ABSTRACT

LARSEN, ERIKA MARIE. Evaluating Soil Carbon Pools and Losses in Long-Term Organic and Conventional Farming Systems. (Under the direction of Julie Grossman).

Corn cropping systems in the Southeast lose an estimated 1.4 tons of topsoil per acre per year, with a total of 4.2 million tons of topsoil lost annually (NRCS, 2006). Agricultural soil as sediment and nutrient runoff is the leading pollutant to our surveyed rivers and lakes (USEPA, 2010) with an estimated one third of the soil and associated nutrients carried by runoff and discharged into streams and water bodies. Topsoil losses have severe implications for farmers, as well as surrounding ecosystems and watersheds. Organic matter additions often lead to increased aggregation of soil particles, shown to increase infiltration and decrease water and nutrient runoff, as well as increase soil retention by stabilizing the soil surface from erosion. Management systems that incorporate organic additions as a primary nutrient source, such as those used in organic production, have been shown to increase SOC in agricultural soils. However, heavy reliance on tillage to control weeds in many organic systems may in parallel promote soil degradation and lead to increased runoff. Two indicators of microbial activity include soil microbial biomass and the quantity of labile fraction organic matter undergoing decomposition. Increases in microbial activity can lead to increased aggregation in agricultural soils due to the microbial production of extracellular polysaccharides, which in turn prevent sediment losses. In this project we seek to determine how long-term organic and conventional management systems under different tillage regimes impact soil biological properties and carbon losses. In particular our three objectives included to: 1) quantify labile fractions of organic matter based on different tillage and fertility regimes, 2) determine correlations between soil organic carbon and sediment loss in agricultural fields under conventional and organic management systems and two tillage types, and 3) determine long-term management and tillage impacts on total organic matter lost via runoff. Based on evidence that organic farms increase soil organic carbon, especially where tillage is absent, we hypothesize that organic farming practices can lead to reduced soil losses due to stabilization of soil. Treatments included 1) organic management + no tillage, 2) organic management + conventional tillage 3) conventional management + no tillage 4) conventional management + conventional tillage, and 5) a control, replicated 4 times each. Soil samples from all plots were analyzed for particulate organic matter (POM) using density fractionation, total carbon, and microbial biomass using chloroform fumigation extraction. Soil bulk density was assessed using an Uhland coring device. Plots were instrumented with automated electronic samplers and runoff samples from each rain event collected and dried until water evaporated, then sediment analyzed for total carbon. We found that organic systems with reduced tillage enhanced labile, total and microbial fractions of organic matter. Our data showed that despite the increases in organic carbon pools, organic treatments had greatly decreased yields, attributed to the lack of available nitrogen and to weed competition. No tillage systems, especially those that were organically managed, lost less soil carbon via surface runoff as compared to plowed systems. We found that as total soil carbon increased in agricultural fields, suspended solids lost through surface runoff also decreased. In particular, organic systems with reduced tillage accumulated more soil carbon and may subsequently have lower total suspended solids (TSS) rates than plowed systems. Overall, this study found that increases in organic matter in no-tillage systems were associated with decreases in total sediment load into watersheds.

Evaluating Soil Carbon Pools and Losses in Long-Term Organic and Conventional Farming Systems

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DEDICATION

To my sisters, Minda and Kara Larsen: the ultimate mentors.

BIOGRAPHY

Erika was born and raised in Ponte Vedra Beach, FL. She attended Flagler College in 2005, but later transferred to the University of Florida in Gainesville, FL to pursue science. She received a B.S. in Horticultural Sciences and a minor in Soil and Water Sciences. It was at UF that Erika gained an interest in natural resource conservation. After working in multiple biology labs, Erika started graduate school at North Carolina State University in January 2011 under the direction of Julie Grossman. Upon completion of her Master's of Science, Erika will begin working as a research fellow for the Environmental Protection Agency's Office of Water in the Non-point source control branch where she will be researching strategies to improve water quality through agricultural pollution. She hopes to use her love for science to explore and promote management strategies that better the planet's natural resources.

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1.1.1 Soil Retention and Loss in Agricultural Systems

Soil loss through erosion is a serious issue and plays an important role in determining soil health. In corn cropping systems in the Southeast U.S., there is an estimated 1.4 tons of topsoil lost per year per acre, a total of 4,197,000 tons of soil lost annually (NRCS, 2006). The potential for a soil to erode is based on the slope and topography of the land, the soil texture and structure, the amount of organic matter in the soil, and rainfall intensity and duration (NRCS, 2006).

Agricultural soil and nutrient runoff is the leading pollutant of rivers and lakes (USEPA 2010), with an estimated one third of the soil and associated nutrients carried by runoff discharged into streams and water bodies (Kok et al., 2009). Nonpoint source pollution comes from diffuse sources and is caused by rainfall moving across the ground, carrying natural and human-made nutrients and pollution with it, and delivering these contaminants to our watersheds. Sedimentation of these water bodies occurs when soil particles are transported from fields and is the primary source of pollution from agriculture. In many aquatic systems, nitrogen or phosphorus is the limiting nutrient. Plant or algal growth in water ecosystems is accelerated when the limiting nutrient becomes sufficient. Excessive nitrogen enrichment in fresh and coastal waters proliferate algal blooms. As algae die, decomposition uses up much of the dissolved oxygen, resulting in oxygen-depleted waters. These stressed systems develop hypoxia, producing dissolved oxygen concentrations of less than 2 mg/L, and cause stress on aquatic organisms that often lead to fish kills (Diaz & Rosenberg, 2011).

The demand to find environmentally sound farming practices that reduce runoff and erosion, improve soil retention, and increase soil organic matter has been increasing throughout the decades. Specific management practices that lead to improved soil physical properties include no till or conservation tillage, manure and green manure (legume) additions, the usage of cover crops, and crop rotations. Growers who have practiced continuous conservation tillage or no-till farming have observed consistent improvements in soil properties, including improved drainage, infiltration and noticeably more earthworms, leading to improved porosity, organic matter and aeration, and significantly less runoff and erosion following heavy rains (Kok et al., 2009). However, we do not have a clear understanding as to how soil biological properties and processes in different fertility and tillage regimes impact organic matter fractions and ultimately the stabilization of soils on sloped lands. This literature review will discuss how benefits derived from organic production practices can possibly aid in reducing soil losses via erosion and runoff, and then describe challenges in attaining these goals. Specifically, it will define and describe the importance of soil organic matter (SOM) and biological processes in organic systems, and outline common management practices that can modify SOM, including tillage and cover cropping.

1.2 Organic Agriculture and Soil Health

1.2.1 Organic Agriculture

One way in which soil retention may be able to be improved in agricultural systems is through organic production practices. Organic farming has been practiced informally for centuries, however it wasn’t until the last few decades that the Organic Foods Production Act under the United States Department of Agriculture (USDA) established a set of uniform standards and regulations for the production of organic foods, requiring that growers strictly follow mandated management practices. The USDA National Organic Standards Board defines organic agriculture as an ecological production management system that promotes biodiversity, biological cycles and soil biological activity that is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony (Gold, 2009). According to the International Federation of Organic Agriculture Movements, organic agriculture bases its practices on the principle of health, the principle of ecology, the principle of fairness and the principle of care (IFOAM, 2009).

Organic agriculture has an abundance of benefits for soil and the surrounding environment, among them soil structure enhancement, soil conservation, and potentially climate change mitigation (IFOAM, 2009). The awareness of organic farming has promoted the growth of organic production and growth in sales of organic food. U.S. sales of organic food and beverages were around $1 billion in 1990, and grew to $24.8 billion in 2009 (Organic Trade Association, 2010). In 2008, there was approximately 4.8 million acres of organic farmland with organic cropland acreage increasing 15 percent between 2002 and 2008 (Organic Trade Association, 2010).

1.2.2 Organic Matter

One of the main soil quality benefits supported by the scientific literature is the finding that many organic agriculture practices help to build soil organic matter (SOM). Soil organic matter is defined as any material produced by living organisms, usually from plant tissue, that is returned to the soil and eventually decomposed, releasing plant-available nutrients to the soil (Bot and Benites, 2005). Nitrogen, phosphorus, sulfur, and other micronutrients such as iron, copper, and zinc are all released in the soil during the formation and decomposition of organic matter (Gaskell et al., 2006). Soil organic matter can reflect the soils functioning capability by serving as an organic nutrient reserve while providing organic material to stabilize the soil and protect the surface from erosion, promote microbial population and buffer against nutrient extremes (Franzlubbers and Haney, 2006).

1.2.3 Fractions of Organic Matter

Soil organic matter is composed of a continuum of material ranging from recently deposited litter (active or labile fraction) to highly decomposed stable unrecognizable plant residue, known as humus. Humus accounts for 70-80 percent of soil organic matter (Gaskell al., 2006), and is relatively the most stable of the SOM fractions. It is considered to be the end product of soil decomposition with very few or very slow changes occurring after humus is formed.

The SOM fraction undergoing active decomposition is often referred to as Particulate Organic Matter (POM), and can be a reliable measurement of labile organic matter and nutrient availability resulting from decomposition of recently-added organic materials (Marriott and Wander, 2006a; Wander, 2004; Wander et al., 2007). Microbial activity in the POM fraction is often greater than other total organic matter pool fractions, because POM serves as a primary energy resource in soils (Wander, 2004; Wander et al., 2007).

The POM fraction is defined methodologically through various means, using characteristics such as low density (1.4-2.2 g/cm^3; density fractionation approach) and/or coarse-size fractions greater than 53 µm (size fractionation approach). Density fractionation procedures can be used to separate light fractions (LF) of organic carbon from the rest of the mineral soil known as the heavy fractions (HF) (Wander and Traina, 1996). Light fraction carbon is heavily influenced by plant litter additions and is considered young recently decomposed carbon, or carbon in the early stages of decomposition (Gregorich, 1996). The coarse or heavier fraction of organic matter is slightly more stable and characterized by continuum of organic materials that have undergone varying degrees of decomposition (Marriott and Wander, 2006b, Gregorich, 1996).

Soil organic carbon (SOC) is the largest single component of SOM (Dungait et al., 2012) and soil organic carbon and its dynamics resulting from land use and management changes can partially be explained by the way carbon (C) is allocated in different fractions of SOM (Tan et al., 2007). Soil organic matter fractions can be isolated and quantified to provide information about how management practices affect soil fertility status (Boone, 1994). Identifying fractions that are sensitive to short term changes in soil organic matter is critical for evaluating the fertility of organic and sustainable farming systems because this LF organic matter is reported to be a major nitrogen (N) source in a variety of agricultural soils and is a major food source for microorganisms (Boone, 1994). Particulate organic matter is often measured over total SOM because of its sensitivity to soil management, allowing correlation between management and organic matter that total SOM quantification could not identify (Wander, 2004). Management practices that increase soil organic matter and resulting nutrients available to crop plants is critical for the success of organic agriculture, as SOM is known to influence numerous soil physical, biological and chemical properties. Because organic farming systems rely on non-synthetic fertilizers for their nutrient needs, organic farms often incorporate leguminous cover crops and/or animal wastes as a primary nutrient source, which has been linked to increased organic matter in agricultural soils (Bot and Benites, 2005).

1.2.4 Organic Matter Fractions specific to Organic Systems

Aggregate formation plays an important role in soil physical, chemical and biological processes. Many published studies have become available in recent years comparing the quantity of organic matter present in organic and conventional farming systems. Some studies have shown that while long-term organic farming systems generally accumulate soil organic matter over time, conventionally managed soils may fail to accumulate any detectable SOM due to the lack of organic matter additions (Wander and Traina, 1996). One analysis assessing total SOM in organic farming systems (manure-based and manure/legume-based) compared to conventional farming systems across the USA showed that organic systems had greater concentrations of POM-C and POM-N than the conventional systems (Marriott and Wander, 2006a). Another study found organically managed soils to have significantly greater total and labile soil organic matter likely due to the inputs of manure and plant residues (Leite et al., 2010). Additionally, organically managed soils can have significantly higher quantities of carbon in certain fractions of organic matter, including humin, humic substances and heavy fractions of organic matter (Marriott and Wander, 2006b; Wander and Traina, 1996).

1.2.5 Organic Matter and Aggregation

Studies have shown that organic matter content is the primary determinant of aggregate stability, and that the addition of organic matter to agricultural soils may be more important than the farming system itself (Shepherd et al., 2002b; Williams and Petticrew, 2009). Aggregates are clusters of soil particles held together by physical and chemical bonds. These aggregates determine the pathways through which water enters the soil and therefore affect infiltration and runoff. Soil particles can be classified as micro- and macroaggregates. Macroaggregates constitute the bulk soil structure, and can be mobilized by some processes (like mass movement), while microaggregates are usually of a size that can be mobilized by hydraulic processes and which constitute part of the sediment load lost through runoff (Williams and Petticrew, 2009).

Aggregation is often more related to the free or active organic matter over the total organic matter in the soil (Tisdall and Oades, 1982). Free organic matter acts as a substrate for microbial production of polysaccharides and also constitutes fungal hyphae and roots, both of which work to stabilize organic matter into aggregates (Shepherd et al., 2002b; Tisdall and Oades, 1982). Because microbial communities play an important role in the aggregation of soils, measuring microbial biomass can be used as an indicator for potential aggregation in agricultural soils.

1.2.6 Role of Microbial Activity in Organic Systems

Increased microbial activity is another benefit often resulting from organic management, as microbes help to release nutrients bound in organic nutrient pools for crop uptake. A portion of soil organic matter is living and is composed of a variety of microorganisms, including bacteria, fungi, protozoa, nematodes and algae, and accounts for about 5% of the total organic matter in the soil (Bot and Benites, 2005). These microbial communities provide a nutrient source and sink, as well as control the stabilization of soil organic matter (Liu et al., 2007). Organic matter decomposition rate is dependant in part on quantity and activity of existing soil microorganisms. Soil organic matter contains approximately 5% N bound in complex organic forms. Microbial activity serves as the primary driver for soil N cycling as N is released through oxidative decomposition processes. A portion of this organic matter N is either present in the microbes themselves, or can be readily used by microorganisms. Soil microorganisms break down organic monomers and release N as ammonium, a plant available form of N, giving soil microorganisms an extremely important role in farming systems, which by definition rely on organic additions for nutrient sources.

Many studies have shown that organically managed systems positively impact microbial communities in terms of population size and resulting nutrient mineralization. A study in North Carolina comparing certified organic, non-certified organic, and conventional farms found that the soils from organic farms had significantly higher microbial biomass, resulting in net N mineralization for three consecutive years (Liu et al., 2007). Drinkwater et al. compared soils from 20 organic and conventional strawberry farms in California and found organically managed soils to be characterized by higher levels of microbial activity based on FDA hydrolysis rate (1995). A study in Switzerland found that conventional management reduced microbial biomass by 30 percent when compared to organic management (Birkhofer et al., 2008). Populations of organisms respond quickly to changes in management, with sharp increases in microbial biomass observed to occur shortly after additions of composts and organic carbon often found in organic systems (Leite et al., 2010).

1.2.7 Measurement of Microbial Activity

There is a wide range of approaches used to assess soil microbial communities. Microbial biomass is the fraction of the soil organic matter actively involved in the transformation of soil organic residues (Merino et al., 2004) and is defined as the total mass of living microorganisms in a given volume or mass of soil (Franzlubbers and Haney, 2006). Its measurement has been used to estimate the biological status of the soil (Kennedy and Papendick, 1995; Visser and Parkinson, 1992), as microbial population size fluctuates with changes in available nutrients and food sources. Microbial biomass, important for its regulation of soil processes such as C and N cycling, has been used as an indicator of improved soil quality (Moeskops et al., 2010). It is both a source and sink of nutrients, and contributes to soil structure, stabilization, and transformations of C, N, phosphorus and sulfur (Leite et al., 2010), and can indicate changes in soil C pools among contrasting treatments (Powlson et al., 1987; Valpassos et al., 2001). Microbial biomass C and N are accurately measured by a procedure known as fumigation extraction (Jenkinson et al., 2004; Vance et al., 1987; Visser and Parkinson, 1992) in which soils are fumigated with chloroform to kill microbial cells. Soils are then extracted with K_2SO_4 and the filtrate is analyzed for total C and N, and compared with an unfumigated set of soil samples. Although there are many different approaches to assess soil microbial biomass, the chloroform fumigation and extraction procedure provides reliable measurements and a relatively quick and simple method to measure changes in microbial communities among varying management systems.

1.3 Runoff from Organic Farms

1.3.1 Importance of quantifying runoff from organic systems

As fore mentioned, organic farming practices are known to build soil organic matter, enhance microbial activity and potentially reduce the risk of sediment and nutrient runoff losses into surrounding lakes and rivers. Organic matter increases often found in organic farms can increase water infiltration and water holding capacity, resulting in decreased runoff on agricultural lands (Shepherd et al., 2002a). However, heavy reliance on tillage to control weeds may in parallel promote soil degradation and lead to increased runoff and erosion.

The few studies that exist comparing organic systems to conventional systems show that in general, organic systems may reduce runoff and nutrient losses, however, there is limited data comparing water quality and nutrient losses in organic and conventional systems with different tillage regimes. One study comparing nitrate concentration in runoff water from organic and synthetic fertilized treatments of sweet corn found that more nitrates were lost from the synthetically fertilized treatment (38 ppm) than the organically amended treatment (23 ppm), and that soil potassium retention was greater in the organically amended treatment (Dufault et al., 2008). According to Wells et al. (2000), conventionally managed soils are more likely to produce large runoff flows with sediment loads due to their lower aggregate stability and nutrient holding capacity than organic managed soils.

1.3.2 Aggregate Stability implications on Erosion

Aggregation is linked to increased microbial activity and organic matter in soils, and therefore may be expected to increase when organic management practices are applied. Aggregate stability is a common measurement to estimate predicted soil loss through erosion (Reicosky et al., 1995; Tisdall and Oades, 1982). Aggregate stability is often a good indicator of soil quality because percentage of water stable aggregates present in a field is often positively correlated with soil organic matter content (Rhoton et al., 2002). Because organic matter addition is a key practice in organic farms, organically managed farms generally have greater aggregate stability than farms with synthetic fertilizer additions (Shepherd et al., 2002). Research has shown that soils receiving synthetic fertilizer consistently exhibit less aggregate stability than organic amended soils (Williams and Petticrew, 2009; Shepherd et al., 2002). Similarly, a long term study in Switzerland comparing erosion in organic and conventional farms found that the organic soils typically had higher percolation rates, or percentage of water entering the soil profile, and a less percentage of non-stable soil, resulting in greater aggregate stability (Siegrist et al., 1998).

1.3.3 Carbon loss through runoff

In addition to nutrient losses, runoff also reduces beneficial organic matter, as the organo-mineral soil fraction is lost as part of this runoff. In general, organic practices tend to sequester more C in surface soils due to the increase in organic inputs. However, the fate of displaced soil organic carbon (SOC) by erosion in organic systems is not well understood. Organic systems often undergo a greater number of tillage and cultivation operations in a season, losing soil structure and SOM through oxidative decomposing processes. Soil carbon thus increases vulnerability to runoff and loss via surface erosion. In contrast, increases of SOM resulting from organic practices may serve to stabilize against losses, despite increases in cultivation. Additionally, in both organic and conventional systems, conservation tillage systems may actually encourage losses of the high amounts of carbon remaining on the soil surface via surface runoff (Bernoux et al., 2006). Particulate organic carbon can account for up to 10% of the total suspended solids carried to aquatic systems (Lal, 2005). One study estimated global annual total organic C loss to rivers to be 3.35×10^8 tons (Deggens et al., 2001), and another estimated riverine TOC discharge to be 4.34×10^{14} g annually (Schlünz and Schneider, 2000). These losses in carbon can leave agricultural fields depleted and can reduce carbon pools in the soil, decreasing soil health.

1.4 Tillage

1.4.1 Tillage in organic systems

Tillage is defined as the preparation of the soil by mechanical agitation for seedbed preparation, sowing, transplanting or weed control. However, important soil biological properties such as microbial activity and organic matter formation can be negatively impacted by soil mechanical operations. As residues are incorporated into soil, aggregates embedded with old and protected organic matter are broken apart, exposing microorganisms to increased oxygen and facilitating the rapid decomposition of SOM (Bot and Benites, 2005).

Tillage can also increase soil losses through disruption of protective surface residue, increasing susceptibility to water and wind erosion (Gruver and Wander, 2010). This sensitivity to water erosion leads to problems with runoff from agricultural fields to watersheds, causing water quality problems discussed previously, including nutrient loading, eutrophication, eventual fish kill, and habitat degradation. Maintenance of surface residue is the most recommended practice for reducing soil erosion (US Environmental Protection Agency, 2010), however agricultural practices have historically been largely dominated by plow-based tillage that leaves little or no surface cover. Such tillage practices have been acknowledged as the primary cause of erosion, due to the burial of residue that would otherwise be effective in slowing runoff and soil loss (Kok et al., 2009).

Many farmers, both organic and conventional, are eager to introduce conservation tillage practices into their farming regime to allow for increased soil retention and organic matter. Reduced, or conservation tillage is defined as a method of cultivation that leaves the previous crop's residue on the fields, covering at least 30% of the soil surface. Conservation tillage operations include no till, strip till, ridge till and mulch till. No till is an agricultural management system that leaves almost all plant residues from the previous crop on the soil surface, while conservation tillage systems, by definition, leave more than 30% surface residue.

No tillage or conservation tillage systems may decrease soil compaction, surface sealing, and aggregate stability, all which reduce soil erosion potential (Kasper et al., 2009). When used for many consecutive years, conventional tillage can significantly reduce SOC contents compared to farming systems that did not use tillage, where long-term conservation tillage systems have significantly larger SOC pools than tilled systems (Yang and Kay, 2001).

The extent of negative soil quality effects due to tillage may depend in part on stage of crop growth. A Brazilian study investigating the effect of tillage method on soil erosion found conventional tillage treatments produced greater soil loss during initial growth periods than no-till systems due to the absence of residue cover (Engel et al., 2009). The data also concluded that the most dominant factor for reducing soil loss associated with surface runoff was soil cover by previous crop residue, concluding that no-till systems are an important conservation method for soil erosion (Engel et al., 2009).

Organic farmers in particular have two often-competing goals in the management of their agricultural system: promote and increase soil organic matter, and control weeds. Despite the soil quality benefits resulting from organic agriculture practices, the challenge of weed control leads most organic producers to rely on tillage for weed control and field maintenance. Tillage for the purpose of weed control is commonly referred to as cultivation, and is a common practice in organic systems due to the required avoidance of synthetic herbicides. Weed control is a serious and somewhat daunting task in organic farming because of restricted use of synthetic, chemical herbicides that would otherwise be used to control weeds. Many scientists have called perennial weeds among the most serious impediments to the adoption, expansion, and sustainability of organic farming (Knebusch, 2009), and most organic farmers thus rely on cultivation to give their crops a competitive advantage. Although tillage is important for crop protection, constraints on SOM accrual and disruptions in soil structure can lead to serious long-term problems (Bond and Grundy, 2001).

1.5 Conclusions

There is a strong body of literature providing evidence that organic cropping systems can positively affect soil processes that lead to a larger and more stable soil C pool. Organic matter content is often higher in organic cropping systems, and microbes proliferate in these carbon rich soils. However, the greater prevalence of tillage in organic systems can negatively affect organic matter content by breaking up stable aggregates that otherwise protect organic matter, and by introducing a highly aerobic soil environment. In combination, these outcomes increase soil organic matter decomposition (Bot and Benites, 2005). Because tillage also alters the soil structure and buries residue into the soil profile, erosion and runoff can be much higher in conventionally tilled fields than conservation tillage operations that leave plant residues on the soil surface (Six et al., 2002). Hence, management systems and tillage regimes are critical in promoting soil retention and decreasing soil and nutrient losses.

Increased labile fractions of organic matter and subsequent increases in microbial community size can potentially lead to increased aggregation in agricultural soils due to the microbial production of extracellular polysaccharides (Six et al., 2002). The POM fraction of organic matter can be a good indicator of microbial activity because this fraction is the dominant food source for microbes. Additionally, quantifying microbial biomass is a viable method for determining microbial community abundance and activity (Jenkinson et al., 2004; Wu et al., 1996). Both POM and microbial biomass can provide us with information regarding aggregation and soil retention.

Limited information exists in the literature that compares runoff and sediment losses between organic and conventional cropping systems, while at the same time incorporating different tillage regimes. Since each system type utilizes different management practices that alter soil processes, there are likely differences in soil retention that will affect erosion rates.

Both conventional and organic systems are now utilizing conventional and conservation tillage practices, therefore information is critically needed to determine which biological properties correlate with sediment losses and runoff. Such information will serve to determine the most sustainable approach for reducing runoff in agricultural soils. This study will evaluate soil biological parameters, including organic matter content and microbial biomass in organic and conventionally managed fields, to allow us to relate changes in soil properties to total runoff, and C in runoff. Our objectives are to 1) determine how the suite of management practices common in organic and conventional agricultural systems impacts long-term soil biological properties, 2) determine how long-term management and tillage operation impact the total organic matter lost from runoff, and 3) identify soil properties that correlate with runoff under conventional and organic management.

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CHAPTER 2 : EVALUATING SOIL CARBON POOLS IN LONG-TERM ORGANIC AND CONVENTIONAL FARMING SYSTEMS ACROSS DIFFERENT TILLAGE REGIMES

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1. Introduction

Corn cropping systems in the Southeast lose an estimated 1.4 tons of topsoil per acre per year, with a total of 4.2 million tons of topsoil lost annually (NRCS, 2006). Agricultural soil and nutrient runoff are the leading pollutants to our surveyed rivers and lakes (USEPA, 2010), with an estimated one third of the soil and associated nutrients carried by runoff and discharged into streams and water bodies (Kok et al., 2009). This loss of surface soil has severe implications for farmers, as well as surrounding ecosystems and watersheds.

Soil organic matter (SOM) additions stabilize soil and protect the soil surface from erosion (Apezteguía et al., 2006). Soil organic carbon (SOC) is the largest single component of SOM (Dungait et al., 2012) and carries out critical soil functions such as filtration of pollutants and pesticides, reduction of river sediment loading by increasing infiltration and water holding capacity, and ultimately decreasing hypoxia in coastal ecosystems (Bollag et al., 1992; Lal, 2004). Additionally, increased organic matter often leads to greater soil aggregation, which has been shown to increase infiltration and decrease water and nutrient runoff (Shepherd et al., 2002; Williams and Petticrew, 2009).

Tillage can greatly increase SOM loss as residues are incorporated into soil, breaking up aggregates embedded with old and protected organic matter and exposing microorganisms to increased oxygen, both which facilitate rapid decomposition of SOM (Bot and Benites, 2005; Tisdall and Oades, 1982). Tillage operations have been shown to emit as much as 15 kg C ha^{-1} to the atmosphere due to the degradation of SOM and subsequent release of carbon dioxide (Lal, 2004). Tillage is acknowledged as a primary cause of erosion due it its disruption of the soil surface and removal of protective residue that would otherwise be effective in slowing runoff and soil loss (Kok et al., 2009). However, conservation tillage is defined as a method of cultivation that leaves the previous crop's residue on the fields, covering at least 30% of the soil surface, and has been shown to reduce soil erosion potential (Kasper et al., 2009).

Management systems that incorporate organic additions as a primary nutrient source have been shown to increase SOM in agricultural soils (Lal, 2004; Wander and Traina, 1996), with organic farming practices in particular linked to increases in SOM (Wander and Traina, 1996). However, heavy reliance on tillage to control weeds in many organic systems may in parallel promote soil degradation and lead to increased runoff (Bot and Benites, 2005).

Two indicators of microbial activity include microbial biomass and the quantity of labile fraction organic matter undergoing decomposition present in a system. Microbial biomass is the fraction of the soil organic matter actively involved in the transformation of soil organic residues (Merino et al., 2004) and is defined as the total mass of living microorganisms in a given volume or mass of soil (Franzlubbers and Haney, 2006). The SOM fraction undergoing active decomposition is often referred to as Particulate Organic Matter (POM). Particulate organic matter can be a reliable measurement of labile organic matter and serves as a primary energy resource in soils (Marriott and Wander, 2006; Wander, 2004; Wander et al., 2007). Density fractionation procedures can be used to separate light SOM fractions (LPOM), consisting of recently deposited organic matter, from more decomposed heavy fraction POM (HPOM) (Wander and Traina, 1996). The LPOM is heavily influenced by plant litter additions and is considered young recently decomposed carbon or carbon in the early stages of decomposition (Gregorich, 1996). The coarse or heavier fraction of organic matter is slightly more stable and characterized by continuum of organic materials that have undergone varying degrees of decomposition (Marriott and Wander, 2006, Gregorich, 1996).

In this experiment we seek to determine how long-term organic and conventional management systems under different tillage regimes impact soil biological properties. In particular our three objectives include: 1) determine cover crop biomass and nitrogen contributions to soils of these various systems, 2) quantify labile fractions of organic matter based on different tillage and fertility regimes, and 3) determine microbial activity in these soils. We hypothesize that labile, as well as stable soil carbon pools will be highest in treatments characterized by increased organic inputs and reduced tillage.

2. Materials and methods

2.1 Study Site

The field site is located at the Mountain Horticultural Crops Research Station in Mills River, NC. The land is gently sloped at 2-7% and is situated on a stream terrace of the French Broad River. The soil type of the field is a Delanco fine-sandy loam (fine-loamy, mixed, mesic, Aquic Hapludult) (Overstreet et al., 2010). The site includes 20 plots, each 9.14m x 18.29m and five treatments replicated 4 times. Plots are arranged in a completely randomized design with treatments including 1) organic management + no-tillage (org no), 2) organic management + conventional tillage (org plow), 3) conventional management + no-tillage (chem no), 4) conventional management + conventional tillage (chem plow), and 5) control (plowed, disked and no inputs of fertilizers or pesticides [control plow]). Plots have been under these treatments since 1994 and the organic plots are certified organic by International Certification Services, Inc. (Medina, ND).

2.2 Field Preparation

The long-term sequence of vegetables grown in the field plots is described by (Wang et al., 2011). Table 1 outlines all field operations for the 2011 and 2012 growing seasons. Cover crops were planted on October 18, 2010 (2011 field season) and October 10, 2011

(2012 field season). In 2010, “Sunrise” crimson clover and “Arthur” wheat was planted in all treatment plots except the control. In 2011, crimson clover and wheat was again planted in all plots, but Banvel II herbicide [sodium salt of dicamba (3,6-dichloro-o-anisic acid)] was applied in February 2012 at 0.29 liters ha^{-1} (0.25 pt $acre^{-1}$) to kill clover in conventional plots to better represent conventional production practices. Crimson clover was planted at 33.6 kg ha^{-1} (30 lbs $acre^{-1}$) and wheat applied at 80.6 kg ha^{-1} (72 lb $acre^{-1}$). Cover crops were not planted in control plots. In treatment plots, cover crops were terminated at flowering in the spring and sweet corn planted in all plots in May or June and harvested approximately 90 days after planting. “Luscious” certified organic seed was applied to the organic and control plots and “Luscious” with insecticide seed was planted in the chemical plots. Sweet corn was planted at a rate of 65,235 seeds ha^{-1} (26,400 seeds $acre^{-1}$). Fertilizer nitrogen was applied to all organic and chemical treatment plots at a rate of 201.6 kg N ha^{-1} (180 lbs $acre^{-1}$). Perdue AgriRecycle microSTART60 (3-2-3) pelleted poultry litter was surface broadcast applied combining with calculated cover crop nitrogen rate to obtain 201.75 kg N ha^{-1} (180 lbs N/acre) in the organic plots. Synthetic fertilizer nitrogen as ammonium nitrate (33-0-0) was surface broadcast applied to the chemical plots at a rate of 112 kg N ha^{-1} (100 lbs N $acre^{-1}$) prior to sweet corn planting and then side-dressed 30 days after planting by surface banding at a rate 89.6 kg N ha^{-1} (80 lb N $acre^{-1}$). Bicep II Magnum 5.5F herbicide a.i. S-Metolachlor /atz/benoxacor (Syngenta, Greensboro, NC) was applied directly after sweet corn planting at a rate of 4.68 liters ha^{-1} in the chemical plots. Warrior insecticide a.i. Lambda-cyhalothrin

(Syngenta, Greensboro, NC) was applied to the chemical treatments, and Entrust certified organic insecticide a.i. spinosad (Dow AgroSciences-Indianapolis, IN) to the organic treatments weekly in July until August 1st in both 2011 and 2012. The organic treatments relied on mechanical weed control including rototilling of plowed plots and mowing of no-till plots. The plot borders, between-row regions, and plot interiors were mowed/tilled as needed (weekly or biweekly) during the sweet corn growing season until late July to minimize weed competition.

At the down slope end of each plot a collection trough was installed to funnel surface runoff to a central outlet point. Wooden boards were installed around the outside perimeter of the field plots by partially burying them in the soil to prevent lateral flow of surface water and to ensure rainfall water was collected at the central outlet. A monitoring station was established at the outlet point of each plot. The monitoring station included an Isco automated sampler and weir, designed by the Department of Biological and Agricultural Engineering fabrication shop at NCSU, with integrated flow meter and a flume to measure flow volume and collect water/sediment samples flowing through a flume (Virtual Polymer Compounds, Medina, NY).

2.3 Soil Sampling

Soil samples were collected from all plots and taken in October 2010, April 2011, July 2011, May 2012, and July 2012 for microbial biomass and December 2009, April 2011 and May 2012 for particulate and total organic matter. Ten subsamples were taken to a 15 cm (6 inches) depth from each plot in a “z” pattern with a 2.54 cm (one-inch) diameter soil probe, homogenized, oven dried for 48 hours at 45°C, ground to 2mm and stored at room temperature for organic matter measurements, and stored at 4°C and sieved to 2mm for microbial biomass measurements.

2.4 Microbial Biomass

The chloroform fumigation method was used to measure microbial biomass and obtain soil microorganism C and N as an indicator of biological activity among treatments (Iyyemperumal et al., 2007; Vance et al., 1987). This approach compares total microbial N and C of two sets of soils, with one set killed via fumigation compared to a set of unfumigated samples. Moist soils sieved to 2mm were sealed in zip lock bags and refrigerated at 4°C until extraction and all soils fumigated and extracted within 10 days of sampling. Microbial biomass C and N (MBC/ MBN) were calculated using the following equations:

MBC= (C in fumigated soil- C in non-fumigated soil)/ k_{ec}

MBN= (total N in fumigated soil- total N in non-fumigated soil)/k_{en}

Where k_{ec} = 0.33, the factor used here to convert the extracted carbon to MBC and k_{en} is 0.45, the factor used to convert the extracted organic N to MBN (Jenkinson et al., 2004).

2.5 Organic Matter

Soil samples were oven dried for 48 hours at 45°C and ground to 2mm. Total organic matter was assessed by evaluating total C, as soils without mineral carbonates and total C can be equated with total soil organic carbon. Total soil C was analyzed by whole soil combustion using a Perkin- Elmer PE 2400 CHN Elemental Analyzer (Norwalk, CT, USA) in the Environmental and Analytical Testing Service (EATS) facility in the Soil Science department at NCSU.

2.6 Particulate Organic Matter

Particulate organic matter (POM, both LPOM and HPOM) was separated from the whole soil using a density fractionation protocol following methodology from the Soil Ecology Lab at University of Illinois from Marriott and Wander (2006). We used a modified version of this method described by Golchin et al. (1994) to separate the labile light fraction particulate organic matter (POM) from the heavy fraction of POM. Soil samples were oven dried for 48 hours at 45°C and ground to 2mm. The labile POM fraction was first separated by placing 20 g of soil in a 250 ml tube and adding 50 ml sodium polytungstate (1.6 g cm^{-3}). The contents of the tube was orbitally shaken at low speed (200 oscillations min^{-1}) for 30 min. Particles adhering to the tube sides were rinsed free with 10 ml of sodium polytungstate and the solution allowed to stand overnight. Tubes were centrifuged and materials recovered from the supernatant on 2μm polycarbonate filters, rinsed with 25mL $CaCl_2$ and 50 ml of deionized water, and dried at 45 °C for 48 hours.

To obtain the relatively humified, mineral associated fraction (HF), the remaining soil in the tube was washed with 40mL $CaCl_2$ and shaken at high speed on an orbital shaker for 30 minutes. The tube sides were then rinsed with 10mL $CaCl_2$ and centrifuged at 7000rpm for 45 minutes. Any floating material was discarded. The pellet was then washed with 40mL DI water and shaken at high speed on an orbital shaker for one hour. Tube sides were then rinsed with 10mL DI water, centrifuged, and the supernatant was discarded, leaving only the heavy fraction (HF) POM. The pellet was oven dried at 50°C for at least 48 hours. The light fractions were ground with a ball-mill and the heavy POM was ground by hand with a mortar and pestle until no visible granules were observed. The resulting POM fractions and bulk soils were analyzed for POM-C determined on a Perkin-Elmer 2400 CHNS/O elemental analyzer (Norwalk, CT, USA) in the Environmental and Analytical Testing Service facility in the Soil Science department at NCSU.

2.7 Cover Crop Biomass

Cover crop biomass was taken at flowering in late April 2011 and early May 2012. Samples were taken using a 0.5 m^2 frame, with all biomass within the quadrant clipped to ground level. When weeds occupied >25% of total harvested biomass, they were weighed separately from cover crop biomass. Biomass was dried for at least 96 hours at 65° C, weighed and ground. The sample was homogenized and a subsample was collected and analyzed for total N and C at the NCSU Environmental and Analytical Testing Lab using a Perkin Elmer 2400 CHNS/O Elemental Analyzer (Norwalk, CT, USA). Percent N in the plant sample was then converted to crop biomass N per hectare and used to calculate potential plant nutrient N supplied in the organic treatments.

2.8 Weed Biomass

In 2012, weed biomass data was collected during sweet corn growth due to our observation of high weed competition in the field in 2011. The weed samples were taken during highest weed competition in early August before sweet corn harvest using a 0.5 m^2 frame, with all weed biomass within the quadrant clipped to ground level. Biomass was dried for at least 96 hours at 65° C, weighed and ground. The sample was homogenized and a subsample was collected and analyzed for total N and C at the NCSU Environmental and

Analytical Testing Lab using a Perkin Elmer 2400 CHNS/O Elemental Analyzer (Norwalk, CT, USA). Weed biomass C was then converted to g carbon per kg soil to determine the significance of weed biomass contribution to total soil carbon.

2.9 Sweet corn yield

Sweet corn was hand harvested in August of each year, approximately 85 days after planting. Yield measurements were taken from 10-meter lengths of the two center rows of each plot. All sweet corn ears harvested were counted and weighed after separating into marketable and cull grades (total ears included marketable and cull ears).

2.10 Data Analysis

Data were analyzed using SAS software (SAS Institute, Cary, NC). Total C, POM, cover crop biomass, weed biomass, and sweet corn yield were analyzed using the GLM procedure and microbial biomass carbon and nitrogen were analyzed using the MIXED procedure. A combined analysis was performed on all C and yield data in both years to determine year interactions, as well as treatment by year interactions. Mean separations were performed using the LSD on least squared means. Regression analysis was also preformed to examine the relationship between total carbon (TC) as measured by POM, the relationship between TC as measured by MBC and the relationship between POM as measured by MBC. Correlations were determined using CORR and REG procedure.

3. Results

3.1 Microbial biomass

No treatment by year interaction was observed for MBC for Spring 2011 and 2012, or Summer 2011 and 2012 sampling times; however a year interaction for spring sampling dates in 2011 and 2012 was identified (Table 2-5). Across all dates except for July 2012, MBC was significantly higher in the org no plots than all other treatments and was approximately 2 times greater than org plow treatment, and 3-4 times greater than the chem plow treatment (Figure 2-1). Microbial biomass C in the chem plow treatment was lower than any other treatment across all sampling dates. The org plow and chem no treatments did not have significantly different MBC values.

For MBN, no treatment by year interaction, or year interaction for spring 2011 and 2012 sampling dates were seen (Table 2-5). Data could be compared for the MBN data due to lab experimental error for July 2012 sampling period, therefore no 2011 and 2012 interactions were calculated. MBN followed similar trends as the MBC data with the org no treatment containing significantly greater MBN than all other treatments (Figure 2-2). Microbial biomass N in the org no treatment was 2-4 times greater than the plowed treatments. We did not find an increase in MBC/N in any one sampling date for all treatments, however MBC was highest in October 2010 and July 2011 in org treatments and highest in October 2010 and July 2012 in chem treatments.

3.2 Soil carbon

Soil samples taken in 2009 (year 15 of the long term study), 2011 and 2012 indicated that org no plots contained significantly greater organic matter in the form of total carbon than the org plow, chem plow and control plow treatments, with the chem plow plots containing the least amount of total C (Figure 2-3). Org no plots did not differ significantly from the chem no plots in terms of total C. No significant year by treatment, or year interaction for total C were measured in baseline (2009), 2011 and 2012 (Table 2-5), therefore mean total C values from 2011 and 2012 were averaged and shown in Table 2-5.

There was no treatment by year or year interaction for light fraction LPOM or heavy fraction HPOM soils in 2009, 2011, and 2012 (Table 2-5), therefore mean values are shown in Figure 2-5 and Figure 2-6. Similar to total C, soil analyses indicated that the org no treatment contained the greatest amount of LPOM, and LPOM was lowest in the chem plow treatment; org plow, chem no, chem plow and control plow treatments, however were not significantly different (Figure 2-5). Heavy fraction POM was greatest in the org no treatment and org plow and chem no treatments had significantly greater HPOM than the chem plow and control plow treatments (Figure 2-6).

3.3 Regression analysis of biological properties

Total C was positively correlated with MBC with a r^2 of 0.66 (Figure 2-7). Additionally, LPOM was positively correlated with TC with a r^2 value of 0.34 (Figure 2-8) and positively correlated with MBC with a r^2 value of 0.53 (Figure 2-9). Although these r^2 values are relatively low, all correlations are significant. When LPOM and TC values were low, microbial biomass decreased, and as LPOM increased in soils, TC increased.

3.4 Cover crop biomass

There was a treatment by year and year interaction in cover crop biomass due to the extreme differences in weather conditions (Table 2-5). Cover crop mixtures had poor stands in 2011 due to dry conditions. This same year, total cover crop N was significantly higher in the chem no treatment as compared to the org no treatment (Table 2-2), however total cover crop biomass was not significantly different among plots (Table 2-2). Although org no cover crops had the lowest N, there was large variation among plot data, where cover crops in the org no and the org plow plots ranged from 11.8 to 40.3 kg ha^{-1} and 31.6 to 77.3 kg ha^{-1}

respectively. Nitrogen concentrations in all of the cover crops ranged between 1.15% and 2.74% with mean C:N ratio for 2011 at 21.3:1 (Table 2-2).

In 2012, total cover crop biomass was greater due to a mild winter and heavy spring rainfall. There were no significant differences in cover crop N and cover crop biomass among treatments (Table 2-2), however 2012 cover crop N increased from 2011 in all treatments (Table 2-2). Again, large variation in cover crop N was observed in the organic plots, ranging from 79.8 to 170.5 kg N ha^{-1} in org no treatments and 98.6 to 163.9 kg N ha^{-1} in the org plow treatments. Nitrogen concentrations in both the legume and grass/legume mix did not exceed 1.94%. The mean C:N ratio for 2012 was 33.6:1 (Table 2-2).

3.5 Weed biomass

In 2012, org no, control plow and org plow had the highest weed biomass supplying the most C to the soil as compared to the chem treatments (Table 2-3). Org no treatment had approximately 35 times more weed biomass carbon than the chem plow treatment. The chem treatments contained significantly less weed biomass carbon than the org no treatment. Percentage of weed biomass as broadleaf weeds and grass weeds are shown in Table 2-3.

3.6 Sweet corn yield

Similar to cover crop biomass, we found a year and treatment by year interaction for sweet corn yields in 2011 and 2012 due to differences in weather conditions and planting date (Table 2-5). In 2011, marketable sweet corn yield was highest in the chem no plots, followed by the chem plow plots (Table 2-4). Organic management treatments had lower marketable yields, where sweet corn yield were 8 times greater in the chem no and 5 times greater in the chem plow treatments than organic treatments. Total sweet corn yield was similar to marketable yield, with greatest yield found in the chem no treatment and lowest in both organic treatments. Percentage of total yield that was marketable was much higher in the chemical treatments (75% and 86%) compared to organic treatments (39% and 42%). Control plots did not yield sweet corn in 2011.

In 2012 sweet corn yield was higher in all treatments as compared to 2011 (Table 2-4). Chemical treatments yielded significantly more than the organic treatments, but within the organically managed treatments, plow treatment was higher than the no-till treatment. Percent marketable yield decreased in 2012 compared to 2011 for all treatments except organic plow. Additionally, control treatment yield results were comparable to organic no till treatments in 2012.

3.7 Total nitrogen applied to plots

Quantity and forms of nitrogen applied to treatments for 2011 and 2012 are shown in Figure 15 and Figure 16 respectively. In 2011, approximately 20% of the N in the applied in the organic treatments was in the form of cover crop N with the remainder of the N applied from the pelleted poultry litter. Both organic N forms necessitate mineralization for release of available N. However in 2012 about 65% of the N was supplied from cover crops with the remaining 35% of N applied from poultry litter. In 2011, chemical treatments received about 23% more N and 31% more N in 2012 due to the additional nitrogen provided by the cover crops.

4. Discussion

4.1 Soil properties

We found that although yields in organic treatments were lower than conventional treatment combinations, soil quality indicators were generally higher in the organic treatment with reduced tillage (org no) than all other treatments. In particular, MBC and MBN were significantly greater in organic no till treatment than all other treatments across all dates, except for in the July 2012 sampling date, where both no till management treatments were comparable. This increase in MBC/N in the organic no till treatment has three possible explanations: 1) labile C pool increases that provided additional energy sources for soil microorganisms, 2) lack of tillage that decreased soil disturbance and increased microbial populations through organic matter preservation and the movement of crop residue into the soil via soil macrofauna not present in tilled systems and 3) the avoidance of synthetic fertilizers and herbicides/pesticides, possibly increasing soil microorganism population activity. It is likely that a combination of these possibilities explain the increased microbial biomass C/N in the organic no-till treatment. Microbial biomass has been shown to increase rapidly due to both organic management that provides high compost input (Liu et al., 2007) as well as reduced tillage operations (Gosai et al., 2010). As tillage practice and/or conventional fertilizers are implemented into these systems, microbial populations decrease (Leite et al., 2010). This experiment indicates non-significant MBC/MBN differences in the organic plow and the conventional no till treatments, inferring that no till practices in the conventional treatment provided similar benefits to soil quality with regard to microbial activity as did organic management practices. However, when faced with reduced C inputs as well as tillage events (chem plow), conventional systems may substantially decrease microorganism population size and activity. Microbial biomass C was highest in fall and summer of 2011 in the organic plots, and summer of 2012 in the conventional plots possibly due to the recently added C from cover crops in May/June in both conventional and organic treatments, as well as additional pelleted poultry litter in the organic treatments, which may have further increased microbial activity. Climate differences and possible changes in soil moisture might account for the differences in MBC for both years. Although we did not collect data on soil moisture, plots were irrigated in July of 2012, which might have increased microbial activity in the conventional treatments as compared to the dry season of 2011. However, since enhanced organic treatment soil C might have already allowed for sufficient soil moisture (Bot and Benites, 2005), it is possible that microbial activity increase in summer of 2011 may be due to microbial preference to the greater proportion of pelleted poultry litter added, as compared to 2012, over other nutrient sources.

Soil labile organic C pools, such as POM, are a critical fraction of the total organic matter pool, as they are known to be an indicator of readily available nutrient sources for soil microbes. In 2011 and 2012, LPOM and HPOM, as well as total C, were significantly greater in the organic no till treatment as compared to conventional plow treatments. While few studies involving soil C pools exist comparing conventional to reduced tillage in both organic and conventional systems, those that have report similar findings, whereas organic no till systems have higher total and labile organic C (Leite et al., 2010). When comparing organic to conventional management, others have shown that in general organic systems tend to increase labile fractions of organic matter (Marriott and Wander, 2006), and conservation tillage systems increase light particulate organic matter in particular (Dou et al., 2008; Yang and Kay, 2001).

No significant differences were seen between the LPOM and total C in organic plow and the conventional no till treatment soils. This observation may be related to the observed increase in total C and POM in the no tillage systems, where such systems offer increased substrates for microbial use due to the lack of tillage-based oxidative activities, and suggest that additions of labile organic matter may be enough to compensate for any soil carbon losses incurred due to tillage. Additionally, disruption of soil due to tillage in the organic plow systems increased decomposition of labile and total organic matter, while lack of tillage in the conventional system (chem no) increased fractions of carbon due to reduced decomposition, therefore allowing comparable quantities of LPOM and total C. These results support our MBC data, concluding that increased LPOM and total C in organic no till systems lead to an increase in MBC, but similar quantities of LPOM in organic plow and conventional no till systems lead to similar microbial biomass. We also showed that increases in LPOM increase total C in the soil, suggesting that higher quantities of LPOM help to increase total C in soils.

4.2 Yields

Although yields were higher in 2012 than in 2011, in both years conventional plots significantly outperformed organic by at least double the yield. Possible and likely reasons for this significant observed yield reductions in the organic treatments include weed competition driven by lack of weed control options in organic no till plots and N limitation due to necessary N mineralization from added inputs. Additional possibilities for yield-limiting factors in organic treatments include soil moisture and surface crusting in plowed treatment.

Weed competition in organic treatments was likely a primary driver of yield reductions, where in 2011 weed biomass accounted for as much as 80% of the total harvested cover crop weight in 2011 and up to 13% in 2012. It is also probable that weeds captured a portion of the available nitrogen and the remainder of the available nitrogen was not sufficient for adequate sweet corn yields. In 2011, we observed weed height as tall as sweet corn within the corn rows in both the organic no till and organic plow treatments prior to harvest, and in 2012 in the organic no till treatments, suggesting severe competition for nutrients, water, and possibly sunlight.

Nitrogen limitation in the organic systems could be a limiting factor for yield reduction, especially in 2012. Winter legume biomass in organic systems contributed less N than expected. Differences among treatments in terms of cover crop nitrogen were not observed in 2012, nor were differences in total cover crop biomass produced by all treatment combinations in both 2011 and 2012. However cover crop N differences observed between organic no till and conventional no till treatments in 2011 showed that conventional no till plots received almost double the N from cover crops as compared to the organic no till treatment. While no data was taken on grass vs. legume occupation in mixed stands, visual observations of plots during cover crop harvest showed that in 2011, crimson clover did not produce a strong stand, resulting in the majority of both system types being dominated by wheat. As a result, cover crop N was similar in both the organic and chemical treatments, where little N was contributed to the soil via crimson clover through N fixation. Cover crop C:N ratios increased to 30:1 and likely limiting N release from the decomposing cover crops. Wagger et al., (1998) found that cover crops with high C:N ratios have low N release available for the preceding crop, and corn following crimson clover rye mixes could recover only about 12-15% of inorganic N from the cover crop. Additionally, other studies have shown N release to occur very slowly from crimson clover terminated at full flowering, as compared to clover terminated at the vegetative state due to the increased structural carbohydrates and lignin (Ranells and Wagger, 1992). Because our cover crops were terminated at full flowering late in the clover growth cycle in both years, N might have been mineralized too late in the growing season for sufficient crop growth, especially in organic treatments that relied heavily on N from cover crops to meet crop demands. Although we expected increased N in organic plots in 2012 due to the presence of the leguminous cover crop, it is possible that the dominance of wheat and weeds in the organic treatments, especially where there was a lack of tillage to reduce weed populations, increased total carbon and led to increased C:N ratios and immobilization rather than mineralization of organic N that can occur when substrates' C:N ratio is generally less than 20-25:1 (Bengtsson et al., 2003) .

The organic corn leaves were yellow in color in 2011 and yellow in the organic no till treatments in 2012, suggesting N deficiency. In 2011, approximately 15% of the applied N in the organic no till treatments was contributed from the cover crops, and approximately 70% in 2012, which might not have mineralized sufficiently due to N immobilization, or mineralized rapidly to be later lost in the growing season. The pelleted poultry litter had a C:N ratio of 12:1 and was approximately 80% available (Perdue AgriRecycle, Seaford, MD), which likely has a greater mineralization rate than the cover crops. In 2011, marketable sweet corn yield in organic no till treatments was twice as high as marketable yield in 2012, possibly because more of the N was added in the form of pelleted poultry litter in 2011 and therefore more N made available to the sweet corn due to the lower C:N ratio. However, total sweet corn yield was comparable in 2011 and 2012 in the organic no till treatments, which suggests that not enough N in 2012 was available to produce large, marketable sized ears as compared to 2011. Conventional plots received approximately 25% more N in both years due to the added nitrogen from the cover crop, which could have further increased yields in the conventional treatments.

Other factors including soil moisture, surface crusting and climatic factors are additional possibilities for observed yield differences. We observed a thick mat of wheat residue in the chemical no till plots that remained following cover crop termination in the spring, which may have possibly led to increased soil water holding capacity and/or decreased evapotranspiration, as well as weed suppression, and thus increased yields in 2011 in the face of drought. Surface soil crusting was also observed in conventional plow treatments which could have reduced yield in conventional plow treatments as compared to conventional no till treatments in 2011. Surface crusting has been shown to decrease water infiltration and moisture holding capacity in agricultural soils, significantly reducing crop yields (FAO, 1993). Similar studies have shown that conservation tillage systems effectively retain soil moisture, as opposed to traditional plow systems, and increase yields (Holland, 2004). In 2012 yields were higher possibly due to both the warmer climate in the later planting date and emergency irrigation applied on the plots in response to abnormal seasonal drought. In 2012 corn was planted two weeks later than in 2011, allowing perennial weeds to emerge in the organic no till plots, where plots lacked any weed control besides mowing, possibly increasing weed competition for nutrients and water, resulting in a poor yield in the organic no till treatments.

4.3 Soil biological properties and soil losses

This study showed that the organic systems with reduced tillage enhanced labile, total and microbial fractions of organic matter, but at the expense of greatly reduced sweet corn yields. However, many studies have shown that increasing SOC can increase yield substantially due to increased water holding capacity, mineralization of nitrogen due to increased microbial populations, and increased cation exchange capacity provided by enhanced organic matter (Weil and Magdoff, 2004; (Karlen et al., 1992). Our data suggests that despite the increases in organic carbon pools, decreased yields were reported in organic treatments due primarily to weed competition and reduced N availability.

Increased organic C did not enhance yields in this study but increased labile fractions of organic C and subsequent increases in microbial community size found in these organic systems can potentially lead to increased aggregation in agricultural soils due to the microbial production of extracellular polysaccharides (Six et al., 2002). It is widely understood that increased soil aggregation increases water infiltration and decreases runoff and sediment loss (Tisdall and Oades, 1982; Williams and Petticrew, 2009). Increases in organic C and aggregation could prevent excess loss of soil and nutrients through stabilization of soil (Shepherd et al., 2002) and the increase in SOC protects the soil against surface erosion (Franzlubbers and Haney, 2006). Over time, these decreased soil losses found in reduced tillage systems and with management practices that enhance soil organic carbon will likely decrease nutrient and sediment pollution in watersheds, and possibly enhance yields due to the stabilization and reduced losses of important and nutrient-rich surface soil that would otherwise be lost.

5. Conclusion

Management systems that incorporate organic additions as a primary nutrient source have been shown to increase SOC in agricultural soils (Lal, 2004; Wander and Traina, 1996) therefore organic farming practices have also been linked to increases in SOC. Our study supports this claim, with increased labile (both microbial and particulate C) and total C pools in organic systems especially evident with reduced tillage. In this study, reduced tillage was an important factor for increasing organic matter in both conventional and organic systems and for increasing yield in conventional systems. Higher soil organic carbon found in organic systems often lead to increased aggregation of soil particles, which correlates to low water and nutrient runoff (Shepherd et al., 2002; Williams and Petticrew, 2009), as well as increase soil retention by stabilizing the soil surface from erosion (Apezteguía et al., 2009; Bot and Benites, 2005; Franzlubbers and Haney, 2006). More research is needed to determine how C increases correlate with sediment losses, and how much soil organic C is needed to increase soil retention and decrease soil loss.

6. Acknowledgements

We would like to acknowledge the work of Maximilian Sherard, Sarah Seehaver, and Collin Suttles for their time and effort with fieldwork.

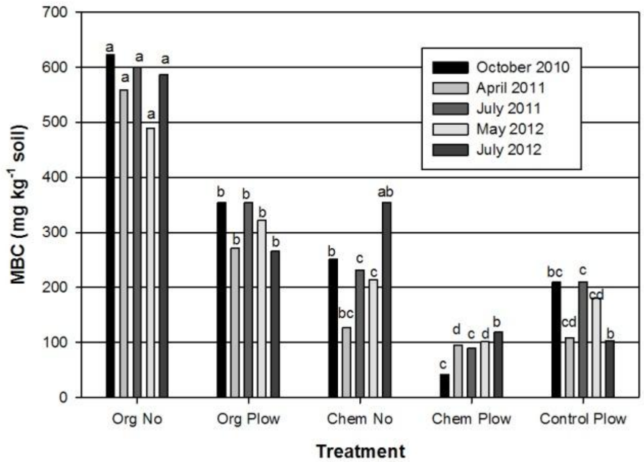

Figure 2-1: Microbial biomass carbon in 2010-2012 sampling dates. Data are analyzed within each sampling date. Bars represent means. Bars with the same letter are not significantly different at $p<0.05$ (LSD).

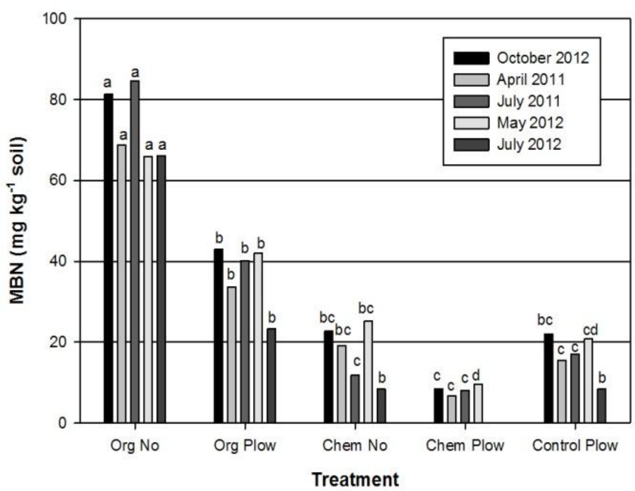

Figure 2-2: Microbial biomass nitrogen in 2010-2012 sampling dates. Data are analyzed within each sampling date. Bars represent means. Bars with the same letter are not significantly different at $p<0.05$ (LSD).

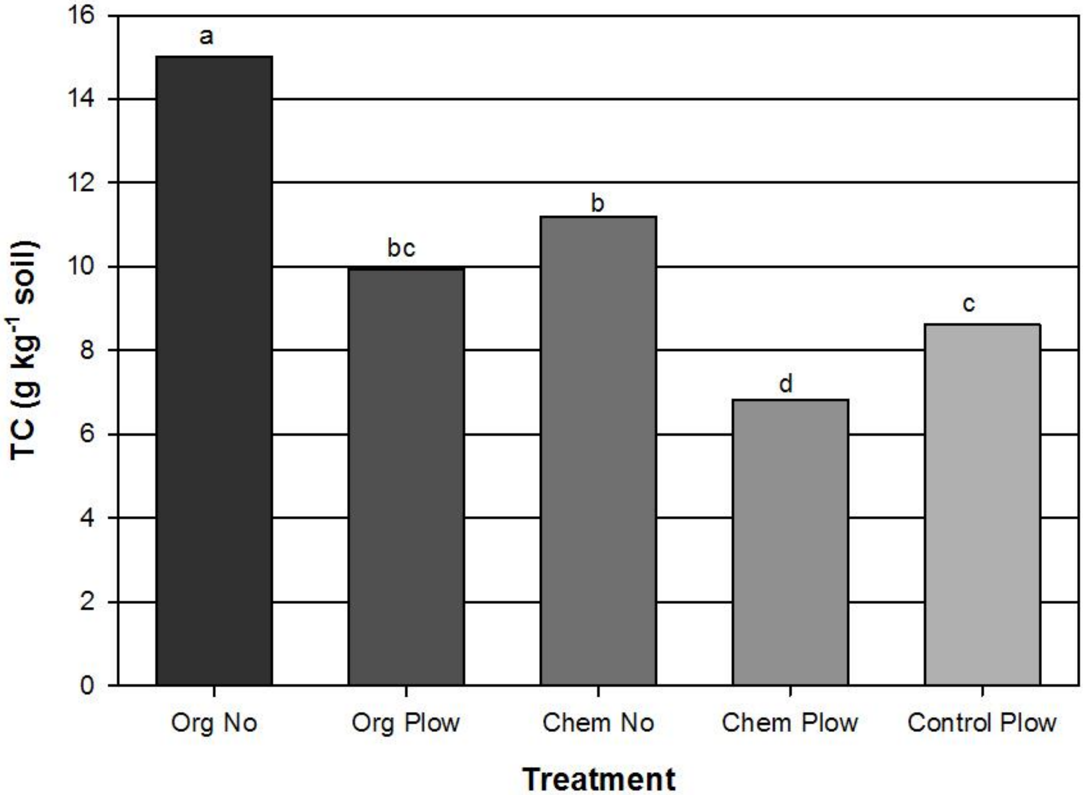

Figure 2-3: Mean total carbon from all soil sampling dates. Bars represent means. Bars with the same letter are not significantly different at $p<0.05$ (LSD)

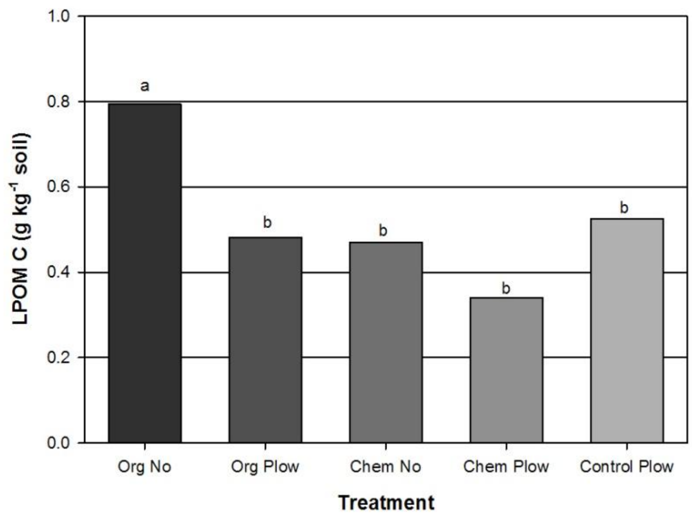

Figure 2-4: Mean light fraction POM-C from all sampling dates. Bars represent means. Bars with the same letter are not significantly different at p<0.05 (LSD).

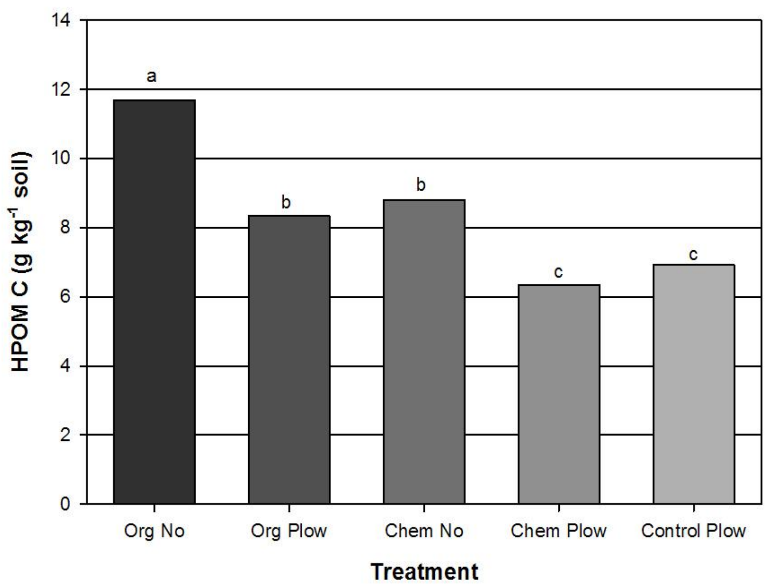

Figure 2-5: Mean heavy fraction POM-C from all sampling dates. Bars represent means. Bars with the same letter are not significantly different at p<0.05 (LSD).

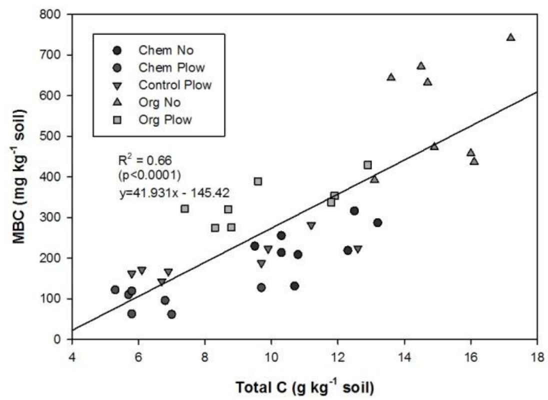

Figure 2-6: The relationship between microbial biomass carbon and total carbon.

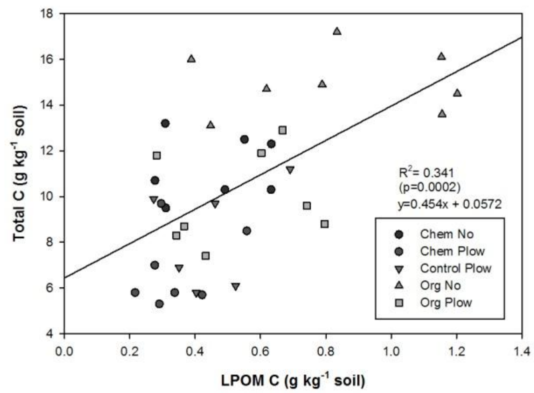

Figure 2-7: The relationship between total carbon and light fraction particulate organic matter.

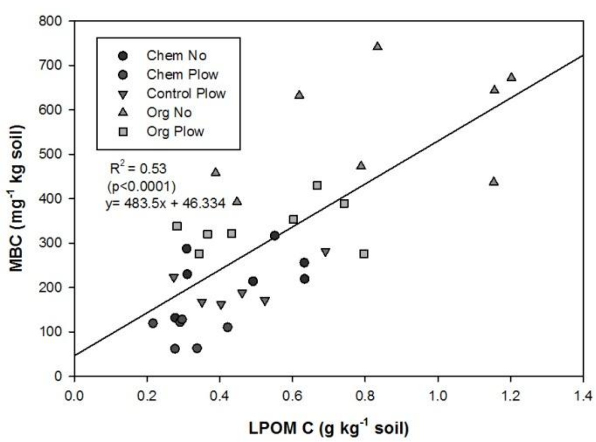

Figure 2-8: The relationship between particulate organic matter and microbial biomass carbon

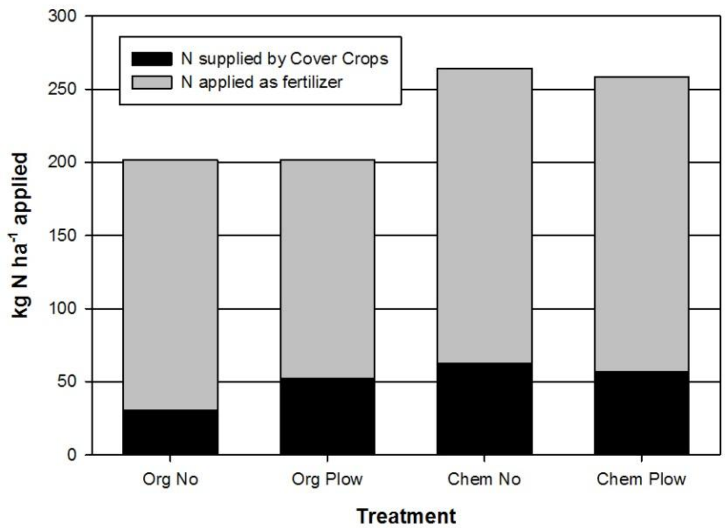

Figure 2-9: Type and quantity of nitrogen applied to soils in 2011 growing season. Bars represent means.

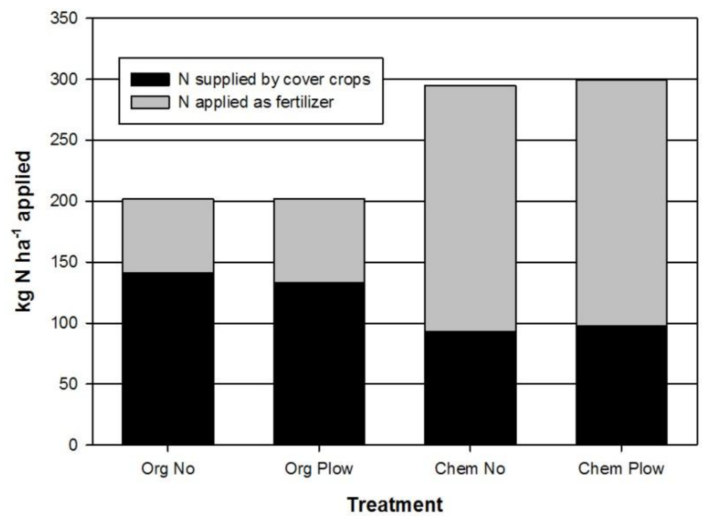

Figure 2-10: Type and quantity of nitrogen applied to soils in 2012 growing season. Bars represent means.

Table 2-1: Field operations

	2011		2012	
	Organic	Conventional	Organic	Conventional
Cover Crop Planting	18 October 2011	18 October 2011	14 October 2011	10 October 2011
Cover Crop sampling	21 April	21 April	1 May	1 May
Cover Crop Termination	28 April	28 April	3 May	3 May
Fertilizer Application	16 May	16 May	30 May	4 June
Fertilizer Side-dressed	NA	22 June	NA	8 July
Sweet Corn Planting	22 May	22 May	4 June	4 June
Corn Harvest	3 August	3 August	15 August	15 August

Table 2-2: Cover crop data from 2011 and 2012 growing season.

		Treatments			
		Organic No	Organic Plow	Chem No	Chem Plow
2011	Biomass (Kg ha^{-1})	1572.0 a	2777.0 a	2652.5 a	2438.0 a
	% N	1.89	1.66	2.73	2.38
	C: N	22.6	24.3	18.6	19.6
	Total N (kg N ha^{-1})	30.5 a	51.8 ab	62.4 b	56.5 ab
2012	Biomass (Kg ha^{-1})	9216.5 a	8121.5 a	7376.0 a	7918.5 a
	% N	1.51	1.63	1.26	1.21
	C: N	31.0	27.5	35.6	40.3
	Total N (kg N ha^{-1})	140.5 a	132.7 a	92.6 a	97.5 a

Within a row different letters following least squared means indicate significant differences at $p < 0.05$ (LSD). Within a row same letters following least squared means indicate non-significant difference at $p < 0.05$ (LSD).

Table 2-3: Weed biomass data from 2012 sweet corn growth.

	Treatments				
	Org No	Org Plow	Chem No	Chem Plow	Control Plow
C supplied (kg ha^{-1})	1060.4 a	626.9 ab	298.8 bc	30.1 c	759.2 ab
% Broadleaf	57.14	88.71	61.21	33.33	27.99
% Grasses	42.86	11.29	38.79	66.67	72.01

Within a row different letters following least squared means indicate significant differences at p <0.05 (LSD).
Within a row same letters following least squared means indicate non-significant difference at p <0.05 (LSD).

Table 2-4: Sweet corn yield data from 2011 and 2012 growing season.

	2011			2012		
Treatments	Marketable Yield (kg ha^{-1})	Total Yield (kg ha^{-1})	% Marketable of Total Yield	Marketable Yield (kg ha^{-1})	Total Yield (kg ha^{-1})	% Marketable of Total yield
Org No	2053 c	5204 c	39.45%	640 c	3781 c	16.93%
Org Plow	2023 c	4716 c	42.90%	8528 b	13112 b	65.04%
Chem No	15866 a	18356 a	86.43%	13894 a	18488 a	75.15%
Chem Plow	9869 b	13142 b	75.10%	12451 a	19576 a	63.60%
Control Plow	0	0	NA	224 c	488 c	45.90%

Within a column, different letters following least squared means indicate significant differences at $p < 0.05$ (LSD). Within a column, same letters following least squared means indicate non-significant difference at $p < 0.05$ (LSD).

Table 2-5: Interactions between experimental measurements.

	Interaction		
Measurement	Treatment	Treatment x year	Year
Total C	*	-	-
LPOM	*	-	-
HPOM	*	-	-
MBC	*	*	*
MBN	*	*	-
Marketable sweet corn yield	*	*	*
Total sweet corn yield	*	*	*
Cover crop N	*	*	*
Cover crop biomass	-	*	*
Weed biomass	*	NA	NA

"*" indicates significant interactions at the 0.05 level, and "-" indicate non-significant interactions at $p < 0.05$ (LSD).

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CHAPTER 3 : EFFECT OF SOIL BIOLOGICAL PROPERTIES ON RUNOFF POTENTIAL IN MOUNTAIN SOILS

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1. Introduction

Soil organic carbon (SOC) additions often lead to increased aggregation of soil particles, shown to increase infiltration and decrease water and nutrient runoff (Shepherd et al., 2002; Williams and Petticrew, 2009), as well as increase soil retention by stabilizing the soil surface from erosion (Apezteguía et al., 2009; Bot and Benites, 2005; Franzlubbers and Haney, 2006). Management systems that incorporate organic additions as a primary nutrient source, such as those used in organic production, have been shown to increase SOC in agricultural soils (Lal, 2004; Wander and Traina, 1996).

Losses of SOC can occur through tillage, which facilitates rapid decomposition of SOM due to the disruption of aggregates and exposure of soil microorganisms to increased oxygen (Bot and Benites, 2005; Tisdall and Oades, 1982). Reductions in SOC may also occur due to soil and carbon losses in surface water runoff. In the southeastern US, organo-mineral soil carbon losses have been observed to occur in runoff, transporting agrichemicals sorbed to such particles off the farm and into waterways, limiting soil organic carbon accumulation at the surface of agricultural soils (Truman et al., 2007). Additionally, the lack of legume green manures and small grain cover crops in the crop rotation can also reduce soil organic carbon. These losses in soil carbon can leave agricultural fields depleted of plant nutrients and vulnerable to soil losses through surface runoff (Magdoff and Weil, 2004).

The demand to find environmentally sound farming practices that reduce runoff and erosion, improve soil retention, and increase soil organic matter has been increasing throughout the decades. This experiment compared the long-term effects of organic and conventional management practices under two tillage regimes on soil carbon losses. The objectives of this study were 1) to determine correlations between soil organic carbon and runoff in agricultural fields under conventional and organic management systems and two tillage types, and 2) to determine long-term management and tillage type impacts on total organic matter lost via runoff. Based on evidence that organic farms increase soil organic carbon, especially where tillage is absent and high inputs of compost occur, we hypothesize that organic farming practices can lead to reduced soil losses due to stabilization of soil.

2. Materials and methods

2.1 Study Site

The field site is located at the Mountain Horticultural Crops Research Station in Mills River, NC. The land is gently sloped at 2-7% and is situated on a stream terrace of the French Broad River. The soil type of the field is a Delanco fine-sandy loam (fine-loamy, mixed, mesic, Aquic Hapludult) (Overstreet et al., 2010not in reference section) . The site includes 20 plots, each 9.14m x 18.29m with five treatments replicated 4 times. Plots are arranged in a completely randomized design with treatments including 1) organic management + no-tillage (org no), 2) organic management + conventional tillage (org plow), 3) conventional management + no-tillage (chem no), 4) conventional management + conventional tillage (chem plow), and 5) control (plowed, disked and no inputs of fertilizers/pesticides [control plow]). Plots have been under these conditions since 1994 and the organic plots were certified organic by International Certification Services, Inc. (Medina, ND).

2.2 Field Preparation

The long-term sequence of vegetables grown in the field plots is described by (Wang et al., 2011). Table 3-1 outlines all field operations for the 2011 and 2012 growing seasons. Cover crops were planted on October 18, 2010 (2011 field season) and October 10, 2011 (2012 field season). In 2010, “Sunrise” crimson clover and “Arthur” wheat was planted in all treatment plots except the control. In 2011, crimson clover and wheat was again planted in all plots, but Banvel II herbicide [sodium salt of dicamba (3,6-dichloro-o-anisic acid)} was applied in February 2012 at 0.29 liters ha^{-1} (0.25 pt $acre^{-1}$) to kill crimson clover in conventional plots to better represent conventional production practices. Clover was planted at 33.6 kg ha^{-1} (30 lbs $acre^{-1}$) and wheat applied at 80.6 kg ha^{-1} (72 lb $acre^{-1}$). Cover crops were not planted in control plots. In treatment plots, cover crops were terminated at flowering in the spring and sweet corn planted in all plots in May or June, then harvesting approximately 90 days after planting. “Luscious” certified organic seed was applied to the organic and control plots and “Luscious” with insecticide seed was planted in the chemical plots. Sweet corn was planted at a rate of 65,235 seeds ha^{-1} (26,400 seeds $acre^{-1}$). Fertilizer nitrogen (N) was applied to all organic and chemical treatment plots at a rate of 201.6 kg N ha^{-1} (180 lbs ac^{-1}). Perdue AgriRecycle microSTART60 (3-2-3) pelleted poultry litter was applied combining with calculated cover crop nitrogen rate to obtain 201.75 kg ha^{-1} (180 lbs ac^{-1}) in the organic treatments. Commercial fertilizer was surface broadcast applied to the chemical plots at a rate of 112 kg ha^{-1} (100 lbs N ac^{-1}) prior to sweet corn planting and then side-dressed 30 days after planting by surface banding at a rate 89.6 kg ha^{-1} (80 lb N ac^{-1}). Bicep II Magnum 5.5F herbicide a.i. S-Metolachlor /atz/benoxacor (Syngenta, Greensboro, NC) was applied directly after sweet corn planting at a rate of 4.68 liters/ha in the chemical plots. Warrior insecticide a.i. Lambda-cyhalothrin (Syngenta, Greensboro, NC) was applied to the chemical treatments, and Entrust certified organic insecticide a.i. spinosad (ow AgroSciences-Indianapolis, IN) applied to the organic treatments weekly in July until August 1st in both 2011 and 2012. The organic treatments relied on mechanical weed control including rototilling of plowed plots and mowing of no-till plots. The plot borders, between-row regions, and plot interiors were mowed/tilled weekly in June and biweekly in July until mid July to minimize weed competition.

At the down slope end of each plot a collection trough was installed to funnel surface runoff to a central outlet point. Wooden boards were installed around the outside perimeter of the field plots by partially burying them in the soil to prevent lateral flow of surface water and to ensure rainfall water was collected at the central outlet. A monitoring station was established at the outlet point of each plot. The monitoring station included an Isco automated sampler and weir, designed by the Department of Biological and Agricultural Engineering fabrication shop at NCSU, with integrated flow meter and a flume to measure flow volume and collect water/sediment samples flowing through a flume (Virtual Polymer Compounds, Medina, NY).

2.3 Soil Sampling

Soil samples were collected from all plots and taken in October 2010, April 2011, July 2011, May 2012, and July 2012 for microbial biomass and December 2009, April 2011 and May 2012 for particulate and total organic matter. Ten subsamples were taken from each plot in a "z" pattern to 15 cm (6 inch) with a 2.5 cm (one inch) diameter soil probe, homogenized, oven dried for 48 hours at 45°C, ground to 2mm and stored at room temperature for organic matter measurements, and stored at 4°C and sieved to 2mm for microbial biomass measurements.

2.4 Soil biological properties

Soil biological properties were measured according to Larsen et al., 2012 Chapter 2.

2.5 Total suspended *solids (TSS)*

Runoff samples were analyzed for TSS using the USEPA approved standard method 2540D for dry total suspended solids (need a reference here citing location of methods). A well-mixed sample of collected runoff was filtered through a glass-fiber filter that had been previously rinsed, dried, and weighed. The residue retained on the filter after filtering was dried to a constant weight at 105°C and weighed. Total suspended solids were calculated as follows:

mg total suspended solids/L= (A-B) x 1000/ sample volume, mL

where :

A= weight of filter + dried residue, mg and

B=weight of filter, mg

Total suspended solids was measured on all collected runoff samples from rainfall events in October 2010 through June 2012.

2.6 Sediment carbon

A homogenized sub-sample of total collected runoff (water + sediment) was used to assess carbon contained in runoff sediment. Water in the sub-sample was oven-dried at 85°C until all water was evaporated and only sediment was remaining. Sediment was then scraped from the beaker, ground with a mortar and pestle to a fine powder, and analyzed for total carbon using a Perkin Elmer 2400 CHNS/O Elemental Analyzer. Due to lack of collected runoff samples during some storm events, sediment was categorized and collected in four combined sampling dates, including Jan-April 2011, May-Oct 2011, Oct-May 2012, and June-Aug 2012, and the total sample for each plot submitted for analysis. Soil collection dates were chosen based on expected differences in runoff and soil loss during corn growth and cover crop growth in 2011 and 2012 due to changes in soil cover. Table 3-2 indicates collection time point dates and corresponding field conditions. Total carbon loss through surface runoff was calculated using the following equation:

C loss (kg ha^{-1} $year^{-1}$) = (mean percent carbon in sediment/100) x TSS (kg ha^{-1} $year^{-1}$).

2.7 Soil physical measurements

Soil bulk density samples were taken from a tractor wheel row and a non-wheel row in all twenty plots for a total of 2 samples per plots. The samples were taken in the middle of the field between corn rows. An Uhland core (7.5-cm diameter, 7.5-cm length) was pounded into the soil surface and removed without further compacting the soil. Soil samples were oven dried at 105°C for 72 hours and sample weight recorded and divided by uhland core volume to obtain soil bulk density.

2.8 Data Analysis

Data were analyzed using SAS software version 9.3 (SAS Institute, Cary, NC). Bulk density and surface carbon loss data was analyzed using GLM procedure, and sediment carbon was analyzed using MIXED procedures. In order to fit the assumptions of equal variance, percent carbon in sediment data were log transformed and back transformations of least square means reported in graphs. Regressions were performed using CORR and REG procedures. A p-value of 0.05 was used to test the significance for all data. LSD was used to determine differences among treatments.

3. Results

3.1 TSS and Organic matter correlation

Total suspended soil solids lost in runoff was negatively correlated with organic matter content, whereas total suspended solids decreased with increases in total organic carbon content in treatment plots (Figure 3-1). Organic no-till treatments contained highest soil total carbon quantities and lost lower amounts of TSS than all other treatments. Chemical plow treatments contained the lowest soil total carbon and lost the highest amount of TSS (approximately 2912.72 kg ha^{-1} $year^{-1}$). Total suspended solids measured as a function of POM and MBC was also negatively correlated (Figure 3-2; Figure 3-3) however there was no significant correlation between TSS and bulk density.

3.2 Sediment carbon losses

A correlation between percentage of C contained in runoff sediment and total C contained in treatment plot soils showed that as total soil carbon increases percentage of carbon in the sediment also increases significantly (Figure 3-4). Org no treatments contained significantly more carbon in runoff sediment than all other treatments in Jan-April 2011 and Oct-May 2011/12 (Figure 3-5). Percent carbon in lost in sediment runoff was at least 2 times greater in Jan-April 2011 in the org no than all other treatments, and about 1.5 times greater in May-Oct 2011. The lowest percentage of carbon found in sediment was in the October-May 2011/12 collection time point during cover crop growth for the organic treatments and the chem no treatment, and May-Oct 2011 during sweet corn growth for the chem plow and control plow treatments, but was highest in May-Oct 2011 for both no-till treatments. Conversely, when measuring total carbon loss through sediment runoff, total carbon loss through surface runoff was greatest in the chemical plow treatments and lowest in the organic no till treatments (Figure 3-6). Chemical plow treatments lost approximately two times more carbon overall as compared to the org plow treatments, and approximately four times more carbon as compared to the org no treatments. Both the org no and chem no treatments lost comparable quantities of carbon.

3.3 Physical measurements

Bulk density varied tremendously across all treatment combinations, ranging from 1.28 g cm^{-3} to 1.79 g cm^{-3}. Bulk density was higher in the wheel rows than the non-wheel rows in all treatments except org no, due to the compaction of farming equipment (Table 3-3). Soil bulk density was higher in the chemical treatments than the organic treatments. The chem no treatment had significantly higher bulk density than the org plow and org no treatments. The org no treatment had the lowest bulk density, at 1.45 g cm^{-3}. The chem no plots and chem plow plots were not significantly different.

4. Discussion

In our experiment, plowed systems, particularly the conventional plow treatment, lost the highest quantity of total carbon through surface runoff as compared to the no till treatments. Similar to our findings, Truman et al. (2007) found conventionally tilled systems to lose more sediment carbon than conservation tillage systems. Although sediment from both no till treatments contained high percentages of carbon in sediment across all sampling dates, these systems lost very little sediment overall, suggesting tillage to be a dominant factor in sediment loss. The percentage of carbon in sediment was highest in the no tillage treatments likely due to the large proportion of carbon found on the soil surface that was prone to surface losses, such as surface applied pelleted chicken litter and cover crop residues. Thick mulch layers of organic matter and crop residue remaining on the surface in no till systems, however, may have also protected soil from surface erosion and thus reduced total sediment lost through runoff.

We found that as total soil carbon increased in agricultural fields, suspended solids lost through surface runoff also decreased. In particular, organic systems with reduced tillage (org no) accumulated more soil carbon and subsequently had lower TSS rates than plowed systems. Although limited literature exists comparing soil loss and runoff in organic and conventional management systems, especially with different tillage regimes, numerous studies have indicated decreased runoff and soil loss in reduced or no-tillage operations as compared to conventional tillage due in part to the stabilization of the surface by the accumulation of crop residues and increased SOM (Reicosky, 1995; Rhoton et al., 2002). Reganold et al. (1987) found that conventionally managed lands lost more soil via surface runoff than organically managed lands likely due to the increased aggregation and organic matter content in the organic fields. These findings may help to explain our results showing that decreased TSS found in surface runoff is associated with increases in microbial community size (Larsen et al., 2012), and suggests that soil aggregation may be due to microbial excretion of extracellular polysaccharides which work to hold soil particles together (Six et al., 2002). Additionally, results showed that as particulate organic matter increases, TSS decreases, potentially explained by MBC increases caused by the increased energy supply provided by POM, or to the increased organic matter content, which may promote infiltration and decrease surface runoff (Carter, 2002).

Surprisingly, our bulk density measurements were not correlated with carbon losses or TSS. Although studies have shown that higher bulk densities can lead to increase losses of sediment due to the small porosity and increased compaction (Rhoton et al., 2002), our results found more significance with organic matter contributions, which can also have similar physical benefits to the soil as low bulk densities, due to increased porosity and infiltration. Our measurements also showed bulk density not to correlate with total organic carbon. The low bulk densities in the organic no till system may have occurred due to high perennial weed biomass and increased root channels in the soil, which can increase porosity and decrease bulk density. We presume that the conventional no till treatments had high bulk density measurements due to the constant wheel traffic of heavy machinery for the extent of this long-term study, and the presence of weeds in the organic no till treatment caused significant decreases as compared to the conventional no till treatment.

5. Conclusions

This study showed that the increases in organic matter found in no tillage systems were associated with decreases in total sediment load into watersheds. No tillage systems, especially those that were organically managed, were also able to reduce soil carbon loss via surface runoff as compared to plowed systems. These results offer land managers additional information to help predict runoff in agricultural soils based on organic carbon content. Also, our results indicate that management systems that include organic farming techniques such as cover crop additions and organic fertilizer, allow for organic matter accumulation that helps stabilize the soil against soil losses as compared to conventional systems. Additional research is needed to determine specific quantities of organic soil carbon necessary to decrease sediment loads into watersheds.

6. Acknowledgements

We gratefully acknowledge the work of Collin Suttles and Maximilian Sherard for their help with this project.

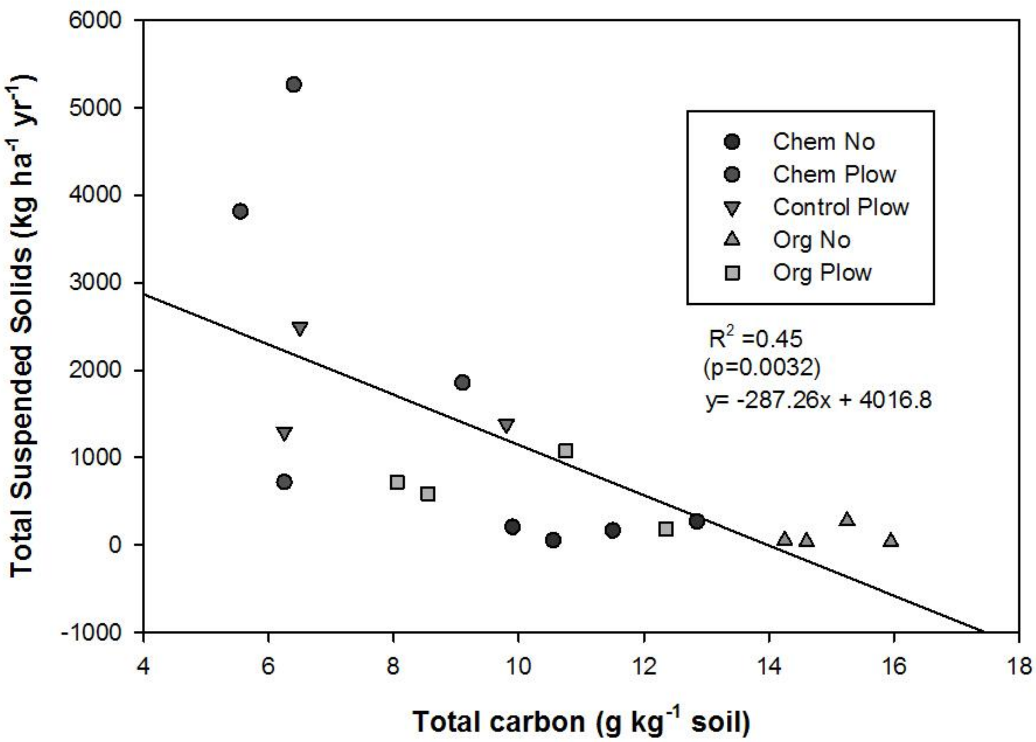

Figure 3-1: TSS associated with total carbon found on experimental treatment plots. Points represent mean total carbon values of each experimental plot from 2011 and 2012.

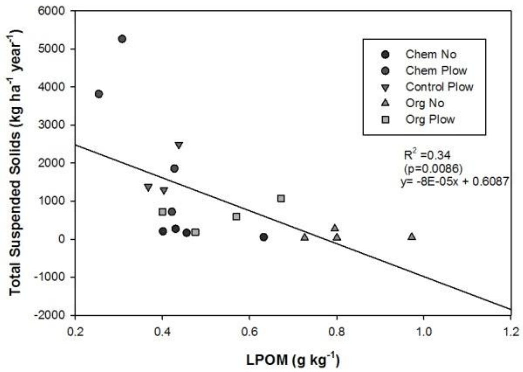

Figure 3-2: TSS associated with light fraction particulate organic matter. Points represent mean values of LF POM from 2011 and 2012 for each plot.

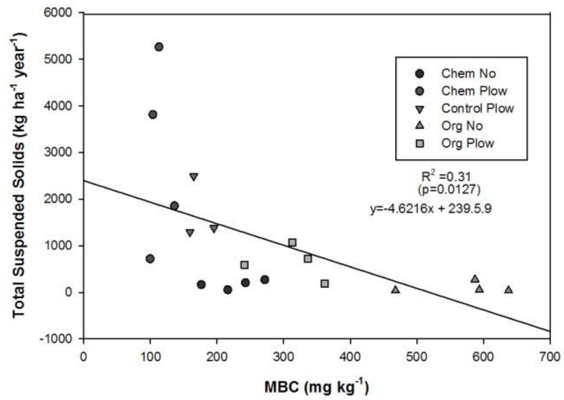

Figure 3-3: TSS associated with microbial biomass carbon. Points represent mean MBC values from 2010 and 2012 for each plot.

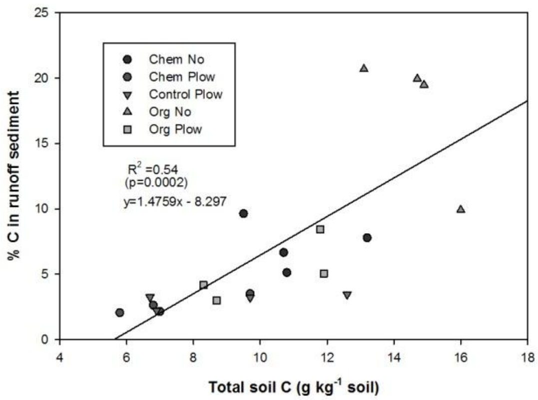

Figure 3-4: Carbon losses associated with total soil carbon found on each treatment plot. Points represent mean soil carbon values from 2011 and 2012.

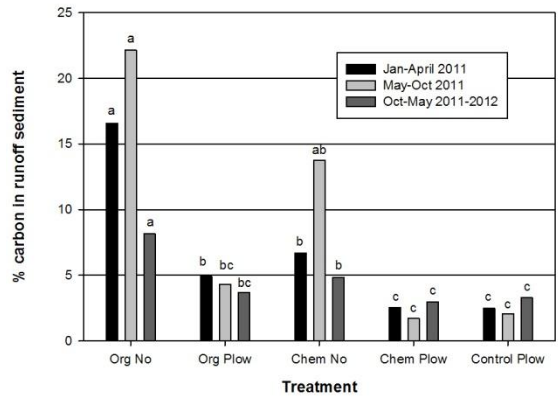

Figure 3-5: Percent carbon in runoff sediment measured in different collection time points across 2011-2012. Comparisons were made among treatments within each timepoint. Bars represent means. Bars with the same letter are not significantly different at $p<0.05$.

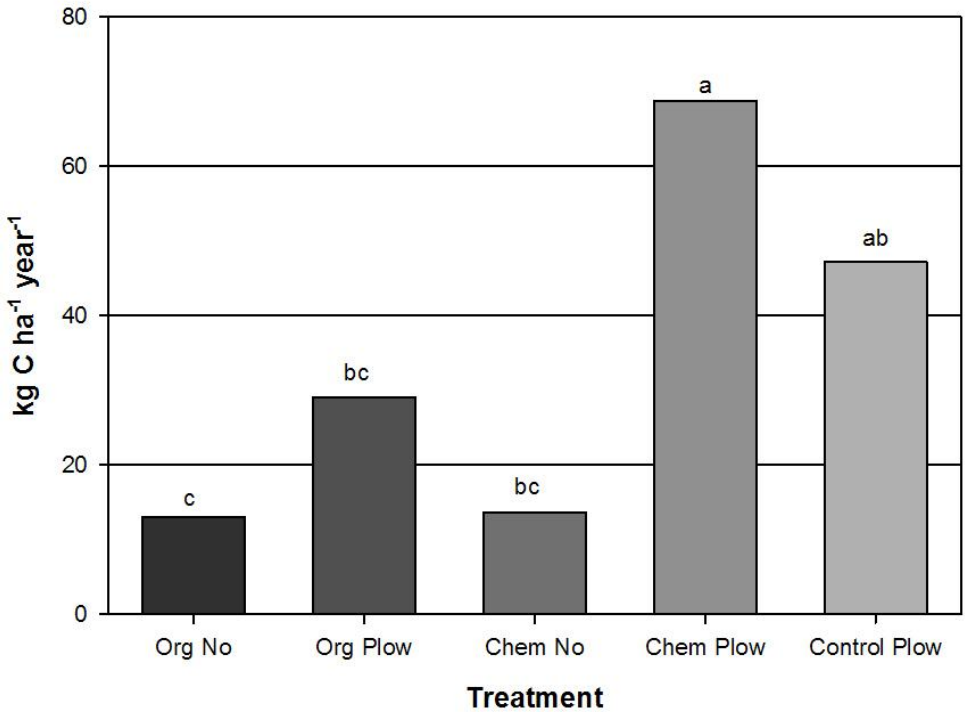

Figure 3-6: Total amount of carbon lost annually per hectare per year through surface runoff among organic and conventional plots under two tillage regimes, no-tillage and conventional tillage. Bars represent means. Bars with the same letter are not significantly different at p<0.05 (LSD).

Table 3:1: Field operations

Field Activity	2011		2012	
	Organic	Conventional	Organic	Conventional
Cover Crop Planting	18 October 2011	18 October 2011	14 October 2011	10 October 2011
Cover Crop sampling	21 April	21 April	1 May	1 May
Cover Crop Termination	28 April	28 April	3 May	3 May
Fertilizer Application	16 May	16 May	30 May	4 June
Fertilizer Side-dressed	NA	22 June	NA	8 July
Sweet Corn Planting	22 May	22 May	4 June	4 June
Corn Harvest	3 August	3 August	15 August	15 August

Table 3-2: Dates and field conditions for runoff sediment collection

Collection Point	Dates of collection	Field conditions
1	Jan-April 2011	Cover crop growth
2	May-October 2011	Sweet corn growth and residue
3	October 2011-May 2012	Cover crop growth
4	June 2012-August 2012	Sweet corn growth

Table 3-3: Bulk density measurements from 2011 growing season

	Treatments				
	Control Plow	Organic No	Organic Plow	Chem No	Chem Plow
Average Bulk density (g cm^{-3})	1.528bc	1.473c	1.525bc	1.661a	1.599ab
Wheel row Bulk density (g cm^{3})	1.596	1.469	1.688	1.721	1.617
Non-wheel row Bulk density (g cm^{3})	1.460	1.476	1.362	1.601	1.580

Within a row different letters following least squared means indicate significant differences at $p < 0.05$ (LSD)..
Within a row, same letters following least squared means indicate non-significant difference at $p < 0.05$ (LSD).

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