springs, Mississippi (31.9872° N, 90.3569° W) on a Providence silt loam soil (fine-silty, mixed, thermic Typic Fragiudalf) (NRCS, 1984). The experiment was designed using a randomized complete block design, with a split plot arrangement of treatments with cover crop as the main plot and CBL rate as the sub-plot. The studies were carried out in 2011 and 2012, with treatments in each plot and subplot repeated in the same main- and subplot in both years.

Summer cover crops, sunn hemp (*Crotalaria juncea* L. var. *sun hemp*), sesame (*Sesamum indicum* L. var. *sesame*), sorghum sudan grass (*Sorghum X drummondii* var. *Southland Honey Pasture Hybrid*) and a sunn hemp + sesame blend, were seeded at rates of 44, 13.2, 38.5, and 22 + 6.6 kg·ha^{-1} respectively in 12 x 4.5 m plots. Seeds were ordered from Adams-Briscoe Seed Co. and Peacefull Valley Farm Supply as either certified organic or untreated raw seeds. Four weeks after the incorporation of the cover crops, the composted broiler litter was spread at rates of 0, 2,800, 5,600, and 11,200 kg·ha^{-1} within 3 x 4.5 m subplots. The composted broiler litter was donated by Currie Farms from Smith County, MS and was made from a combination of broiler litter + hard and soft wood sawdust hot composted, under cover. The succeeding broccoli crop, *Brassica oleracea* L. var. *italic* Plenck. cv. Marathon, from Johnny's Selected Seeds (2011) and Snow Seed Co. (2012) was transplanted at 0.5 m x 1 m spacing.

Management practices

The cover crop seed was rolled in after spreading by hand onto disked and tilled soil, then sprinkler irrigated (+/- 2 cm/acre). At 57 days after sowing (2011) and 56 days after sowing (2012), they were flail-mowed (*model 360, John Deere, Moline, IL*) and roto-tilled (*model GHT60, Woods Equipment, Oregon, IL*) for incorporation. The bulk density of the composted litter was calculated, and applied by volume to the subplots using clean buckets dedicated to organic research. Chemical and compost-specific analysis was done on the composted broiler litter by A&L Laboratories (*Memphis, TN*) and by Woods End Laboratories (*Mount Vernon, ME*) (Table 2.1). For transplant production, broccoli was seeded into new 98-cell trays filled with organic ProMix (*Sungro Horticulture, Bellevue, WA*), germinated in a germination chamber set at 80°F (26.6°C), then grown four to five weeks in a controlled climate greenhouse. Beginning at the first true leaf stage, the seedlings were fertilized with Megagreen© made from fish protein (*Consolidated Catfish, Isola, MS*) that has an analysis of 2·2·2. When threshold levels were exceeded, as determined from weekly scouting, aphids and whiteflies were treated as needed with a pyrethrum product Pyganic© (*MGK®, Minneapolis, MN*). The broccoli plants were transplanted by hand at 0.5 m spacing in the row, and 1 m spacing between rows (3 rows/plot, 10± plants per row) and hand-watered. The broccoli was watered with an impact sprinkler on a hard-hose retriever reel (*KIFCO, Havana, IL*) as needed and weeded once by roto-tilling between the rows and hand hoeing in the rows. The broccoli was harvested within the middle row of each subplot and graded according to standards defined by the United States Department of Agriculture (USDA) for grading of Italian sprouting broccoli (USDA, 2006).

Soil tests

Soil samples were taken before the summer cover crops were planted, before the composted broiler litter was spread, and during the peak of the broccoli harvest during both years. At each sampling time, 6 cores eight inches deep were taken randomly in each subplot using an Oakfield 0.5 inch diameter soil probe. The samples were dried in a glass greenhouse, and then taken to the Mississippi State University Extension Service (MSU-ES) Soil Testing Laboratory for analysis. Samples were further air dried, ground, and analyzed using the Lancaster method for nutrient concentrations and the DeBolt procedure for determining organic matter (Crouse, 2012).

Tissue tests

Using a 0.25 m^2 sampling frame, the fresh weights of the cover crops and weeds within each subplot were determined by harvesting a representative portion of each plot 60 days after seeding. The cover crop and weed fractions were separated, weighed and then dried in a forced-air oven at 65°C and weighed again. The dried samples of the cover crops were ground using a stainless steel Wiley Mill (*Thomas Scientific, Swedesboro, NJ*) and sent to the Mississippi State University Extension Service (MSU-ES) Soil Testing Laboratory for tissue analysis in which the micro kjeldahl and ICP methods were used (Crouse, 2012).

Results

All data was analyzed using the PROC MIXED procedure in SAS.

2011 Soil tests

Soils testing before cover crops were planted in 2011 were done as a baseline for the project (Table 2.2). In 2011 soil samples were taken 54 days after the cover crop was seeded and after the cover crop was cut, but before incorporation, with a two inch augur probe because of hard, dry soil conditions which prevented the proper use of the 0.5 inch push-type probe used for other soil samples taken in this study. Soil samples taken after cover crop cutting showed no differences in soil pH (5.8) or organic matter content (%OM) (0.63), nor in extractable P, K, Ca, Mg, Zn, S or Na which were 96.63, 300.63, 3605.13, 849.00, 6.11, 180.13, 198.00 ppm respectively.

Post planting broccoli soil samples were taken 107 days after transplanting and 18 days after final harvest. In samples taken after broccoli harvest, there were no significant differences in soil pH, %OM, or any extractable nutrients among the cover crop treatments. Extractable P, K and Zn were significantly different among composted broiler litter rates, each increasing significantly as the compost rate increased (Table 2.3). The two highest rates of compost were significantly higher in %OM than the lower two rates

(Table 2.3). In respect to extractable Ca, Mg and pH, applying no compost resulted in significantly lower levels than found in the other treatments (Table 2.3). Extractable S showed a significant increase with the two highest rates of compost (Table 2.3). Extractable Na significantly increased through the 5,600 kg·ha^{-1} CBL application rate (Table 2.3).

2011 Cover crop tissue analysis

Cover crop tissue samples were taken from each cover crop main plot on August 18, 2011, 49 days after sowing. There was a significant difference between the monocrops in N, K, Ca, Mg, S, Fe, Cu and B whole shoot tissue concentration (Table 2.4). Sorghum sudan grass tissue was significantly lower in N, Mg, S, Fe and B than the other monocrops (Table 2.4). All crops were significantly different from each other in Ca and Cu concentrations (Table 2.4). Sesame was significantly higher in K concentrations than the other mono-crops (Table 2.4).

No significant differences in tissue nutrient concentrations were seen between the monocrop sesame and sesame in the blend (data not shown). The blended sunn-hemp and mono-cover sunn-hemp showed significant differences in tissue levels of only Zn and Cu with the blended having higher levels at 25.00 and 8.67 ppm of Zn and Cu, respectively, and the mono-cover sesame having 30.33 and 11.67 ppm of Zn and Cu, respectively.

2012 Soil tests

Pre-cover crop soil samples were taken from each cover*CBL sub-plot June 21-22, 2012. A significant interaction was seen between the cover crops and the composted broiler litter when comparing %OM (Figure 2.1) and S (Figure 2.2) in the 2012 pre-cover soil tests. In respect to sorghum sudan grass combined with the composted broiler litter, the highest rate of composted broiler litter applied was significantly different in %OM (Figure 2.1) and S (Figure 2.2) than the other compost rates. Significant differences were seen among extractable P, K and Zn levels in the composted broiler litter treatments (Table 2.5). The highest rate of composted broiler litter was significantly different from all other rates in P, K and Zn concentrations (Table 2.5). Extractable K levels in the 5,600 kg·ha^{-1} CBL plots were also significantly greater than in the 0 kg·ha^{-1} plots (Table 2.5). Soil pH in the sunn-hemp plots was significantly different than in the sesame plots in the 2012 pre-cover crop soil tests (Table 2.5).

In respect to 2012 pre-compost soil samples, taken September 11, 34 days after cover crop incorporation, no significant interactions were seen (data not shown). The highest composted broiler litter rate of 11,200 kg·ha^{-1} was significantly different from all other compost application rates in P and Zn (Table 2.5). The highest rate was significantly higher in K than the 2,800 and 0 kg·ha^{-1} application rates (Table 2.5).

In 2012 post-broccoli soil tests, from samples taken 126 days after transplanting and 26 days after final harvest, a significant interaction was seen in the Na content between cover crops and composted broiler litter rates. Sesame + 11,200 kg·ha^{-1} and sunn-hemp + sesame + 11,200 kg·ha^{-1} of composted broiler litter were significantly different from all other cover crop X compost combinations. The highest compost application rate was significantly greater in %OM, P, K, Ca, Mg, Zn, S and pH than all other compost rates (Table 2.6). When comparing %OM, Ca, Mg, and S, no other compost rates were significantly different from each other (Table 2.6). In P, 5,600 kg·ha^{-1} was also significantly greater than the two lowest rates (Table 2.6). For K and pH, the

0 kg·ha^{-1} treatment was significantly lower than all other application rates (Table 2.6). When comparing extractable Zn, 5,600 kg·ha^{-1} was significantly different from the 0 kg·ha^{-1} rate, but not the 2,800 kg·ha^{-1} (Table 2.6).

2012 Cover crop tissue analysis

Cover crop tissue samples were taken August 13, 2012, 48 days after sowing. A significant interaction was seen between the cover crops and the composted broiler litter in the uptake of Ca (Figure 2.3) and B (Figure 2.4). No other significant differences were found between the compost rates (data not shown).

In respect to the cover crops, sorghum sudan grass had significantly higher weights in cover crop, weed and total dry weights than all other cover crops (Table 2.7). Sorghum sudan grass also had significantly higher P, K and Cu uptake than all other cover crops (Table 2.7). Sunn-hemp had significantly lower uptakes of Mg and S among the cover crops (Table 2.7).

Discussion

Cover crops led to few differences in soil tests throughout the experiment. Tissue tests in 2011 showed the nutrient concentration to be lower in sorghum sudan grass than the other three cover crops, while 2012 results showed sorghum sudan grass to have a significantly higher total nutrient uptake. This was because the sorghum sudan grass had significantly greater biomass than the other cover crops. This high biomass production is a positive characteristic of the sorghum sudan grass, allowing it to take up nutrients, preventing them from leaching or running off. This conflicts with findings by Wang et al.

(2003), in which a much larger biomass was produced by legumes, including sunn hemp, than the non-legume, sorghum sudan grass.

The composted broiler litter had a positive effect on soil tests, increasing organic matter and most extractable nutrients in both years. The two highest rates of litter showed the most increases, even doubling some levels from the initial soil tests in 2011. This suggests that the application of composted broiler litter not only supplies macro-nutrients but also micro-nutrients that some salt-soluble fertilizers do not provide. This agrees with Wilkinson (1979) who reported that manure can alleviate micronutrient deficiencies, even after it has been composted.

While the data indicate no clear best choice for cover crop/composted broiler litter combination, it is certain that sorghum sudan grass had the largest nutrient uptake. Although the large biomass of sorghum sudan grass could cause a nitrogen tie-up for following crops, appropriate decomposition time could alleviate this problem. While other seeds are readily available, sunn hemp seed supplies can be scarce because of tropical climate needs for seed production (USDA ARS, 2006). This could lead to other leading choices of cover crops if seed cost is high or unavailable regularly. Changes in nutrient levels from each soil sampling period could be attributed to the up-take or decomposition of cover crops and broccoli in the field, as well as the application of composted broiler litter. Abdul-baki et al. (1997) stated that the head of the broccoli appeared to be a nitrogen sink with higher priority than the leaves. This could mean that the head of the broccoli is a sink for other nutrients as well. Since we harvested the heads of the broccoli and removed them from the field, this could explain a decrease in some nutrient levels. Changes could also be seen from seasonal variations at the times of soil sampling and fixation of extractable nutrients.

The relatively short period of time this project has been underway indicates that cover crop testing should be continued on the same site for several more years to determine if there are any lasting effects and if they lead to more improvement over time. Applications of composted broiler litter should be continued, but since high rates doubled phosphorus levels in just two years of applications, further rates should be applied with caution, to avoid over-application of phosphorus.

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Tables and Figures

Table 2.1 Composted broiler litter analysis results.

Test	Dry Basis	Method
Nitrogen, N % [a]	2.42	RMMA [1]
Phosphorus, P % [a]	2.46	SW – 6010B [2]
Potassium, K % [a]	3.46	SW – 6010B [2]
Sulfur, S % [a]	0.996	SW – 6010B [2]
Magnesium, Mg % [a]	0.998	SW – 6010B [2]
Calcium, Ca % [a]	3.96	SW – 6010B [2]
Sodium, Na ppm [a]	9260	SW – 6010B [2]
Iron, Fe ppm [a]	3680	SW – 6010B [2]
Aluminum, Al ppm [a]	1680	SW – 6010B [2]
Manganese, Mn ppm [a]	701	SW – 6010B [2]
Copper, Cu ppm [a]	540	SW – 6010B [2]
Zinc, Zn ppm [a]	618	SW – 6010B [2]
Boron, B ppm [a]	65.2	SW – 6010B [2]
Moisture % [a]	20.7	RMMA [1]
Solid % [a]	79.3	RMMA [1]
Total Chromium, ppm [a]	7.09	SW – 6010B [2]
Total Nickel, ppm [a]	35.2	SW – 6010B [2]
Total Lead, ppm [a]	2.98	SW – 6010B [2]
Total Cadmium, ppm [a]	0.197	SW – 6010B [2]
pH [b]	7.6	EPA 150.2: MAP [1]
Total Organic Matter, %[b]	51.5	LOI – Total N [3]
Total Carbon: Nitrogen (C:N) Ratio [b]	9:1	Volatile Solids [3]

[a] Analysis was completed by A & L Analytical Laboratories, Inc. (Memphis, TN).

[b] Analysis was completed by Woods End Laboratories, Inc. (Mount Vernon, ME).

[1] Peters, J., S. Combs, B. Hoskins, J. Jarman, J. Kovar, M. Watson, A. Wolf and N. Wolf. 2003. Recommended Methods of Manure Analysis. University of Wisconsin Extension. A3769. http://learningstore.uwex.edu/assets/pdfs/A3769.pdf

[2] United States Environmental Protection Agency. 2012. Wastes – Hazardous Waste – Test Methods. SW – 846 Online. http://www.epa.gov/osw/hazard/testmethods/sw846/online/index.htm

[3] Woods End Laboratories, Inc. 2011. Laboratory Test Interpretation. Journal of Woods End Laboratories, Inc. ver. 9.

Table 2.2 Initial soil test values on June 21, 2011.

Organic Matter (%)	P (lbs./A)	K (lbs./A)	Ca (lbs./A)	Mg (lbs./A)	Zn (lbs./A)	S (lbs./A)	Na (lbs./A)	pH
0.56	51.75	155.75	2259.75	461.50	3.40	80.75	297.00	6.125

Table 2.3 Influence of composted broiler litter rate on soil test values on January 6, 2012, after broccoli harvest.

CBL (kg·ha^{-1})	Organic Matter (%)	P (lbs/A)	K (lbs/A)	Ca (lbs/A)	Mg (lbs/A)	Zn (lbs/A)	S (lbs/A)	Na (lbs/A)	pH
0	0.86 b^z	62.06 d	185.88 d	2085.38 c	487.81 b	2.49 d	123.56 b	92.56 c	6.34 c
2,800	0.86 b	96.19 c	240.81 c	2217.19 b	527.19 a	3.78 c	123.63 b	117.81 b	6.48 b
5,600	0.95 a	137.19 b	290.50 b	2249.69 ab	537.88 a	5.39 b	137.00 a	164.19 a	6.57 ab
11,200	0.99 a	188.13 a	373.69 a	2320.75 a	560.13 a	7.06 a	142.56 a	164.56 a	6.61 a

^{z} Means followed by the same letter within each column are not significantly different at $p \leq 0.05$.

Table 2.4 Extractable nutrients in mono-crops of tissue tests in summer 2011.

Mono-crop	N (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Cu (ppm)	B (ppm)
Sunn-hemp	2.74 a[z]	1.78 b	1.09 b	0.71 a	0.26 a	66.50 a	9.00 b	17.50 a
Sesame	2.61 a	2.68 a	1.51 a	0.77 a	0.29 a	67.50 a	12.25 a	21.75 a
Sorghum sudan grass	1.09 b	1.64 b	0.36 c	0.29 b	0.08 b	32.50 b	6.25 c	3.50 b

[z] Means followed by the same letter within each column are not significantly different at $p \leq 0.05$.

Table 2.5 Influence of cover crops and composted broiler litter on pre- and post-cover crop soil test values in 2012 season.

		Organic matter (%)	P (lbs/A)	K (lbs/A)	Ca (lbs/A)	Mg (lbs/A)	Zn (lbs/A)	S (lbs/A)	Na (lbs/A)	pH
Pre-cover soil test										
Cover crops	CR[z]	0.76	55.44	180.94	1971.50	485.75	3.03	110.06	64.31	6.03a[y]
	CS	0.75	58.75	180.75	1960.63	470.88	3.25	108.75	63.94	5.93ab
	SE	0.77	59.50	195.25	1962.50	479.13	3.17	111.56	66.13	5.79b
	SO	0.77	60.69	189.25	1919.44	445.50	3.19	111.00	60.06	5.93ab
CBL (kg·ha^{-1})	0	0.73	50.75b	166.44c	1950.94	469.25	2.83b	1005.44	58.00	5.87
	2,800	0.75	51.50b	176.69bc	1973.50	478.13	2.88b	107.88	60.38	5.91
	5,600	0.77	59.25b	188.06b	1899.13	463.19	3.20b	110.75	66.69	5.91
	11,200	0.81	72.88a	215.00a	1990.50	470.69	3.73a	117.31	69.38	5.99
Post-cover soil test										
Cover Crops	CR	0.77	51.06	176.56	1896	474	3.14	111	57	6.1
	CS	0.78	49.31	178.25	1861	479	3.09	113	58	6.0
	SE	0.77	50.31	173.69	1826	439	2.98	110	51	6.1
	SO	0.77	44.19	178.63	1891	475	3.16	111	59	6.2
CBL (kg·ha^{-1})	0	0.73	43.94b	159.88b	1840	466	2.74b	106	53	6.1
	2,800	0.78	43.69b	174.00b	1880	474	2.86b	112	56	6.1
	5,600	0.80	48.50b	178.63ab	1843	463	3.13b	116	58	6.1
	11,200	0.78	58.75a	194.63a	1912	463	3.64a	112	59	6.1

[z] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

[y] Means followed by the same letter in each column for each test period are not significantly different at $p \leq 0.05$.

Table 2.6 Influence of composted broiler litter on post-broccoli harvest soil test values on January 28, 2012.

		Organic matter (%)	P (lbs/A)	K (lbs/A)	Ca (lbs/A)	Mg (lbs/A)	Zn (lbs/A)	S (lbs/A)	Na (lbs/A)	pH
Cover Crops	CR^z	0.78	128.25	331.50	1684.25	438.13	5.39	111.69	56.31	6.73
	CS	0.81	141.06	364.44	1830.06	476.38	5.78	116.88	64.94	6.76
	SE	0.85	148.69	363.19	1704.19	437.69	5.84	122.44	62.69	6.69
	SO	0.85	140.94	361.69	1714.38	422.63	5.99	122.44	50.69	6.69
CBL (kg·ha^{-1})	0	0.75 b^y	81.88 c	242.94 c	1611.44 b	405.75 b	3.97 c	107.56 b	43.00	6.55 c
	2,800	0.81 b	100.75 c	306.69 b	1693.19 b	425.31 b	4.40 bc	116.38 b	52.50	6.66 bc
	5,600	0.82 b	132.63 b	336.69 b	1695.25 b	431.13 b	5.42 b	117.75 b	59.13	6.72 b
	11,200	0.92 a	243.69 a	534.50 a	1933.00 a	512.63 a	9.21 a	131.75 a	80.00	6.94 a

[z] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

[y] Means followed by the same letter in each column for each test period are not significantly different at $p \leq 0.05$.

Table 2.7 Yield in cover crops of tissue tests on August 13, 2012.

Cover Crops	Dry weight of cover crop (g·m^{-2})	Dry weight of weeds (g·m^{-2})	Dry weight of total plot (g·m^{-2})
CR^z	264.72c^y	1903.20a	2167.92b
CS	1049.32bc	860.40bc	1909.72bc
SE	1301.32b	503.00b	1805.60b
SO	3533.20a	441.40b	3974.60a

[z] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

[y] Means followed by the same letter within each column are not significantly different at $p \leq 0.05$.

Table 2.8 Extractable nutrients in cover crops of tissue tests August 13, 2012.

Cover Crops	N ($g \cdot m^{-2}$)	P ($g \cdot m^{-2}$)	K ($g \cdot m^{-2}$)	Mg ($g \cdot m^{-2}$)	S ($g \cdot m^{-2}$)	Fe ($mg \cdot m^{-2}$)	Mn ($mg \cdot m^{-2}$)	Zn ($mg \cdot m^{-2}$)	Cu ($mg \cdot m^{-2}$)
CR[z]	1.97c[y]	0.13c	1.35c	0.34b	0.14b	4.48b	2.85c	1.41c	0.56c
CS	6.39bc	0.54bc	6.58bc	1.72a	0.51a	16.57bc	10.07bc	6.07bc	2.24bc
SE	8.23ab	0.65b	9.27b	2.33ab	0.63ab	20.87b	12.98b	8.46b	2.92b
SO	13.05a	1.34a	18.6a	2.49a	0.59a	164.11a	35.22a	19.82a	5.92a

[z] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

[y] Means followed by the same letter within each column are not significantly different at $p \leq 0.05$.

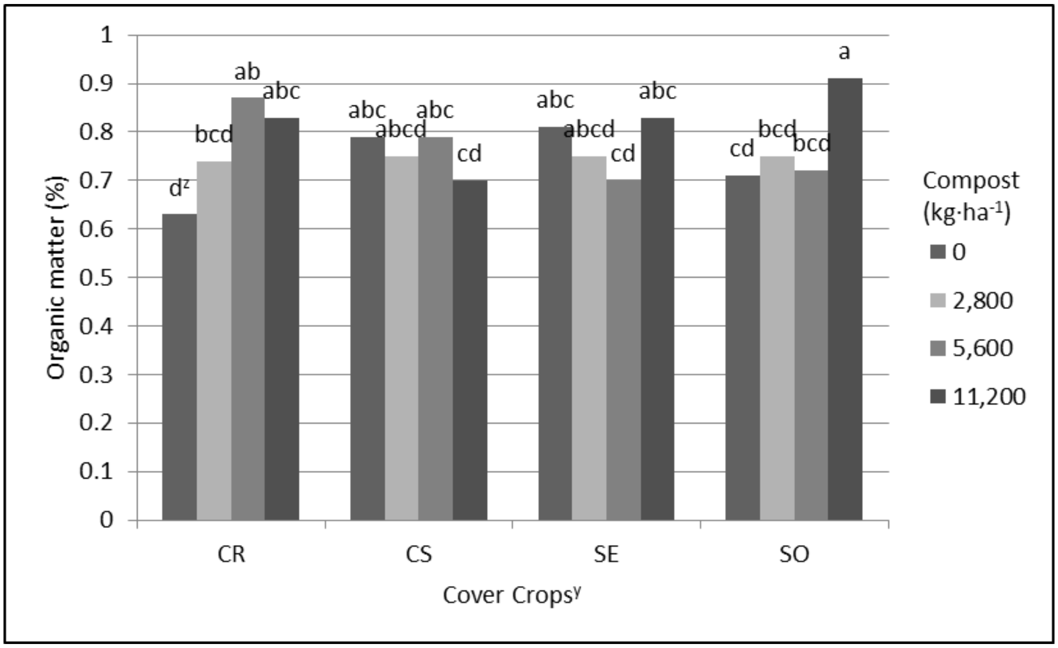

Figure 2.1 The influence of cover crops and composted broiler litter on organic matter in pre-cover soil tests June 21, 2012.

[z] Means represented by the same letter are not significantly different at $p \leq 0.05$.
[y] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

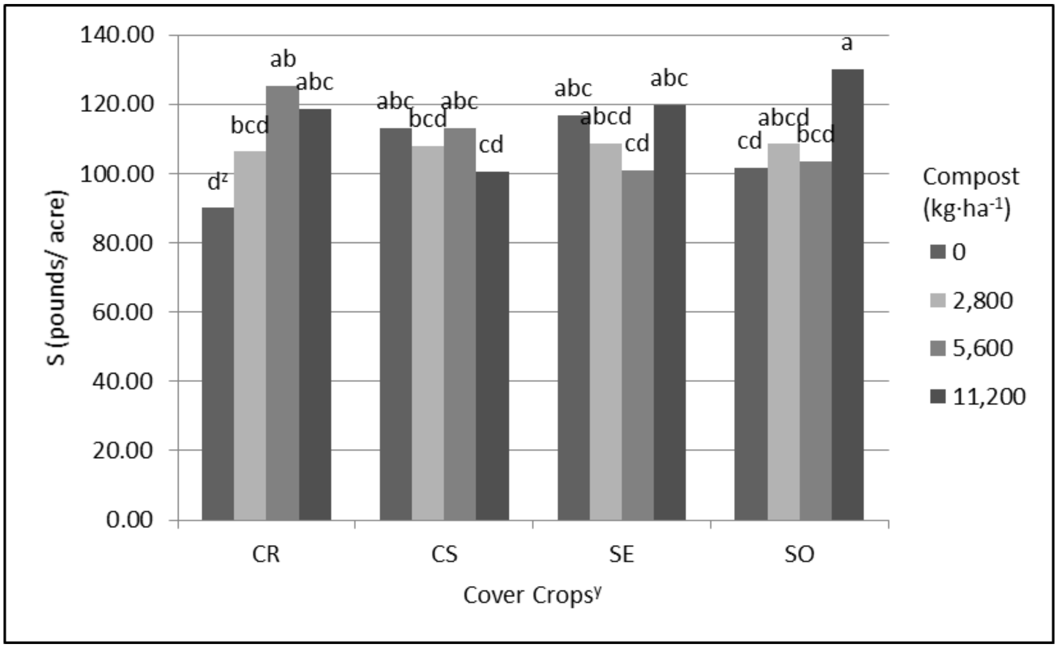

Figure 2.2 Influence of cover crops and composted broiler litter on sulfur concentrations in pre-cover soil tests on June 21, 2012.

[z] Means represented by the same letter are not significantly different at $p \leq 0.05$.
[y] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

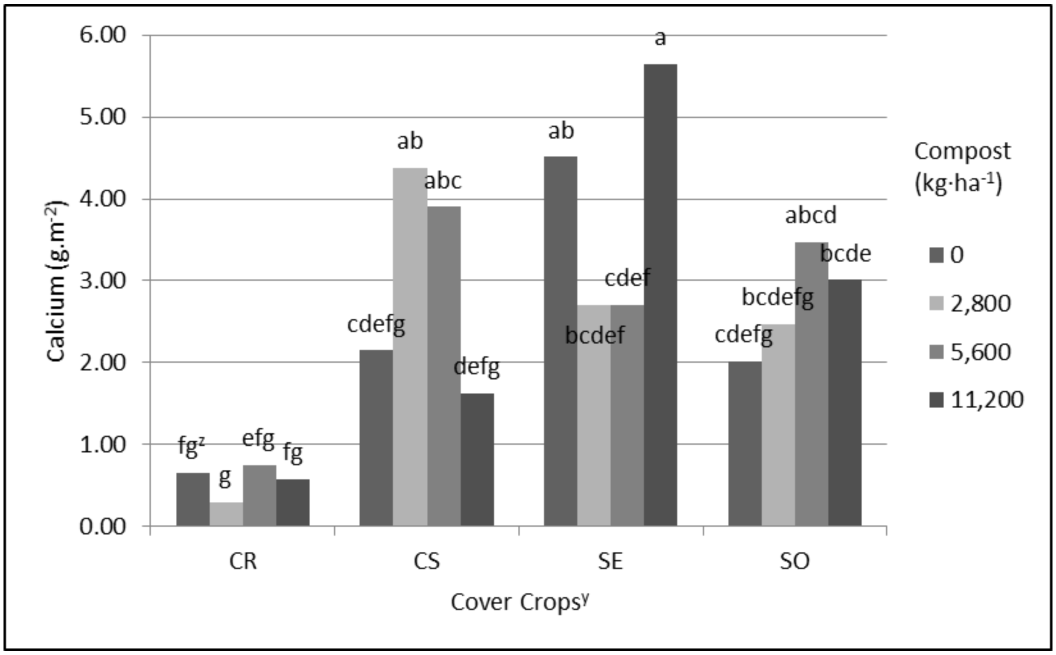

Figure 2.3 The influence of composted broiler litter on calcium uptake in cover crops in 2012.

[z] Means represented by the same letter are not significantly different at $p \leq 0.05$.
[y] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

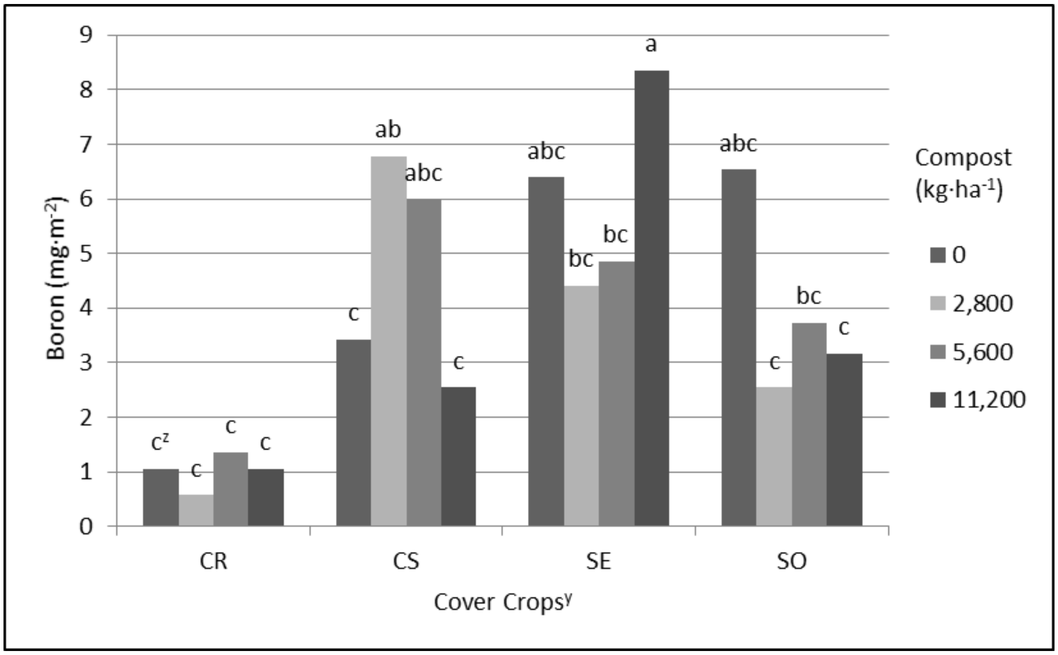

Figure 2.4 The influence of composted broiler litter on boron uptake in cover crops in 2012.

[z] Means represented by the same letter are not significantly different at $p \leq 0.05$.
[y] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

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CHAPTER III

SUMMER COVER CROPS AND COMPOSTED BROILER LITTER ON FALL VEGETABLE PRODUCTION

Abstract

Cover crops and composted broiler litter (CBL) are two methods used to improve soils and vegetable crop production. A study in Crystal Springs, Mississippi tested the influence of four cover crops: sunn hemp (*Crotalaria juncea* L. var. *sun hemp*), sesame (*Sesamum indicum* L. var. *sesame*), sorghum sudan grass (*Sorghum X drummondii* var. *Southland Honey Pasture Hybrid*) and a sunn hemp + sesame blend, in combination with four concentrations of composted broiler litter: 0, 2,800, 5,600, 11,200 kg·ha^{-1} on fall vegetable production. The cover crops were established in four replicates, mowed and incorporated. Four weeks after incorporation, the CBL was applied within each subplot and tilled before bedding of broccoli (*Brassica oleracea* L. var. *italic* Plenck. cv. Marathon). Leaf tissue samples were taken at the peak of broccoli harvest and analyzed. Broccoli was harvested, counted and weighed in marketable and unmarketable groups. Data showed that sorghum sudan grass significantly lower the yield of broccoli unless combined with increased rates of CBL. All other cover crops showed little differences, even across CBL applications. As the CBL rate increased, broccoli yield increased.

Introduction

The USDA National Organic Standards require growers to maintain and/or improve soil health while raising crops (CFR, 2013). Organic vegetable growers must also produce high quality crops at a volume sufficient to be profitable. Two ways to maintain soil quality and add nutrients to the soil for vegetable crops are by planting cover crops and applying organic fertilizers such as chicken broiler litter. How best to use these two together in southeastern U.S. organic vegetable production has not been studied extensively, especially for fall vegetable crops.

In 1955, Heddle and Herriott published a paper stating that cereal cover crops can aid in plant establishment by reducing weed competition. J. Lewis (1959) found that sowing seed crops without a cover crop produced leafy material and had a lower seed yield. Cover crops can also reduce erosion, runoff and associated pollution, capture soil nitrogen that could be lost to leaching, improve pastures, impact insect and disease life cycles, suppress weed and nematode growth, and provide a significant source of nitrogen for crops in the future (Mutch, 2010; Baldwin and Creamer, 1999). Legumes provide nitrogen fixation, and can be particularly helpful in organic production systems, where synthetic fertilizers cannot be used (Nolte and Wang, 2010). For example, when sunn hemp, a legume, was used as a cover crop it led to a net increase of soil nitrogen (Bosch et al., 2008). Using grass or non-legume cover crops help keep nitrogen in the plant-soil system by taking up and storing residual nitrogen that may otherwise be lost to leaching (Baldwin and Creamer, 1999). Economic and environmental concerns have fueled the reappearance of cover crop use (Mutch, 2010) and other alternatives to conventional fertilizers.

One alternative to conventional fertilizers is composted chicken litter. Wilkinson (1979) found that the use of animal manure, including chicken litter, over several years resulted in little or no addition of phosphorus (P) or potassium (K) and that yields produced from immediately incorporating manure nitrogen (N) were equal to that of conventional fertilizer. He also suggested that waste fertilizer value can exceed waste management costs, shifting manure from a waste to a resource (Wilkinson, 1979). In 1993, Wood et al. found that the lasting effects of using chicken litter resulted in increased yields of bermuda grass hay fields, making it an admirable choice for sustainable agriculture. Sistani et al. (2010) also found that high litter rates will produce significantly greater dry-mass of the cash crop than conventional fertilizer because there is an addition of micronutrients or slow release of nitrogen in the growing season from the litter.

Cover crops can build and maintain soil organic matter, which is a major factor for sustaining and increasing agricultural productivity (Nolte and Wang, 2010). Legume cover crops can fix and contribute nitrogen, while non-legumes can trap soil nitrogen. Both can add organic matter to the soil system. In addition to its properties as a fertilizer, broiler litter is more effective in improving soil property components than conventional fertilizer (Adeli et al., 2010). This research investigated the use and effects of summer cover crops in combination with composted broiler litter for fall vegetable production in Mississippi. The objectives of this research were to determine how summer cover crops and composted broiler litter influence fall vegetable crops in an organic production system and to identify which cover crops and/or broiler litter compost combinations improve fall vegetable crop production the most.

Methods

Site description and experimental design

The experiment took place during 2011 and 2012 in a certified organic field in Crystal Springs, Mississippi (31.9872° N, 90.3569° W) on a Providence silt loam soil (fine-silty, mixed, thermic Typic Fragiudalf) (NRCS, 1984). The experiment was set up using randomized complete block design, with a split plot arrangement of treatments with cover crop as the main plot and CBL rate as the sub-plot. The studies were carried out in 2011 and 2012, with treatments in each plot and subplot repeated in the same main- and subplot in both years.

Summer cover crops, sunn hemp (*Crotalaria juncea* L. var. *sun hemp*), sesame (*Sesamum indicum* L. var. *sesame*), sorghum sudan grass (*Sorghum X drummondii* var. *Southland Honey Pasture Hybrid*) and a sunn hemp + sesame blend, were seeded at rates of 44, 13.2, 38.5, and 22 + 6.6 $kg{\cdot}ha^{-1}$ respectively in 12 x 4.5 m plots. They were ordered from Adams-Briscoe Seed Co. and Peacefull Valley Farm Supply as either certified organic or untreated raw seeds. Four weeks after the incorporation of the cover crops, the composted broiler litter was spread at rates of 0, 2,800, 5,600, and 11,200 $kg{\cdot}ha^{-1}$ within 3 x 4.5 m subplots. The composted broiler litter was donated by Currie Farms from Smith County, MS and was made from a combination of broiler litter + hard and soft wood sawdust hot composted under cover. The succeeding broccoli crop, *Brassica oleracea* L. var. *italic* Plenck. cv. Marathon, from Johnny's Selected Seeds (2011) and Snow Seed Co. (2012) was transplanted at 0.5 m x 1 m spacing.

Management practices

The cover crop seed was rolled in after spreading by hand onto disked and tilled soil, then sprinkler irrigated (+/- 2 cm/acre). At 57days after sowing (2011) and 56 days after sowing (2012), they were flail-mowed (*model 360, John Deere, Moline, IL*) and roto-tilled (*model GHT60, Woods Equipment, Oregon, IL*) for incorporation. The bulk density of the composted litter was calculated, and applied by volume to the subplots using clean buckets dedicated to organic research. Chemical and compost-specific analysis was done on the composted broiler litter by A&L Laboratories (*Memphis, TN*) and by Woods End Laboratories (*Mount Vernon, ME*) (Table 2.1). For transplant production, broccoli was seeded into new 98-cell trays filled with organic ProMix (*Sungro Horticulture, Bellevue, WA*), germinated in a germination chamber set at 80°F (26.6°C), and then grown four to five weeks in a controlled climate greenhouse. Beginning at the first true leaf stage, the seedlings were fertilized with Megagreen© fish emulsion (*Consolidated Catfish, Isola, MS*). When threshold levels were exceeded as determined from weekly scuting, aphids and whiteflies were treated as needed with a pyrethrum product Pyganic© (*MGK®, Minneapolis, MN*). The broccoli was transplanted by hand at 0.5 m spacing in the row, and 1 m spacing between rows (3 rows/plot, 10± plants per row) and hand-watered in. The broccoli was watered with an impact sprinkler on a hard-hose retriever reel (*KIFCO, Havana, IL*) as needed and weeded once by roto-tilling between the rows and hand hoeing in the rows. Broccoli was harvested within the middle row of each subplot and graded according to standards defined by the United States Department of Agriculture (USDA) for grading of Italian sprouting broccoli (USDA, 2006).

Tissue Tests

Leaf samples were taken of the broccoli during the peak harvest time of the most recently matured leaves in each subplot. Ten leaves were taken from plants in the middle row of each three-row subplot. In 2012, the leaves were sampled January 3. The leaves were completely dried in a forced-air oven at 55 to 65°C. The dried samples of the broccoli were ground using a Wiley Mill grinder (*Thomas Scientific, Swedesboro, NJ*) and sent to the Mississippi State University Extension Service (MSU-ES) Soil Testing Laboratory for tissue analysis in which the micro kjeldahl and ICP methods were used (Crouse, 2012).

Harvest

The broccoli was harvested from the center test row of each subplot and graded according to standards defined by the United States Department of Agriculture (USDA) for grading of Italian sprouting broccoli (USDA, 2006). Marketable heads and culls were separated, counted and fresh, trimmed weights recorded. Data were only taken from the main head of the broccoli. Broccoli was harvested December 20 in 2011 (90 days after transplant) and from December 7 through January 3 (75 to 102 days after transplant) in 2012.

Results

All data was analyzed using the PROC MIXED procedure in SAS.

2011 Broccoli harvest

There were no significant interactions between the cover crops and the composted broiler litter in terms of the broccoli yield and quality in 2011. In respect to the cover crops in the 2011 broccoli harvest, sorghum sudan grass resulted in a significant decrease in the total number of heads harvested per plot and average head weight, as well as a significant decrease in the number and yield of marketable broccoli heads harvested (Table 3.2).

There were also significant differences seen among the composted broiler litter rates in number and yield of total, marketable and cull heads (Table 3.2). The 0 kg·ha^{-1} compost treatment was significantly lower in the total number of harvested heads than all other composted broiler litter applications (Table 3.2). The 0 and 2,800 kg·ha^{-1} treatments were significantly lower than the two higher rates in the total yield of all broccoli heads harvested, and the number and yield of marketable heads harvested (Table 3.2). The 2,800 kg·ha^{-1} rate was also significantly higher in the number of culls harvested and their respective yields (Table 3.2).

2012 Broccoli harvest

A significant cover crop X compost interaction was found for the total number of plants harvested (Figure 3.1). Sorghum sudan grass combined with 0 kg·ha^{-1} composted broiler litter was significantly lower than all other treatments in the number of total plants harvested (Figure 3.1). Lower rates of the applied composted broiler litter resulted in fewer total heads harvested than other treatments (Figure 3.1). Higher applications of composted broiler litter increased the total number of heads harvested from sorghum sudan grass plots (Figure 3.1).

There were no significant interactions between the cover crops and the composted broiler litter in the total harvested yield. We found a significant difference between cover crops and compost rates in the total yield of all harvested heads (Table 3.3). With a mean of 1.33lbs./plot, the total yield of broccoli from the sorghum sudan grass treatment was significantly lower than from the sesame, sunn-hemp and the sesame + sunn-hemp blend treatments (Table 3.3). Total broccoli yield from the lowest compost rate of 0 kg·ha^{-1} was found to be significantly lower from rates of 5,600 and 11,200 kg·ha^{-1} (Table 3.3). The highest compost rate, 11,200 kg·ha^{-1}, was significantly higher in total broccoli yield than all other rates (Table 3.3).

There was a significant difference in the cover X compost interactions in the number of marketable heads harvested (Figure 3.2). Sorghum sudan grass combined with no composted broiler litter application caused significantly lower number of marketable heads harvested than all other treatments (Figure 3.2). Higher rates of applied compost were found to cause more marketable broccoli heads harvested (Figure 3.2).

There were no significant interactions between the cover crops and the compost rates in the yield of marketable harvested heads. A significant difference was seen of the marketable yield between cover crops and between compost rates (Table 3.3). The sorghum sudan grass treatment was significantly different from sesame, sunn-hemp and the sesame + sunn-hemp blend treatments (Table 3.3). The broccoli yield from the highest compost rate was significantly different from all others (Table 3.3). Yield from the 0 kg·ha^{-1} compost application was also significantly lower from the application of 5,600 kg·ha^{-1}, the second highest composted broiler litter application (Table 3.3).

Culls were due to small size; no significant disease or insect damage was seen at harvest in the field. There was a significant cover X compost interaction in the number of cull heads harvested (Figure 3.3). Sunn-hemp in combination with the second highest composted broiler litter rate resulted in the least amount of culls with 0 (Figure 3.3).

While it was only significantly different from three out of 15 other combinations, it was the only combination to have 0 culls (Figure 3.3). The highest litter rate produced the lowest amount of culls (Figure 3.3). Although this was not significantly different from some other rates, it was the only compost rate to be relatively consistent across all cover crops.

No significant differences were found in the weight of the broccoli culls among cover crop treatments, compost rates or the interactions.

Discussion

Sorghum sudan grass caused a decrease in fall broccoli production in both years. This could be because of an immobilization of nitrogen by the sorghum sudan's large biomass during decomposition. Sorghum sudan grass is also said to have allelopathic traits, decreasing the growth of some vegetable crops that follow, including broccoli (Summers et al., 2009), although Adler and Chase (2007) stated that using transplants may offer some protection for the crop. In this work, sorghum sudan plots receiving at least some compost, produced yields of broccoli similar to those seen in other cover crop treatments. Thus, either the compost helped ameliorate the effects of any allelopathic chemicals, or the fertilizer value of the litter overcame the nitrogen immobilization caused by the decomposing sorghum sudan grass. While broccoli showed a more positive response to sunn hemp, sesame and the blend, broccoli yields following any of these three cover crops were relatively the same with few significant differences, even across composted litter rates. This is similar in results to Abdul-baki et al. (1997b), in which the yield was not significantly different across cover crops, both legume and non-legume.

In respect to the composted broiler litter rates, data showed that increasing the compost application increased the marketable yield and decreased the number of culls. While in 2011 there was no significant yield difference between the two highest compost rates, there was a significant difference in 2012. This data could suggest that the most efficient amount of composted broiler litter to apply could be between 5,600 kg·ha^{-1} and 11,200 kg·ha^{-1} since in the first year of application there were no differences between the two highest rates, but in the second year they were different from each other.

We found sorghum-sudan grass with no CBL application to have a significantly lower broccoli yield than all other treatments. No other combination of cover crop and composted broiler litter was significantly greater than any other. We found the yield to increase in response to greater CBL rates. This response agrees with Abdul-baki et al. (1997a) in which they stated a yield increase in response to fertilizer N, suggesting that N from cover crops did not fully meet the need of their broccoli crop. There was an overall decrease in broccoli production from 2011 to 2012. This could be from a cooler year and an increase in rainfall over the season in which excess water can stunt growth.

To further this research, the experiment should be repeated for several more years to see if there is a lasting effect of the cover crops and applied composted broiler litter. Since this project has been going on for a relatively short time, the effects of the cover crops may not be fully realized yet. Allelopathy tests should also be conducted to determine if the negative effects from sorghum sudan grass are from an allelopathic interaction with the broccoli. The negative effects could also be from the immobilization of nitrogen during decomposition because the large biomass of sorghum sudan grass would require significant nitrogen to be broken down by soil organisms; therefore, testing for the release of nitrogen by soil organisms should also be conducted. Repeated application of high rates of composted broiler litter should be evaluated to ensure that an over-application of phosphorus or any other nutrient does not occur.

Acknowledgements

We thank the Truck Crops Branch Experimental Station crew in Crystal Springs for maintaining the project, Currie Farms (*Smith County, MS*) for providing the composted broiler litter, and SunGro Horticulture (*Bellevue, WA*) for organic media. This work was funded by the Southern Sustainable Agriculture and Research Education (Southern SARE) program.

Tables and Figures

Table 3.1 Composted broiler litter analysis results.

Test	Dry Basis	Method
Nitrogen, N % [a]	2.42	RMMA [1]
Phosphorus, P % [a]	2.46	SW – 6010B [2]
Potassium, K % [a]	3.46	SW – 6010B [2]
Sulfur, S % [a]	0.996	SW – 6010B [2]
Magnesium, Mg % [a]	0.998	SW – 6010B [2]
Calcium, Ca % [a]	3.96	SW – 6010B [2]
Sodium, Na ppm [a]	9260	SW – 6010B [2]
Iron, Fe ppm [a]	3680	SW – 6010B [2]
Aluminum, Al ppm [a]	1680	SW – 6010B [2]
Manganese, Mn ppm [a]	701	SW – 6010B [2]
Copper, Cu ppm [a]	540	SW – 6010B [2]
Zinc, Zn ppm [a]	618	SW – 6010B [2]
Boron, B ppm [a]	65.2	SW – 6010B [2]
Moisture % [a]	20.7	RMMA [1]
Solid % [a]	79.3	RMMA [1]
Total Chromium, ppm [a]	7.09	SW – 6010B [2]
Total Nickel, ppm [a]	35.2	SW – 6010B [2]
Total Lead, ppm [a]	2.98	SW – 6010B [2]
Total Cadmium, ppm [a]	0.197	SW – 6010B [2]
pH [b]	7.6	EPA 150.2; MAP [1]
Total Organic Matter, % [b]	51.5	LOI – Total-N [3]
Total Carbon: Nitrogen (C:N) Ratio [b]	9:1	Volatile Solids [3]

[a] Analysis was completed by A & L Analytical Laboratories, Inc. (Memphis, TN).

[b] Analysis was completed by Woods End Laboratories, Inc. (Mount Vernon, ME).

[1] Peters, J., S. Combs, B. Hoskins, J. Jarman, J. Kovar, M. Watson, A. Wolf and N. Wolf. 2003. Recommended Methods of Manure Analysis. University of Wisconsin Extension. A3769. http://learningstore.uwex.edu/assets/pdfs/A3769.pdf

[2] United States Environmental Protection Agency. 2012. Wastes – Hazardous Waste – Test Methods. SW – 846 Online. http://www.epa.gov/osw/hazard/testmethods/sw846/online/index.htm

[3] Woods End Laboratories, Inc. 2011. Laboratory Test Interpretation. Journal of Woods End Laboratories, Inc. ver. 9.

Table 3.2 Influence of cover crops and composted broiler litter on total, marketable and cull yields of plots in the December 20, 2011 broccoli harvest.

Factor	Level	Number Total	Yield Total (lbs)	Number Market.	Yield Market. (lbs)	Number Cull	Yield Cull (lbs)
Cover Crop	CR[z]	10.81a[y]	4.80a	7.69a	4.25a	3.13	0.55
	CS	11.75a	5.15a	9.25a	4.67a	2.50	0.48
	SE	11.69a	4.60a	8.25a	3.99a	3.44	0.61
	SO	7.50b	2.88b	4.94b	2.36b	2.56	0.52
CBL (kg·ha^{-1})	0	7.50b	2.58b	5.00b	2.13b	2.50b	0.44b
	2800	10.69a	3.62b	5.94b	2.77b	4.75a	0.85a
	5600	11.88a	5.63a	9.38a	5.16a	2.50b	0.47b
	11200	11.69a	5.60a	9.81a	5.21a	1.88b	0.39b

[z] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

[y] Means represented by the same letter for each factor and column are not significantly different at $p \leq 0.05$.

Table 3.3 Influence of cover crops and composted broiler litter on total, marketable and cull yields of plots in the 2012 broccoli harvest.

Factor	Level	Number Total	Yield Total (lbs)	Number Market.	Yield Market. (lbs)	Number Cull	Yield Cull (lbs)
Cover Crop	CR[y]	9.56	1.86a	8.06	1.50a	1.50	0.10
	CS	9.00	1.93a	7.63	1.38a	1.38	0.12
	SE	9.44	1.89a	8.13	1.31a	1.31	0.11
	SO	7.69	1.33b	6.06	1.63b	1.63	0.13
CBL (kg·ha^{-1})	0	7.13	1.17c[z]	5.00	2.13c	2.13	0.14
	2,800	9.19	1.58bc	7.50	1.69cb	1.69	0.16
	5,600	9.50	1.86b	8.00	1.50b	1.50	0.11
	11,200	9.88	2.41a	9.38	0.50a	0.50	0.06

[z] Means represented by the same letter in each factor and column are not significantly different at $p \leq 0.05$.

[y] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

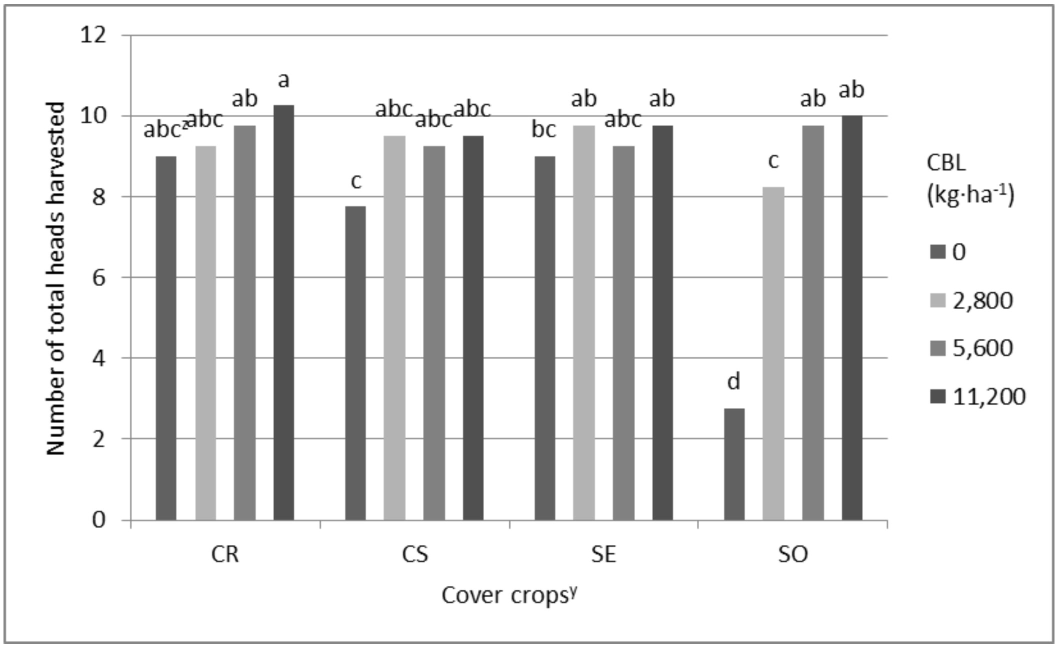

Figure 3.1 Influence of cover crops and composted broiler litter on total number of plants harvested in 2012 broccoli harvest season.

[z] Means represented by the same letter are not significantly different at $p \leq 0.05$.

[y] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

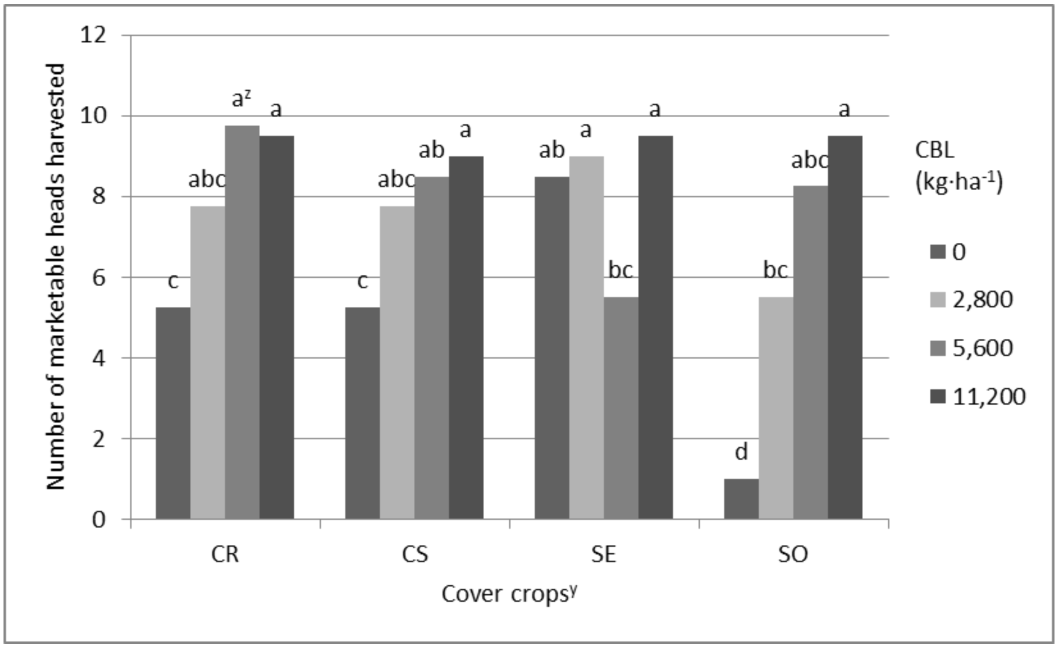

Figure 3.2 Influence of cover crops and composted broiler litter on number of marketable heads harvested in 2012 broccoli harvest season.

[z] Means represented by the same letter are not significantly different at $p \leq 0.05$.
[y] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

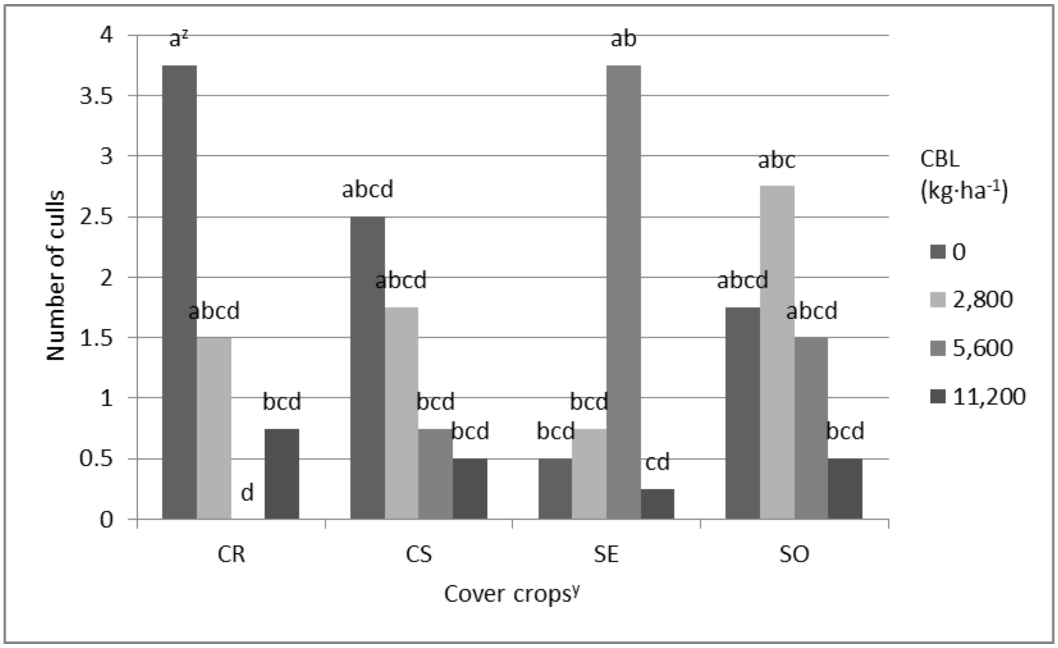

Figure 3.3 Influence of cover crops and composted broiler litter on number of culls in 2012 broccoli harvest season.

[z] Means represented by the same letter are not significantly different at $p \leq 0.05$.

[y] Sunn hemp (CR), sunn hemp + sesame (CS), sesame (SE) and sorghum sudan grass (SO).

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CHAPTER IV

SUMMARY AND CONCLUSIONS

Cover crops resulted in few significantly positive effects on soil and broccoli harvest throughout the experiment. Sorghum sudan grass had a negative effect, resulting in fewer heads harvested and smaller sizes. This could be caused from an immobilization of nitrogen from its large biomass or from an allelopathic effect with broccoli. Composted broiler litter had significant effects on the soil and fall vegetable harvest, increasing organic matter, extractable nutrients and fall vegetable harvest as the compost rate increased. The two highest rates lead to the most improvement, leading to the conclusion that the most efficient rate of composted broiler litter under our conditions was between 5,600 and 11,200 $kg \cdot ha^{-1}$.

This study should be continued to determine whether the cover crops can show more improvement to organically managed soils and fall vegetable production over extended use. Further research could also determine the optimal composted broiler litter rate and to see if there are any negative effects or nutrient build-up caused by the extended use of composted broiler litter.