SOIL QUALITY IN ORGANIC CROPPING SYSTEMS

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DEDICATION

This work is dedicated to William and Dolores Clark

and

Pieter Los, Jill Staples, Kristen Veum, Jodie Reisner, Christi Cole and Kristin Bilyeu

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TABLE OF CONTENTS

Acknowledgements…………………………………………………………………… ii

List of Tables……………………………………………………………...………..… ix

List of Figures…………………………………..…………………….……………… xvii

CHAPTER ONE 1

INTRODUCTION 1

Bibliography.. 8

CHAPTER TWO 13

CORN, SOYBEAN AND WHEAT PRODUCTION ON A CLAYPAN SOIL USING CONVENTIONAL ORGANIC AND ORGANIC NO-TILLAGE PRACTICES 13

Abstract 13

Keywords:.. 14

Abbreviations: 14

Introduction 15

Materials and Methods 18

Research Site and Design 18

Weather.. 19

Equipment modification 19

Crop Management 20

Crop Data Collection 21

Soil Data Collection 22
Statistical Analysis 22
Results and Discussion 22
Cover Crop 22
Corn Population and Yield 25
Soybean Population and Yield 28
Wheat Yield 29
Soil Organic Carbon 30
Conclusion 31
Acknowledgements 33
Bibliography 42
CHAPTER THREE 47
SOIL QUALITY IN CONVENTIONAL TILLED AND NO-TILL ORGANIC SYSTEMS 47
Abstract 47
Keywords 48
Abbreviations 48
Introduction 49
Materials and Methods 52
Research Site and Design 52

Weather 53
Crop Management 54
Soil Analyses 55
Statistical Analysis 57
Soil Management Assessment Framework 58
Results and Discussion 58
Soil Physical Indicator 58
Soil Biological Indicators 60
Soil Carbon 60
PLFA 62
β-Glucosidase 66
Soil Chemical Indicators 67
SMAF Soil Quality Index 68
Conclusion 70
Acknowledgements 70
Bibliography 83
CHAPTER FOUR 91
EFFECT OF CROP ROTATION ON SOIL QUALITY AND THE WEED SEEDBANK DURING THE THREE YEAR TRANSITION TO CERTIFIED ORGANIC PRODUCTION 91

Abstract 91
    Keywords 92
    Abbreviations 92
Introduction 93
Materials and Methods 98
    Research Site and Design 98
    Weather 98
    Crop Management 99
    Plant Analyses 100
    Weed Analyses 100
    Soil Analyses 101
    Statistical Analysis 104
Results and Discussion 105
    Yield 105
    Weed Suppression 108
    Soil Quality 109
Conclusions 113
Acknowledgements 114
Bibliography 128
CHAPTER FIVE 134

TIMING AND METHOD OF ORGANIC CORN PLANTING IN COVER CROPS .. 134

- Abstract 134
  - Keywords 135
  - Abbreviations 135
- Introduction 136
- Materials and Methods 138
  - Research Site and Design 138
  - Crop Management 139
  - Data Collection 140
  - Statistical Analysis 140
- Results and Discussion 141
- Conclusion 144
- Acknowledgements 144
- Bibliography 146

CONCLUSIONS 149

VITA 152

LIST OF TABLES

Table 2.1. Compost applied per compost treatment (0x, 0.5x, 1x, 1.5x recommended rate) for corn, soybean, and wheat from 2012-2014. Compost application was based on yield goal, soil test P fertilizer recommendations and P content of compost...… 38

Table 2.2. Planting, fertilizing, cultivation, harvest, and termination dates for corn, soybean, wheat, and cover crops from 2012-2014……………….…………..…. 39

Table 2.3. Seeding rates, seasons and varieties of cover crops. VNS= variety not stated…………………………...…………………………………………….. 39

Table 2.4. Mean yield of organic corn, soybean and wheat from 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5 x= 1.5x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column, row and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses………….……………………………….…………………….. 40

Table 2.5. Mean of SOC at 0-15 cm soil depth, 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different

lowercase letter within each column or row and year are significantly different (using Tukey’s HSD) at α=0.05. Standard errors are stated in parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started…………………………………………………………………………… 41

Table 3.1. Compost applied per compost treatment (0x, 0.5x, 1x, 1.5x recommended rate) for corn, soybean, and wheat from 2012-2014. Compost application was based on yield goal, soil test P fertilizer recommendations and P content of compost...… 72

Table 3.2. Planting, fertilizing, cultivation, harvest, and termination dates for corn, soybean, wheat, and cover crops 2012-2014…………………..…….……..….. 73

Table 3.3. Seeding rates, seasons and varieties of cover crops. VNS=variety not stated……………………………………………………………………………..73

Table 3.4. Phospholipid fatty acid markers by microbial group…………………………74

Table 3.5. Mean of % aggregate stability at 0-15 cm soil depth, 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5 x= 1.5x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column, row and year are significantly different (using Tukey’s HSD) at α=0.05. Standard errors are stated in parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started…………………………………………………..……………… 75

Table 3.6. Mean % of aggregate stability (Ag Stab), β–glucosidase activity, permanganate oxidizable carbon (POXC), total N, total organic C, and soil quality

index (SQI) from 0-15 cm, 2012-2014 as impacted by compost application. Compost applications were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses…………… 76

Table 3.7. Mean biomass of soil PLFA (0-15 cm) from 2012-2014 as impacted by compost application. Compost applications were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. ACT=actinobacteria, AMF=arbuscular mycorrhizael fungi, ANAER=anaerobic bacteria, EUK=eukaryotes, GNEG= gram negative bacteria, GPOS= gram positive bacteria…………………………………………...…….. 76

Table 3.8. Mean of β–glucosidase activity at 0-15 cm soil depth, 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in

parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started………………………………………………………………….. 77

Table 3.9. Mean % of aggregate stability (Ag Stab), β–glucosidase activity, permanganate oxidizable carbon (POXC), total N, total organic C, and soil quality index (SQI) from 0-15 cm, 2012-2014 as impacted by year. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses…….…..…. 78

Table 3.10. Mean % of aggregate stability (Ag Stab), β–glucosidase activity, permanganate oxidizable carbon (POXC), total N, total organic C, and soil quality index (SQI) from 0-15 cm, 2012-2014 as impacted by tillage/cover crop (TCCP). TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses……………..…….……….. 78

Table 3.11. Mean % of aggregate stability (Ag Stab), β–glucosidase activity, permanganate oxidizable carbon (POXC), total N, total organic C, and soil quality index (SQI) from 0-15 cm, 2012-2014 as impacted by crop. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses……...……. 78

Table 3.12. Mean of permanganate oxidizable carbon (POXC) at 0-15 cm soil depth, 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x=

zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses………………………………………….……..…. 79

Table 3.13. Mean biomass of soil PLFA (0-15 cm) from 2012-2014 as impacted by tillage/cover crop (TCCP). TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. ACT=actinobacteria, AMF=arbuscular mycorrhizael fungi, ANAER=anaerobic bacteria, EUK=eukaryotes, GNEG= gram negative bacteria, GPOS= gram positive bacteria……………………………..……………………..………… 80

Table 3.14. Mean biomass of soil PLFA (0-15 cm) from 2012-2014 as impacted by crop. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. ACT=actinobacteria, AMF=arbuscular mycorrhizael fungi, ANAER=anaerobic bacteria, EUK=eukaryotes, GNEG= gram negative bacteria, GPOS= gram positive bacteria……………………………….………...…………. 80

Table 3.15. Mean Bray 1 P and extractable K from 0-15 cm, 2012-2014 as impacted by compost application. Compost applications were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate.

Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses…………………………………...……………………………. 81

Table 3.16. Mean of soil quality fractional index at 0-15 cm soil depth, 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started………………………………………..…………….. 82

Table 4.1. Seeding rates and seasons of cover crops……..…………………………… 115

Table 4.2. Seven rotational systems used to transition from conventional to organic row crop production. DC soybean =double crop soybean………..…………..…… 116

Table 4.3. Dates of production practices 2011-2014. DC SB= double crop soybean… 117

Table 4.4. Mean above-ground biomass from weeds 2012-2014. Biomass was collected at the time of most weed plants at anthesis. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses…………………………..…….. 118

Table 4.5. Mean yield of cash crops from 2012-2014. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses…...…….. 119

Table 4.6. Mean above-ground biomass of cover crops from 2012-2014. Biomass was collected at anthesis for each crop. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses…………………….…..…… 120

Table 4.7. Mean of NH_4^+-N and NO_3^--N concentrations at 0-15 cm soil depth, 2012-2014. Values followed by a different lowercase letter within each column and section are significantly different (using Tukey's HSD) at α=0.05. NS signifies no significant difference in means between the seven treatments for that year. Standard errors are stated in parentheses. Spring samples were taken at planting and autumn samples were taken at harvest………………………….…..…….. 121

Table 4.8. Mean number of weed seeds in 0-15 cm soil depth. Soil was collected prior to start of experiment in 2011 and at harvest in 2014. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses…………………… 122

Table 4.9. Means of microbial biomass by general type at 0-15 cm soil depth, 2012-2014. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses…………………….……….. 123

Table 4.10. Mean of β–glucosidase reaction at 0-15 cm soil depth, 2012-2014. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses……………..…………….……… 124

Table 4.11. Mean of permanganate oxidizable carbon (POXC) at 0-15 cm soil depth, 2012-2014. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses. Samples were taken at planting in spring and at harvest in autumn………………………….. 124

Table 4.12. Mean of total organic nitrogen (TON), total organic carbon (TOC) and C/N ratio at 0-15 cm soil depth, 2012-2014. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses……...…… 125

Table 4.13. Mean of aggregate stability at 0-15 cm soil depth, 2012-2014. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses…………………………………………………………...……... 126

Table 4.14. Results of soil fertility tests including means for pH(salt), soil organic matter (SOM), neutralizable acidity (NA), cation exchange capacity (CEC), Bray I phosphorus, calcium, magnesium, and potassium…………………….......…… 127

Table 5.1. Production dates for cover crops and corn 2012-2014…………..…..…….. 145

Table 5.2. Plant density and volumetric soil moisture by treatment, 2012-2014. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses……………………………………………………………… 145

LIST OF FIGURES

Figure 2.1. Research field plot layout. Main plots are tillage and cover crop treatments (TCCP). TNCC= tilled plots with no winter cover crop. TCC= tilled with a winter cover crop that was mowed and disked under. NTCC= no-till with a cover crop that was rolled/crimped. Sub-plots were compost rates at 0= 0 compost, 1= 0.5 x the recommended rate of P fertilizer, 2= 1 x recommended rate and 3= 1.5 x recommended rate. Crops were rotated by section each year, but the main and sub-plot treatments remained in the same location throughout the three year rotation …………………………………………………..………………….. 34

Figure 2.2. Cumulative precipitation 2012-2014 compared to 30-year average cumulative precipitation for Boone County, MO …………………………………..…...…. 35

Figure 2.3. Yield of above ground biomass of winter cover crop as affected by species (CR= cereal rye, CR-HV= cereal rye/hairy vetch mix and year (2012-2014). The dashed line represents the weed suppression threshold of 8000 kg ha^{-1} (Mirsky et al., 2013) ……………………………………………………………………….. 35

Figure 2.4. Mean plant density of organic corn from 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within TCCP and year are significantly different (using Tukey’s HSD) at α=0.05. Planting population was 86,400 seeds ha^{-1} ….. 36

Figure 2.5. Mean plant density of organic soybean from 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within TCCP and year are significantly different (using Tukey's HSD) at α=0.05. Planting population was 385,300 seeds ha^{-1} … 37

Figure 3.1. Cumulative precipitation (2012-2014) compared to 30-year average cumulative precipitation for Boone County, MO……………………...……….. 71

Figure 4.1. Cumulative precipitation (2012-2014) compared to 30-year average cumulative precipitation for Boone County, MO………………………...…… 115

CHAPTER ONE

INTRODUCTION

Organic agriculture is a production system that promotes biodiversity and biological cycles and activity. It does this by using practices that are aimed at maintaining, restoring or enhancing soil, plant and environmental quality. Organic food is a consumer-driven market that has experienced an increase in retail sales from $3.6 billion in 1997 up to $21.1 billion in 2008 (Greene et al., 2009). Demand for organic products is currently greater than supply in the United States (Brat, 2015), which has led to increased funding by the United States Department of Agriculture (USDA) for research into organic production practices that may help boost yields and attract new organic producers (Greene et al., 2009).

To gain organic certification, land must be free of synthetic fertilizer or chemical inputs for three years and organic producers must follow practices determined by the National Organic Standards Board of the USDA. These practices became law in 1990 under the Organic Food Production Act. Organic standards address soil and water quality, pest control, livestock practices, and rules for food additives. Organic farms and processors are required to preserve natural resources and biodiversity and to use only approved materials. They may not use genetically modified crops or ingredients, they must receive annual onsite inspections, and they must separate organic food from non-organic food (AMS, 2014).

To enhance soil fertility and improve crop nutrient uptake, organic producers must use cover crops, compost and crop rotations. To combat pests such as weeds or insects, they must use cultural, biological and physical control methods. For weed control, this generally involves tilling of the soil, which has brought criticism to the organic movement (Trewavas, 2004). Additionally, reduced yields often result from difficulty in controlling pests and meeting crop nutrient requirements under organic management practices (de Ponti et al., 2012, Walz, 2004). In a comparison of yield in organic and conventional production systems, a 17.5 kg ha^{-1} reduction in soybean yield was attributed to each 1% increase in weed cover (Cavigelli et al., 2008a).

Organic certification requires that producers use practices that enhance or maintain soil quality. Soil quality is a composite view of the soil's physical, chemical and biological properties and processes that sustain productivity, environmental quality and support a fully functional biological system (Doran and Zeiss, 2000). Measurable soil properties can be used to quantify management effects on soil function. These soil quality indicators can include SOC levels, aggregate stability, soil enzyme activity, soil microbial biomass and activity, pH, soil nutrient availability, bulk density and water holding capacity (Andrews et al., 2004, Wienhold et al., 2004). Although research on soil quality in organic systems is not uncommon (Liebig and Doran, 1999, Wander et al., 1994, Martini et al., 2004, Bulluck et al., 2002, Fließbach et al., 2007), many studies compare soil quality in organic production to that of conventional management systems. Fewer studies have examined the effects on soil quality indicators of different types of organic management and almost no studies have measured soil quality in organic no-till (Carr et al., 2013a). Because organic certification is based on organic standards defined by U.S. law, it is important to elucidate which practices in organic production are best at maintaining, restoring or enhancing soil, plant and environmental quality. For economic survival of organic producers, soil quality should also be set in the context of improved productivity and yield.

Improving plant health through soil health and fertility is a major goal of organic production and should be emphasized in a weed management system. However, most organic producers continue to manage weeds through multiple tillage and cultivation practices (Walz, 2004). Organic growers often use a stale seedbed method of pre-plant weed control that utilizes several primary tillages followed by two or three rotary hoeings, as well as two or three cultivations between rows to keep weeds in check (Place et al., 2009). Tillage leads to soil organic carbon (SOC) loss due to oxidation or mineralization, leaching and translocation, and accelerated erosion (Lal, 2002). Tillage reduces crop residue by increasing the rate of microbial breakdown via residue burying (Doran, 1987). Soil organic carbon is one of the most important constituents of the soil due to its capacity to affect plant growth as both a source of energy for microorganisms and a trigger for nutrient availability through mineralization (Anderson and Domsch, 1985). A direct effect of decreased SOC is reduced microbial biomass and activity, and reduced nutrient mineralization due to a shortage of energy sources. Aggregate stability, airflow, and water infiltration and movement may also be reduced when SOC drops.

Because of these negative effects on soil, tillage of conventional agricultural land has decreased over the past decade and has been replaced by reduced or no-till management in many areas of the Midwest (Archer et al., 2007, Teasdale et al., 2007). Approximately 42% of conventional farms have adopted some form of no-till (ARMS, 2011), while only about 27% of organic farms employ no-till or minimal tillage (USDA-NASS, 2010). Benefits of no-till include higher soil water availability (MacKenzie et al.,

1997) and improved soil microbial biomass and activity (Berner et al., 2008). Soils in no-till systems often accumulate carbon while soils in conventional tillage may not. An organic system with a winter cover crop and tillage accumulates less carbon than no-till and more carbon than a conventional system (Robertson et al., 2000).

A major priority identified for improving the performance of organic production is to determine how organic farming can conserve soil organic matter, build soil quality, reduce erosion, and contribute to C sequestration (Sooby et al., 2007). Sequestration of C requires decomposition and retention of C in soil as humus fractions (Janzen, 2006). A major concern is that many of the benefits of carbon sequestration that occur by utilizing cover crops and compost in organic production are lost when the soil is tilled (Lal, 2002, Abiven et al., 2009, Gomiero et al., 2011).

Recently, studies have examined using no-tillage into cover crop residue to reduce soil erosion, provide nitrogen for a non-leguminous crop, and provide weed control in organic production (Mirsky et al., 2012, Mirsky et al., 2013, Bernstein et al., 2011). If enough biomass is produced by the cover crop, the unincorporated residue in a no-till, cover crop system reduces early weeds while minimizing the need for cultivation (Teasdale et al., 2012). Cover crops, such as winter rye (*Secale cereal* L.) and hairy vetch (*Vicia villosa* Roth), can often sufficiently smother weeds for the critical six weeks after termination, giving the grain crop a chance to outgrow yield limiting weeds (Teasdale and Rosecrance, 2003). If insufficient biomass is produced by the cover crop, a significant increase in weed interference under no-till organic production has been observed (Cavigelli et al., 2008a). Cover crops in organic no-till are usually terminated either by flail or sickle mowing or using a roller crimper to roll over the cover crop, thus breaking the plant’s stalk at its base and creating a thick mat (Smith et al., 2010, Bernstein et al., 2011).

Cover crops are not only a necessary component of weed control in organic no-till, but they also provide a host of ecosystem services including reduced erosion (Langdale et al., 1991), water conservation (Bristow, 1988), increased microbial population and activity (Harris et al., 1994), and reduced fluctuations in soil temperature (Fortin and Pierce, 1991). Management practices that employ cover crops can improve soil quality through additions of vegetative residues that promote microbial biomass and activities involved in decomposition, leading to increased carbon retention in soils (Gomiero et al., 2011, Drinkwater and Snapp, 2007).

In addition to increasing SOC levels, cover crops may also alter soil physical properties. Cover crops grown for four years as part of a corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] rotation on a silt loam in Illinois increased soil aggregate stability, total porosity, and plant available water compared with plots grown without cover crops (Villamil et al., 2006). In a 17-year study on a silt loam and loam in Arkansas, cover crops increased hydraulic conductivity and water holding capacity and reduced bulk density (Keisling et al., 1994). Folorunso et al. (1992) reported reduced soil penetration resistance and increased infiltration after five years of cover crop usage in a conventional tilled system in California. Utilizing legume cover crops can be particularly important during the conversion from conventional to low input systems such as organic farming (Liebhardt et al., 1989).

Legume cover crops such as hairy vetch produce an abundance of dry matter and can fix from 56 to 168 kg N ha^{-1}, which provided all or most of the required N for the cash crop (Reinbott et al., 2004, Sainju et al., 2005). If annual legumes do not produce enough biologically fixed nitrogen to meet the needs of the succeeding crop, a non-expensive alternative, such as compost, must be used. Research from Florida demonstrates that either large quantities of compost (45-67 MT ha^{-1}) or the incorporation of a summer legume such as sunn hemp (*Crotalaria junicea*) is required to maximize tomato (*Solanum lycopersicum* L.) yields (Wang et al., 2008).

The combination of cover crops and manure or compost used in organic production has been found to improve some soil quality indicators. A long-term study that tracked SOC reported that over the 22-year study period SOC increased under manure- and legume-based organic grain cropping by 28 and 15%, respectively, compared with only 9% for conventional systems (Hepperly et al., 2006). Increased organic matter in the manure and legume systems translated to 25% higher plant available water holding capacity, thereby avoiding yield losses due to drought stress and reducing soil erosion. Increases in SOC were also noted for soils after 15 years of a corn-soybean rotation integrated with legume cover crops or annual applications of manure compared to soils under inorganic fertilization (Drinkwater et al., 1998).

Organic grain crop systems often utilize composted manures to provide other essential nutrients such as phosphorus, potassium, sulfur and micronutrients. A yearly application of compost is required because available N in compost is only 5-15% available each year, requiring multiple years of compost addition before an adequate amount of N is available for plant uptake (Heckman et al., 2009). A problem associated with using composted manures for the entire N requirement is that excessive levels of P can build up, causing pollution problems within watersheds. As a result, manure applications in Missouri and elsewhere are based upon soil P levels. If compost is applied on a P basis, then N levels may be insufficient for adequate crop growth. If either method is used over a long period, it can result in a severe imbalance of one or both nutrients (Eghball and Power, 1999b). Surveys of organic farmers indicate that soil fertility is the biggest challenge in organic grain production after weed control (Walz, 2004). In addition to improving soil nutrient status, composted manures can provide benefits to soil quality including increases in surface C and N concentrations (Eghball, 2002), and increased soil pH and cation exchange capacity (Ouédraogo et al., 2001). Compost can also decrease bulk density and penetration resistance, and increase aggregate stability, porosity, water holding capacity, and infiltration rate (Cogger, 2005, Khaleel et al., 1981, Martens and Frankenberger, 1992, Giusquiani et al., 1995).

The objectives of the studies in this dissertation were to quantify soil quality indicator levels under contrasting organic practices and to provide scientific information that can lead to development of best management practices for organic no-till and transitioning to organic production. Chapter two describes research to determine the effects of three organic production systems and four poultry compost rates on crop yield and SOC on a claypan soil. Organic no-till was compared to a tilled organic system using a winter cover crop and to a system using tillage and no winter cover crop. Chapter three discusses the soil quality levels measured in the same three organic production systems. Chapter four investigates soil quality and yield in seven different rotational systems that could be used during the three year transition to organic production and chapter five describes the effects of planting timing and cover crop termination method on corn germination and emergence in organic no-till.

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CHAPTER TWO

CORN, SOYBEAN AND WHEAT PRODUCTION ON A CLAYPAN SOIL USING CONVENTIONAL ORGANIC AND ORGANIC NO-TILLAGE PRACTICES

Abstract

Organic crop production is dependent on tillage for weed control, but because tillage can lead to decreased levels of soil organic carbon (SOC) alternative management needs to be explored. This study was conducted in Boone County, MO in a Mexico silt loam soil (fine, smectitic, mesic Vertic Epiaqualfs) in 2012-2014 to determine the effects of three organic production systems and four poultry compost rates on crop yield and SOC on a claypan soil. Organic no-till was compared to a tilled organic system using a winter cover crop and to a system using tillage and no cover crop in a wheat (*Triticum aestivum* L.)-corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation. Cover crops included cereal rye (*Secale cereale* L) and hairy vetch (*Vicia villosa* L.). Achieving a cover crop biomass sufficient for weed suppression was a challenge when soil fertility declined during the study. Corn yield was reduced 30% in 2013 in no-till plots compared to tilled although plant populations were nearly equal, indicating the N tie-up may be significant in crimped cover crops. Soybean grown after cover crops yielded less in the 2012 drought than when no cover crop was grown. When there was adequate soil moisture and weed control from the cover crop, soybean grown under organic no-till was competitive with tilled treatments. Optimum timing of cover crop crimping for acceptable weed control was more successful in a soybean production system compared with corn. Also, organic no-till in this study was more successful in soybean and wheat than in corn when the cover crop biomass was sufficient to suppress weeds.

Keywords: organic grain production, organic no-till, corn, soybean, wheat, cover crop, rye, hairy vetch, soil organic carbon, claypan.

Abbreviations: ONT, organic no-till; TCCP, tillage/cover crop practice; NTCC, no-till with cover crop; TCC, tillage with cover crop; TNCC, tillage without cover crop; SOC, soil organic carbon; C, carbon; N, nitrogen; RCBD, randomized complete block design; P, phosphorus; K, potassium; DM, dry matter. CR, cereal rye; HV, hairy vetch

Introduction

A relatively new organic production practice is the use of no-till planting into rolled/crimped cover crop residue to provide weed control and reduce soil erosion and soil organic carbon (SOC) loss (Mirsky et al., 2011, Carr et al., 2013a, Teasdale et al., 2007, Mischler et al., 2010a). This system is still in its infancy and many questions remain unanswered on its efficacy and viability. Unincorporated residue from a cover crop such as winter rye (*Secale cereal* L.) provides early season weed control, giving the grain crop a chance to outgrow yield limiting weeds (Teasdale et al., 2012, Mirsky et al., 2011). Cover crops inhibit weed germination and growth through allelopathy or physical suppression through resource competition (Creamer et al., 1996). To be successful for early season weed control, cover crops must be completely killed before commercial crop planting (Mischler et al., 2010a). In organic no-till (ONT) this is usually done with a roller/crimper and may require multiple passes with the roller to sufficiently kill the cover crop (Wayman et al., 2014).

Tillage is currently a primary weed control method in many organic production systems (Guthman, 2000, Bond and Grundy, 2001) and may lead to SOC loss due to oxidation or mineralization, leaching and translocation, and accelerated erosion (Lal, 2002, Doran, 1987). SOC is one of the most important constituents of soil due to its capacity to affect plant growth as both a source of energy for microorganisms and a trigger for nutrient availability through mineralization (Anderson and Domsch, 1985). SOC also increases crop yield by increasing plant available water content and enhancing soil structure (Lal, 2006). Continuous cropping, complex crop rotations and reduced tillage can all lead to increased C sequestration in soil (West and Post, 2002, Sherrod et al., 2003). Although organic production systems have been found to increase SOC pools over conventional tilled systems (Wander et al., 1994, Liebig and Doran, 1999), an organic system with a winter cover crop and tillage may accumulate less carbon in surface soils than a conventional no-till (NT) system (Robertson et al., 2000, Jokela et al., 2011). Sequestration of C in a no-till system is generally attributed to reduced tillage while in a tilled organic system it is generally attributed to increased plant biomass from a winter cover crop or animal manure additions. When coupled with a cover crop and manure additions, an organic reduced tillage system can sequester increased SOC over a NT system after several years (Teasdale et al., 2007). This highlights the importance of organic systems that utilize reduced tillage or no-tillage in improving soil quality and the sustainability of organic production.

Yield results in ONT are varied and largely dependent on both past production history and cover crop biomass production. At the Rodale Institute in PA, improved hairy vetch (*Vicia villosa* Roth) cover crop stands and a previous history of compost additions, cover cropping and diverse crop rotations likely contributed to ONT corn (*Zea mays* L.) yields of 7 to 10 Mg ha^{-1} compared to other research sites in the same study with corn yields as low as 1.1 to 3.4 Mg ha^{-1} (Mischler et al., 2010a). The lower yields were also attributed to reduced biomass of the cover crop and incomplete kill of the hairy vetch using a roller/crimper. Although the rye mulch treatment effectively suppressed early season weeds in North Carolina, rye regrowth competed with soybean (*Glycine max* L.) to reduce crop yield by 24% in ONT treatments compared to tilled (Bernstein et al., 2011). Corn yield in Iowa was reduced up to 92% in ONT compared to organic tilled when low precipitation, competition from the cover crop and possible N immobilization led to reduced plant stands and smaller no-till corn plants (Delate et al., 2012). Soybean yields were not as negatively affected by production practice, but still had an average yield of 2.8 Mg ha-1 in ONT compared to 3.2 Mg ha-1 in tilled treatments. Several studies stress that factors affecting ONT success include adequate soil fertility, optimal performance of the cover crops, and control of low weed populations (Carr et al., 2013b, Mirsky et al., 2012, Teasdale et al., 2012).

Adequately fertilized soil will not only improve crop growth but may also lead to increased cover crop growth and weed control in ONT (Mirsky et al., 2011, Ryan et al., 2011b). In this latter study, increased addition of poultry litter led to increased rye biomass while increasing the rye seeding rate did not increase rye biomass production. However, at high fertility rates, increasing rye seeding rate decreased weed biomass. It was speculated that early ground cover from the cover crop may be the most important driver of weed suppression. Very little research has been aimed at investigating fertility issues in ONT.

It has also been suggested that soil taxonomy could be a factor in attaining consistent crimping of the cover crop with reduction of competition to the commercial crop and that the sandier soils of the mid-Atlantic regions might be more amenable to crimping than silty clay loam soils in Iowa (Delate et al., 2012). Soils with high clay content are extensive in the central Midwest with nearly 4 million hectares designated the Central Claypan Region (USDA-NRCS, 2006). These soils are characterized by very slow permeability, restricted root penetration, low natural fertility, and varying topsoil thickness (Jamison et al., 1967, Kitchen et al., 1999). Claypan soils are prone to structural degradation by compaction induced by farm equipment, although this may be mediated through additions of organic amendments such as poultry litter (Pengthamkeerati et al., 2011). No previous studies have been published on the efficacy of ONT in claypan soils.

The objective of this research was to determine the effects of three organic production systems and four poultry compost rates on crop yield and SOC on a claypan soil. Organic no-till was compared to a tilled organic system using a winter cover crop and to a system using tillage and no winter cover crop. We hypothesized that cover crops, reduced tillage and increased compost would increase SOC, and that yield in ONT would equal or exceed yield in the two tilled systems.

Materials and Methods

Research Site and Design

This research was conducted from 2012-2014 at the University of Missouri Bradford Research Center (BREC), located in Boone County, 8 kilometers east of Columbia, MO. Soils at this site are primarily Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualfs) and are on the central glacial till claypan plain. This site has an argillic horizon, which is a claypan, typically 25 cm below the soil surface. This research site had previously been managed as a conventional row crop field until 2011 when organic management practices were initiated. Land used in this study was certified in organic transition by Quality Certification Services (QCS, Gainesville, FL). The research area was split into three sections (27 m x 67 m) for the three grain crops in the rotation (Figure 2.1). The crop rotation was wheat (*Triticum aestivum* L.)-corn-soybean.

Each crop section was in a randomized complete block split-plot design with main plot treatments of tillage/cover crop practice (TCCP), including tilled, no cover crop (TNCC); tilled, cover crop (TCC); and no-till, cover crop (NTCC) (Figure 2.1). TNCC treatments were tilled with no winter cover crops between grain crop sequences and were cultivated for weed control. TCC treatments utilized a winter cover crop that was mowed and incorporated with tillage followed by cultivation for weed control. NTCC utilized a winter cover crop, was planted using no-till practices, and weed control was provided by the crimped cover crop. Sub-plot treatments consisted of compost rates, which were zero compost (0x), half the recommended rate (0.5x), the recommended rate (1x), and 1.5 times the recommended rate (1.5x). A poultry compost product (Central Missouri Poultry Producers, Inc, High Point, MO) was applied in amounts based on the soil-test P recommendation (Buchholz et al., 2004) and the compost P content to prevent potential P loss. Amounts of applied compost, total P, and total N are listed in Table 2.1. Each crop section had four replications for a total of 48 plots (4.6 x 6.1 m). The TCCP and compost treatments were located in the same plot positions for the three years of the study.

Weather

Due to extreme drought in 2012, irrigation using approximately 2.5 cm of water was applied five times and occurred on 6 June, 6 and 20 July, and 3 and 17 August. The average temperature from May through September in 2012, 2013 and 2014 was 23.3 C, 21.3 C, and 21.3 C; and the total rainfall from May through September in those years was 177.3 mm, 440.9 mm, and 516.7 mm, respectively. The annual cumulative rainfall for 2012-2014 is shown in Figure 2.2 and is plotted against the 30-year average for Boone County, MO.

Equipment modification

The no-till coulters (Yetter Mfg., Colchester, IL) were removed in 2013 and 2014, which caused the planter weight to be centered on the double disk openers and allowed deeper penetration of the seed tubes through the cover crop residue. Additionally, spiked closing wheels (Schoup Mfg., Kankakee, IL) were installed on the planter to effectively close the seed-row furrow.

Crop Management

Composted turkey (*Meleagris gallopavo*) litter was broadcast surface applied by hand once annually each spring at Zadoks growth stage 24 (Zadoks et al., 1974) in winter wheat and just after winter cover crop termination in other treatments (Table 2.2). In tilled plots, the compost was incorporated into the soil and in no-till plots the compost remained on the soil surface.

Pre-plant tillage in TNCC and TCC plots was conducted using a 1.5 m wide plot disk and weed control was done using a Danish S-tine 4-row cultivator. Management dates and processes are shown in Table 2.2. Cover crops in NTCC plots were terminated at Zadoks growth stage 61 for corn (Mirsky et al., 2009) and Zadoks 68 for soybean using three passes with a roller-crimper (I&J Mfg, Gap, PA). Cover crops in TCC were first mowed with a flail mower and then disked into the soil at the same growth stage. Organic corn (Welter Seed hybrid WS2292) and soybean (Blue River Hybrids 389F.Y) were planted using a 4-row John Deere 7000 planter (Moline, IL) in 76 cm wide rows at 86,400 and 385,300 seeds ha^{-1}, respectively.

The winter cover crop (Table 2.3), cereal rye (CR), was planted before soybean, and a mixture of cereal rye and hairy vetch (CR-HV) was planted before corn. All cover crops and the organic wheat (variety “Bess”) were planted using a Tye (AGCO, Duluth, GA) no-till drill at 19 cm row spacing. Wheat was planted at 100 kg ha^{-1}. In 2012, a summer cover crop of buckwheat (*Fagopyrum esculentum* Moench) was planted in the wheat section after the wheat harvest and in 2013-2014 a cover crop mixture of sunn hemp (*Crotalaria juncea* L.) and cowpea (*Vigna unguiculata* (L.) Walp.) was planted after wheat (table 2.3).

Crop Data Collection

Field chlorophyll measurements were taken at VT stage in corn and R3 in soybean (Abendroth et al., 2011, Pedersen and Elbert, 2004) with a hand-held chlorophyll meter (SPAD-502 Chlorophyll Meter, Minolta Camera Co., Ltd., Japan). To determine cover crop yields, a 0.25 m^2 quadrat was randomly placed in two places in the plots and above-ground cover crop biomass was removed from each frame area, dried in a forced air dryer, and weights were averaged. To determine crop plant density at harvest, a 3 meter stick was randomly dropped twice next to the plant row and plants were counted and averaged. Crop treatments were harvested at physiological maturity using plot combines to harvest the middle two rows of corn and soybean and the middle 1.5 m of wheat. Corn was harvested with a two-row Kincaid research combine (Kincaid Equipment Mfg., Haven, KS) while the soybean and wheat were harvested with a Wintersteiger research combine (Wintersteiger Inc., Salt Lake City, UT) with a 1.5 m standard reel platform header. Corn moisture was determined by the combine moisture sensor (Harvest Master, Logan, UT), and yield adjusted to 155 g kg^{-1} moisture. Grain moisture for soybean and wheat was determined using a benchtop moisture meter (Dickey-John, Auburn, IL) and yields adjusted to 130 g kg^{-1} moisture for soybean and 135 g kg^{-1} for wheat. Harvest dates are shown in Table 2.2.

Soil Data Collection

For characterization of SOC, soil was collected just prior to harvest each fall using a probe with a 19.05 mm diameter to a depth of 15 cm. Eight samples were taken in a grid pattern in each plot and were composited and homogenized using a 6.35 mm sieve. SOC was determined on sieved (< 2 mm), air-dried, ground soil samples by dry combustion at 900° C using a LECO® Tru-Spec C/N Analyzer (Nelson and Sommers, 1996).

Statistical Analysis

Statistical analysis was completed with SAS Enterprise Guide 6.1 (SAS, Cary, NC). Results were analyzed using PROC MIXED at $\alpha=0.05$ by crop and year with the ANOVA run as a RCBD split-plot design. The fixed effects in the model were TCCP, compost (sub-plot factor) and TCCP*compost. The random effects were block and block*TillCC (whole plot factor). All means separation differences were tested using Tukey's HSD. Visual inspection of frequency distributions showed that normality assumptions were valid.

Results and Discussion

Cover Crop

An above-ground dry matter yield of 8000 kg ha^{-1} for winter cover crops has been identified as the threshold biomass production for consistent suppression of annual weeds in ONT (Mirsky et al., 2013). Dry matter yield of the cereal rye/hairy vetch mixture (CR-HV) in this study was 94% of the threshold in spring 2012, but was only 55% and 35% of the threshold in 2013 and 2014 (Figure 2.3). The dry matter yield of the cereal rye (CR) was 98% and 114% of the threshold in 2012 and 2013, but the yield was only 40% of the necessary biomass in 2014. Cover crop biomass was affected by the species used, fall planting date, perennial weed competition and soil fertility.

Cereal rye has been found to have the highest biomass production of winter cover crops in most agricultural regions of the U.S. (Teasdale, 1996, Delate et al., 2012, Reberg-Horton et al., 2012) and provided the best weed control in ONT (Mirsky et al., 2013, Ryan et al., 2011a). However, a mixture of cereal rye and hairy vetch may be utilized before a corn crop in ONT due to nitrogen immobilization that can occur in a pure rye stand and for the N contribution from biological nitrogen fixation by hairy vetch (Clark et al., 1994, Rosecrance et al., 2000). A problem with growing hairy vetch as a cover crop component in ONT is that it may produce lower and readily degradable biomass compared with cereal rye (Wagger, 1989) and an early fall planting for good establishment is required in many climates. The ideal planting date for hairy vetch in central Missouri is before 25 September (USDA-NRCS, 2014) but cover crops in ONT are usually drill-seeded rather than broadcasted into a standing crop to achieve optimum plant density for weed control. Planting of the cover crops was delayed until corn and soybean were harvested in the fall (Wayman et al., 2014, Bernstein et al., 2011). The CR-HV mixture used in this study resulted in biomass reductions from 4% to 52% compared to cereal rye in a pure stand (Figure 2.3).

The fall 2011 cover crop planting date was 10 and 8 days earlier than in fall 2012 and 2013 (Table 2.2) because cover crop planting in 2011 followed an early harvest of conventional soybean. Once the field was converted to organic production with a no-till component, spring planting in 2012-2014 was delayed until the cereal rye was past Zadoks growth stage 61 in the spring, which is the recommended time for cover crop crimping (Mirsky et al., 2009). In 2012 and 2013, crimping occurred in the first week of June, which is significantly later than the April 4 average date of initial spring corn planting in Missouri (Kucharik, 2008). Mischler et al (2010a) also indicated that this delay in corn planting may lead to reduced yield potential in an ONT system. Early corn planting often results in increased yields because of increased likelihood that flowering will occur before midsummer heat stress and that maturity will be reached before a killing frost in the fall (Hu and Buyanovsky, 2003). In this region, the federal crop insurance last plant date for corn to avoid coverage reductions is 31-May (USDA-RMA, 2015).

Crimping of the cereal rye cover crop before soybean planting was delayed to Zadoks growth stage 68 due to time constraints imposed by field collection of greenhouse gas samples, a research component of the overall project. Without these constraints, soybean could have been planted in early June in 2013 and 2014, well before the federal crop insurance last plant date for soybean of June 20. (USDA-RMA, 2015). Although the effect of planting date on soybean yield can vary substantially from variation in environmental conditions, relative yield responds to delayed planting with a rapid decline in yield beginning on 30 May in the Midwest (Egli and Cornelius, 2009).

By year three of the study, perennial weed species such as white clover (*Trifolium repens* L.) and curly dock (*Rumex crispus* L.) began to proliferate in the no-till plots, similar to numerous other studies assessing organic no-till (Mirsky et al., 2012, Carr et al., 2013b, Halde et al., 2015). Poor weed control combined with diminished soil fertility from three years of applying compost based on P recommendation led to cereal rye and CR-HV cover crop yields that were insufficient for annual weed control in 2014. Because cover crop biomass was well below the recommended threshold for weed suppression, yields of corn and soybean in the NTCC treatments were only 40% and 26% of the mean yields of the tilled treatments in 2014 compared to 70% and 100% in 2013 (Table 2.4). Yield reduction from insufficient cover crop biomass was also found by Delate et al. (2012). Ryan et al. (2011) confirmed that poor soil fertility is one of the primary challenges in achieving adequate cover crop biomass to suppress weeds and prevent yield reduction in an ONT system.

Corn Population and Yield

Corn population was reduced in no-till plots in 2012 and 2014 (Figure 2.4). In 2012, this was a result of poor seed to soil contact in corn planted through the thick cover crop residue resulting from high biomass produced that year. After that initial planting, the no-till coulters were removed from the planter and improved seed to soil contact was achieved in 2013 and 2014. This was in contrast to Mirsky et al. (2013), who found that a lightly fluted coulter provided the necessary residue cutting to prevent hair-pinning of residue in the seed furrow. Our success with coulter removal may be linked to planting the cash crop in the same direction that the cover crop was planted and crimped while Mirsky et al. (2011, 2009) reported crimping the cover crop and planting the cash crop perpendicular to cover crop planting direction. Removal of the coulters allowed more weight to be placed on the double disk row openers, thereby allowing deeper placement of seeds. Our successful use of a spiked closing wheel agrees with observations of Mirsky et al (2013) that a spiked or spaded closing wheel helped close the seed slit better than a solid closing wheel.

Reduced corn plant population in the TCC treatment was likely caused by interference of the macerated cover crop residue with the germinating corn seeds. This interference could have been an allelopathic effect due to allelochemical release from the decomposing rye residue (Barnes and Putnam, 1986), although this was not evident in wetter years. Interference was more likely a result of the dry cover crop residue entering the seed furrow and either causing a reduction of soil contact with the germinating crop seed or absorption by residue fragments of the small amount of soil moisture present during the harsh drought in 2012 (Figure 2.2). Several other studies have reported decreased soil to seed contact from similar residue hair-pinning (Kornecki et al., 2009, Carr et al., 2003, Luna et al., 2012). In 2014, corn populations were adversely affected in the NTCC treatment by the extremely low biomass of cover crop and subsequent suppression of corn emergence and growth by weeds. Corn plant populations did not exhibit a response to compost rate, but were adversely affected by wet, cold climatic conditions in early summer 2014.

Corn yields were lower in NTCC treatments in all years (Table 2.4). Although low populations may be partially responsible for this, there were two indications that a low population was not the sole cause of reduced yield. In 2012, TCC had very low plant population but had similar yield to the TNCC treatment, suggesting that increased N from the cereal rye cover crop as well as more resource availability per plant (water, sunlight, nutrients) may have prevented a yield reduction due to low population. Similar responses to wider between-plant spacing were described in Nelson (2014) and Kremer and Deichman (2014). Additionally, the 2013 plant population was nearly equal in the three TCCP treatments, but yield was reduced by 30% in NTCC compared to the average of the two tilled treatments. This was likely due to N deficiency. Compost in the tilled treatments was disked into the soil, making it readily available for microbial transformation to inorganic forms of N. However, compost in the NTCC was placed on top of the crimped cover crop, possibly leading to slower mineralization of N and slower plant uptake leading to reduced plant growth. Although previous research found that surface applied compost in a no-till system did not affect corn yield when compared to incorporated compost (Eghball and Power, 1999a, Singer et al., 2004), SPAD readings taken at the VT stage of corn showed that NTCC corn had a significantly lower reading of 32 SPAD units compared to 39 in TNCC corn and 40 in TCC corn. The cover crop residue in NTCC remained intact, was very slow to break down and likely immobilized nutrients compared to the cover crop in the TCC treatment. The TCC treatment was mowed/chopped into small pieces and incorporated into the soil, leading to more rapid microbial transformation and availability of nutrients assimilated by the cover crop during its growth. Our data confirm previous work by Wells et al. (2013) that nitrogen immobilization could result from a crimped rye cover crop.

Increased compost rate resulted in increased yield because crop N needs were being supplied solely by compost additions and the hairy vetch cover crop. In 2012, only the 0x compost rate had reduced yield, probably due to the high fertility of the soil following the completion of conventional production. The mean corn yield in the TNCC treatment at 1.5x compost rate from 2012-2014 was 5.1 Mg ha^{-1} compared to 9.3 Mg ha^{-1} in non-organic plots at the same location (Wiebold et al., 2014a). This 55% yield decrease was likely a result of low fertility in the organic field and an indication that compost application based on P levels does not provide adequate fertility to organic corn.

A trend towards higher yields in the TCC treatments compared to TNCC indicates that the hairy vetch in the winter cover crop may have been providing additional N for corn growth. Late planting dates may also have contributed to lower yields in organic corn.

Soybean Population and Yield

Soybean plant population showed a decrease in NTCC only in 2014, when limited cover crop growth led to very high weed density (visual observation) and inhibition of soybean germination, emergence and growth (Figure 2.5). In 2013, soybean showed a similar population reduction as corn in 2012 in the TCC treatment. Although adequate moisture was available at planting in 2013, the mowed cover crop residue apparently physically interfered with seed to soil contact when cover crop biomass levels were high. The lack of response in TCC in 2014 was likely a result of a much lower cover crop biomass levels compared to 2013.

Soybean yield was not affected by compost rate except in 2014, but this was likely an indirect effect due to lower compost rates reducing cover crop growth, which led to reduced weed suppression and reduced soybean yield from weed interference (Table 2.4). In 2012, soybean in TNCC yielded higher than the tilled and no-till treatments that utilized cover crops, possibly because deep soil moisture was reduced by cover crop growth and was not replenished during the severe drought that year. This theory is supported by research in North Carolina showing that in a dry year, soil moisture at soil depths below 20 cm was less in a NT treatment with rye than in a tilled treatment (Bernstein et al., 2011). Although soybean plant populations were not measured in 2012, visual clues that would otherwise explain the yield decrease in cover crop plots were not observed. In 2013, NTCC soybean yielded similar to the two tilled treatments, indicating that soybean in ONT can be competitive with soybean grown in tilled production systems. This agrees with Smith et al. (2011) and Mischler et al. (2010b) who reported that soybean yield can be maintained under ONT compared to tilled production systems. In contrast, Delate et al. (2012) and Bernstein et al. (2011) showed yield reductions of soybean in ONT. Ryan et al. (2011) suggested that increasing soybean seeding rate in ONT above normally recommended levels may further contribute to establishment and yield success of soybean in ONT.

Additionally, mean soybean yield in the TNCC treatment across all compost applications (2.9 Mg ha^{-1}) was nearly equivalent to yields of conventionally produced soybean (3.1 Mg ha^{-1}) at the same location (Wiebold et al., 2014c). This indicated that fertility was less limiting in organic soybean than in organic corn. Organic soybean competed equally with conventionally grown soybean when weeds were controlled.

Wheat Yield

Wheat in the study received all N from compost additions resulting in increased yields with increased compost amounts in 2012-2013. Although yields generally increased with increased compost amounts in 2014, yields were not significantly different. The mean wheat yield in a non-organic variety trial during 2012-14 at the same location was 3.7 kg ha^{-1} (Wiebold et al., 2013b). Wheat yield was 5% and 11% higher than in the organic TNCC treatment at 1.5x and 1x compost rates, indicating that compost application based on P levels may not provide adequate fertility for acceptable organic wheat production.

Wheat yields responded to TCCP only in 2013, when the NTCC treatment yielded significantly lower than the two tilled systems. This resulted when the crimped cereal rye from the previous year reseeded and established in the following wheat crop. This confirms the assumption by Wayman et al. (2014) that cover crops allowed to mature to the point of producing seed can become a weed in the subsequent crop. Producers who use cereal rye and wheat in their rotations should be wary of this problem and all cereal rye should be terminated well before producing viable seed. Crimping requires that rye reach Zadoks growth stage 61 (Mirsky et al., 2009), which can be a challenge in an organic no-till system that includes wheat because of the likelihood that some rye will set seed before the cover crop is crimped.

Soil Organic Carbon

Although we expected that treatments with tillage would negatively affect SOC compared to no-till, this generally did not occur (Table 2.5). Although there was some response of SOC to TCCP, no discernable patterns could be seen. In 2012 in soybean, SOC was higher in TCC than in TNCC or NTCC but in 2014 it was higher in NTCC than the two tilled treatments. This lack of response to tillage may have been due to the low number of tillage events we conducted. Our field started with very low weed population density, which remained low in 2013 due to drought in 2012. In 2014, weed pressure was high in the NTCC treatment, but still fairly low in the two tilled treatments (visual observation). The short-term nature of the experiment may also affect SOC results. Cover crop breakdown was slow in the NTCC treatment so the effects from increased residue might not be evident after only a few years. This was confirmed by several studies showing that changes in SOC were relatively insensitive to short-term management changes (Weil et al., 2003, Lefroy et al., 1993). Compost application, which is a direct addition of decomposed organic material, did lead to slightly increased SOC levels in corn in 2012 and in soybean in 2013 and 2014. SOC was higher in the two cover crop treatments in wheat in 2013, which was most likely due to the presence of increased residue biomass from high amounts of rye growing in the wheat.

Conclusion

Although it was suspected that ONT might be very challenging in a claypan soil, partial success indicates that organic producers in high clay soils may be able to utilize this production system as part of an overall effort to control weeds while reducing tillage. Although we saw potential in an organic no-till production system, its efficacy at weed suppression was heavily dependent on the health and growth of the cover crop. If soil fertility is low, cover crop growth will not be sufficient for weed suppression and yields will be negatively impacted. Cover crop growth was also highly dependent on climatic conditions, a notoriously difficult-to-predict production factor. Additionally, the longer a system was in ONT the more likely that perennial weeds became problematic. Perennial weeds were not affected by the roller/crimper and if they emerge prior to or during cover crop growth, tillage to break their life cycle may be required. Hairy vetch used in the winter cover crop was difficult to kill with crimping and required three passes with the crimper to achieve adequate control. Planting through the cover crop residue was a significant production challenge and might require equipment modifications. Because soybean is planted at a much higher rate and is less affected by reduced plant population than corn, lower seed germination did not affect final yield as much as it did in corn, which was severely impacted by organic no-till production in this study. Delayed planting while waiting for the cover crop to reach the proper stage for crimping coupled with reduced nitrogen availability to corn in ONT make it questionable that corn can successfully be integrated into an ONT system. Timing of cover crop crimping is better suited for a soybean production system. Wheat in an ONT system can be impacted by self-seeding of cover crops that are crimped after reaching reproductive growth stages. This may cause wheat to be unmarketable due to contamination of the harvested grain. Corn and wheat yields were reduced by basing compost application on P needs. Growing a cover crop at the biomass level needed for ONT may have repercussions for a producer who later decides to disk in the cover crop. High cover crop biomass would necessitate mowing before disking but mowing may lead to reduced soil to seed contact from physical interference from cover crop residue, which might be ameliorated with higher crop seeding rates. However, given the difficulty of attaining high cover crop biomass, this may be an unlikely scenario.

Because weed suppression is dependent on the biomass of cover crop produced, further study is recommended on fertility requirements of the cover crop to achieve ideal cover crop growth for increased weed suppression. Depending on weather conditions, the crimped cover crop may also decompose enough during the growing season to allow germination of weeds. Thus further study is needed on mid- to late-season weed control in an organic no-till production system. Mirsky et al. (2012) has proposed a management system termed “cover crop-based organic rotational no-till” in which some tillage is done prior to cover crop seeding to control perennial weeds and to optimize cover crop establishment. A producer might reduce risk by following this suggested rotational no-till system or by incorporating no-till soybean or wheat into an organic production system using hairy vetch for fertility and tillage for weed control during the corn production phase of the rotation.

Acknowledgements

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Figure 2.1. Research field plot layout. Main plots are tillage and cover crop treatments (TCCP). TNCC= tilled plots with no winter cover crop. TCC= tilled with a winter cover crop that was mowed and disked under. NTCC= no-till with a cover crop that was rolled/crimped. Sub-plots were compost rates at 0= 0 compost, 1= 0.5 x the recommended rate of P fertilizer, 2= 1 x recommended rate and 3= 1.5 x recommended rate. Crops were rotated by section each year, but the main and sub-plot treatments remained in the same location throughout the three year rotation.

Crop Section 1			Crop Section 2			Crop Section 3		
2012	2013	2014	2012	2013	2014	2012	2013	2014
Wheat	Corn	Soybean	Soybean	Wheat	Corn	Corn	Soybean	Wheat

Crop Section 1

▨ 1412 0	▨ 1411 1	░ 1410 1	░ 1409 2	□ 1408 2	□ 1407 3
▨ 1401 3	▨ 1402 2	░ 1403 0	░ 1404 3	□ 1405 1	□ 1406 0
□ 1312 2	□ 1311 3	▨ 1310 1	▨ 1309 0	░ 1308 0	░ 1307 2
□ 1301 0	□ 1302 1	▨ 1303 3	▨ 1304 2	░ 1305 1	░ 1306 3
░ 1212 1	░ 1211 0	□ 1210 0	□ 1209 3	▨ 1208 2	▨ 1207 1
░ 1201 2	░ 1202 3	□ 1203 1	□ 1204 2	▨ 1205 3	▨ 1206 0
▨ 1112 3	▨ 1111 2	░ 1110 2	░ 1109 1	□ 1108 1	□ 1107 0
▨ 1101 0	▨ 1102 1	░ 1103 3	░ 1104 0	□ 1105 2	□ 1106 3

Crop Section 2

□ 2412 3	□ 2411 2	░ 2410 0	░ 2409 3	▨ 2408 1	▨ 2407 0
□ 2401 0	□ 2402 1	░ 2403 1	░ 2404 2	▨ 2405 2	▨ 2406 3
░ 2312 1	░ 2311 2	□ 2310 3	□ 2309 0	▨ 2308 0	▨ 2307 1
░ 2301 0	░ 2302 3	□ 2303 2	□ 2304 1	▨ 2305 3	▨ 2306 2
□ 2212 0	□ 2211 1	▨ 2210 3	▨ 2209 2	░ 2208 1	░ 2207 3
□ 2201 2	□ 2202 3	▨ 2203 1	▨ 2204 0	░ 2205 0	░ 2206 2
▨ 2112 0	▨ 2111 1	░ 2110 1	░ 2109 2	□ 2108 2	□ 2107 3
▨ 2101 3	▨ 2102 2	░ 2103 0	░ 2104 3	□ 2105 1	□ 2106 0

Crop Section 3

░ 3412 1	░ 3411 0	▨ 3410 2	▨ 3409 1	□ 3408 0	□ 3407 3
░ 3401 2	░ 3402 3	▨ 3403 3	▨ 3404 0	□ 3405 1	□ 3406 2
□ 3312 0	□ 3311 1	░ 3310 3	░ 3309 0	▨ 3308 2	▨ 3307 3
□ 3301 3	□ 3302 2	░ 3303 2	░ 3304 1	▨ 3305 1	▨ 3306 0
▨ 3212 2	▨ 3211 0	□ 3210 0	□ 3209 1	░ 3208 3	░ 3207 2
▨ 3201 3	▨ 3202 1	□ 3203 3	□ 3204 2	░ 3205 1	░ 3206 0
▨ 3112 1	▨ 3111 2	░ 3110 3	░ 3109 0	□ 3108 0	□ 3107 1
▨ 3101 0	▨ 3102 3	░ 3103 2	░ 3104 1	□ 3105 3	□ 3106 2

□ TNCC = till, no cover crop	0= 0x compost
░ TCC = till with cover crop	1= 0.5x compost
▨ NTCC = no-till with cover crop	2= 1x compost
	3= 1.5x compost

Figure 2.2. Cumulative precipitation 2012-2014 compared to 30-year average cumulative precipitation for Boone County, MO

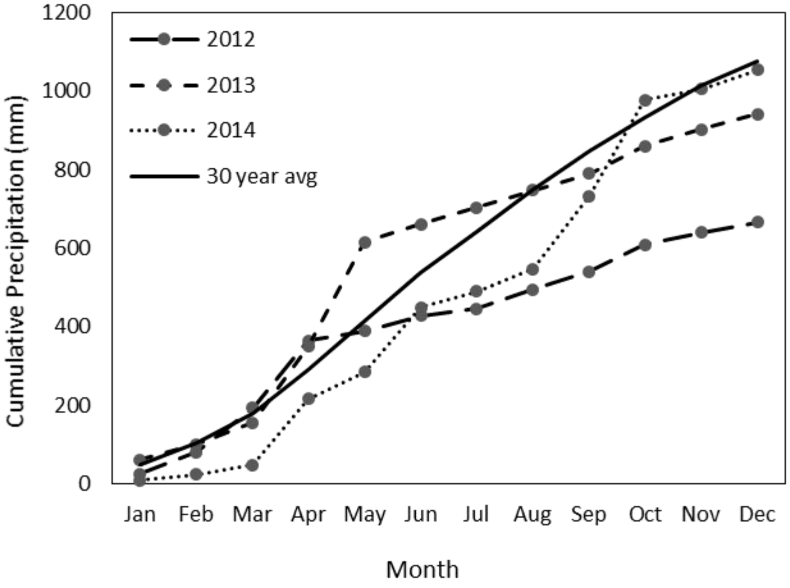

Figure 2.3. Yield of above ground biomass of winter cover crop as affected by species [CR= cereal rye, CR-HV= cereal rye/hairy vetch mix and year (2012-2014)]. The dashed line represents the weed biomass suppression threshold of 8000 kg ha^{-1} in Pennsylvania (Mirsky et al., 2013).

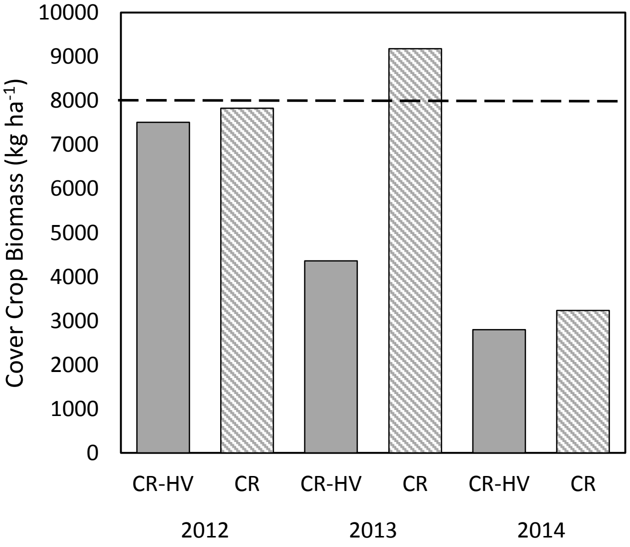

Figure 2.4. Mean plant density of organic corn from 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within TCCP and year are significantly different (using Tukey's HSD) at α=0.05. Planting population was 86,400 seeds ha^{-1}.

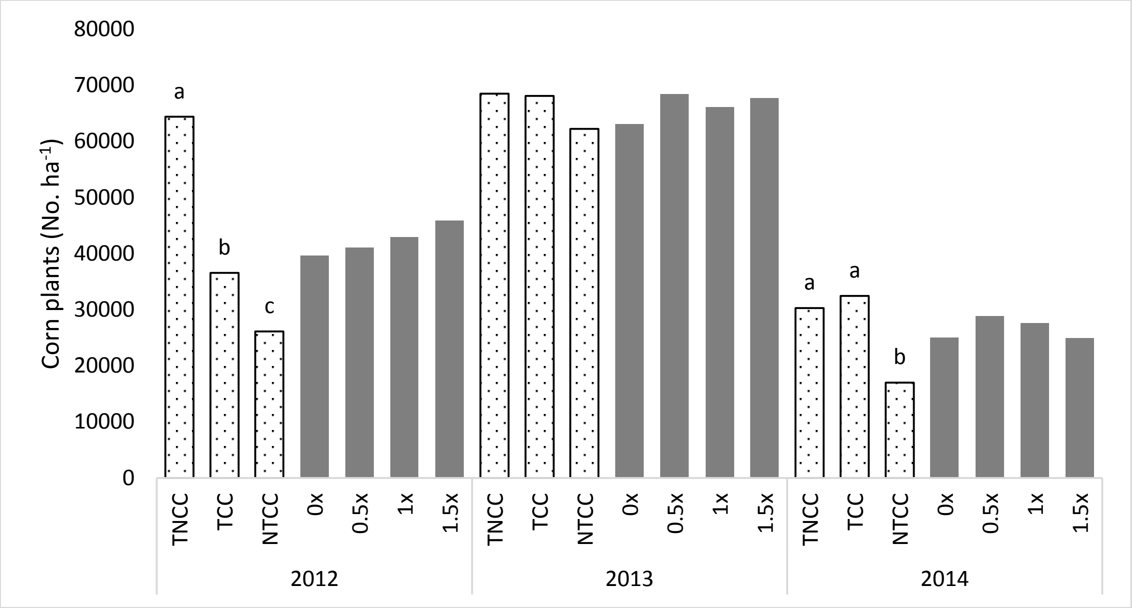

Figure 2.5. Mean plant density of organic soybean from 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within TCCP and year are significantly different (using Tukey's HSD) at α=0.05. Planting population was 385,300 seeds ha^{-1}.

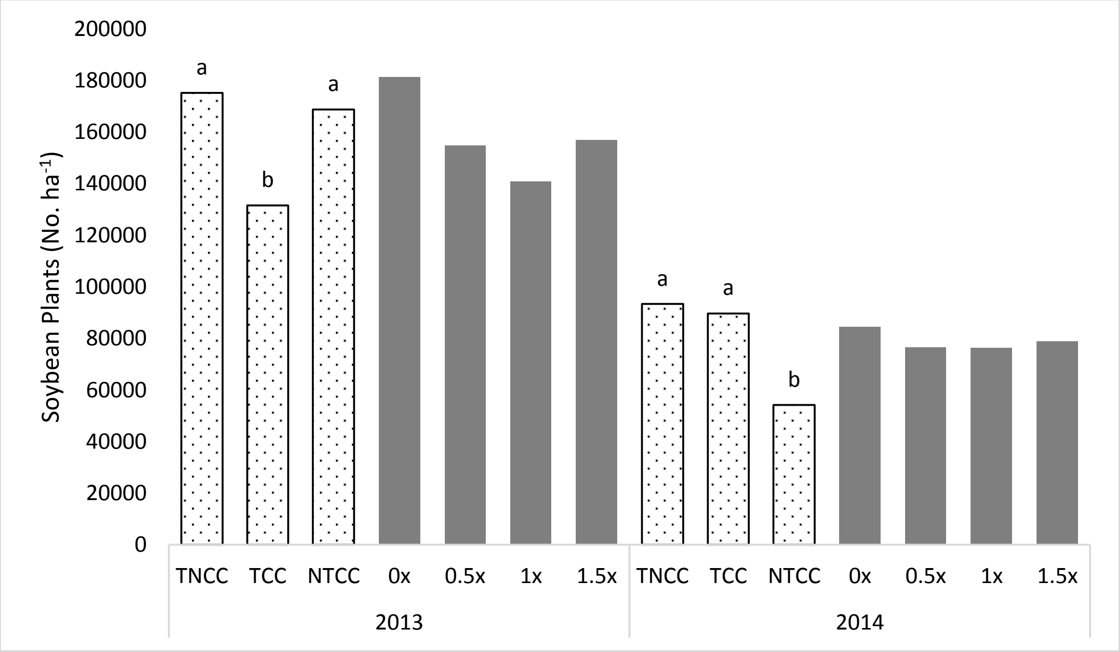

Table 2.1. Compost applied per compost treatment (0x, 0.5x, 1x, 1.5x recommended rate) for corn, soybean, and wheat from 2012-2014. Compost application was based on yield goal, soil test P fertilizer recommendations and P content of compost.

Crop	Year	Compost treatment	Compost applied	Total P	Total N
			———kg ha^{-1} yr^{-1}———		
Corn	2012	0x	0	0	0
		0.5x	3528	71	106
		1x	7000	140	211
		1.5x	10528	211	316
	2013	0x	0	0	0
		0.5x	3714	71	74
		1x	7368	140	148
		1.5x	11082	211	222
	2014	0x	0	0	0
		0.5x	4341	83	122
		1x	8681	165	243
		1.5x	13022	248	365
Soybean	2012	0x	0	0	0
		0.5x	2520	50	76
		1x	5040	101	151
		1.5x	7560	151	227
	2013	0x	0	0	0
		0.5x	2652	50	74
		1x	5305	101	148
		1.5x	7958	151	222
	2014	0x	0	0	0
		0.5x	2713	52	76
		1x	5426	103	152
		1.5x	8139	155	227
Wheat	2012	0x	0	0	0
		0.5x	2240	45	67
		1x	4480	90	134
		1.5x	6720	134	202
	2013	0x	0	0	0
		0.5x	2358	45	66
		1x	4716	90	131
		1.5x	7074	134	197
	2014	0x	0	0	0
		0.5x	2035	39	57
		1x	4070	77	114
		1.5x	6105	116	171

Table 2.2. Planting, fertilizing, cultivation, harvest, and termination dates for corn, soybean, wheat, and cover crops 2012-2014.

Crop	Year	Planting Date	Compost Application Date	Cultivation Date	Harvest or Termination Date
Cover Crops	2011	8-Oct			
	2012	19-Oct			22-May (corn), 28-May (soybean)
	2013	17-Oct			3-Jun (corn), 11-Jun (soybean)
	2014				4-Jun (corn), 16-Jun (soybean)
Wheat	2011	8-Oct	27-Mar		8-Jun
	2012	19-Oct	25-Apr		3-Jul
	2013	14-Oct	16-Apr		30-Jun
Corn	2012	23-May	22-May	21-Jun	16-Oct
	2013	4-Jun	5-Jun	28-Jun	17-Oct
	2014	5-Jun	3-Jun	19-Jun, 2-Jul	8-Oct
Soybean	2012	29-May	29-May	21-Jun	17-Oct
	2013	12-Jun	11-Jun	11-Jul	14-Oct
	2014	16-Jun	15-May	2-Jul, 29-Jul	21-Oct

Table 2.3. Seeding rates, seasons and varieties of cover crops. VNS= variety not stated.

Crop	Season	Variety	Seeding rate
			kg ha^{-1}
Cereal Rye (*Secale cereale* L.)			
Winter cover crop mix	winter	VNS	130
Hairy vetch (*Vicia villosa* Roth)	winter	VNS	30
Cereal rye	winter	VNS	100
Buckwheat (*Fagopyrum esculentum* Moench)	summer	VNS	67
Summer cover crop mix	summer		40
Sunn hemp (*Crotalaria juncea* L.)	summer	VNS	17
Cowpea (*Vigna unguiculata* (L.) Walp.)	summer	Iron and clay	67

Table 2.4. Mean yield of organic corn, soybean and wheat from 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5 x= 1.5x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column, row and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

		2012				2013				2014			
		TCCP											
crop	compost	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean
		Mg ha^{-1}											
Corn	0x	4.25 (0.50)	4.62 (0.25)	1.43 (0.17)	3.43b	2.98 (0.44)	4.11 (0.28)	0.86 (0.50)	2.65d	0.68 (0.20)	2.62 (0.36)	0.097 (0.06)	1.13b
	0.5x	5.62 (0.50)	4.92 (0.38)	3.86 (0.37)	4.80a	4.61 (0.52)	3.86 (0.36)	2.99 (0.16)	3.82c	1.53 (0.64)	2.72(0.70)	0.931 (0.36)	1.73b
	1x	4.26 (0.18)	4.59 (0.27)	4.90 (0.57)	4.58a	5.05 (0.38)	5.22 (0.38)	4.72 (0.47)	4.96b	3.34 (0.58)	3.43 (0.73)	0.87 (0.44)	2.55ab
	1.5x	3.89 (0.08)	4.71 (0.33)	4.74 (0.41)	4.45a	6.92 (0.91)	6.37 (0.44)	5.07 (0.37)	6.12a	4.37 (1.16)	2.92 (0.78)	2.55 (0.95)	3.28a
	Mean	4.50a	4.71a	3.73b		4.89a	4.89a	3.41b		2.48a	2.92a	1.09b	
Soybean	0x	2.91 (0.14)	2.32 (0.32)	2.10 (0.52)	2.44	2.37 (0.17)	2.13 (0.18)	1.75 (0.21)	2.08	2.85 (0.26)	3.03 (0.04)	0.55 (0.17)	2.15b
	0.5x	3.31 (0.22)	2.41 (0.35)	2.34 (0.42)	2.68	1.99 (0.13)	1.88 (0.17)	2.02 (0.12)	1.96	3.45 (0.38)	3.24 (.017)	0.84 (0.11)	2.51ab
	1x	3.25 (0.24)	2.77 (0.26)	2.51 (0.23)	2.84	2.35 (0.23)	1.93 (0.11)	2.48 (0.08)	2.25	3.42 (0.12)	2.82 (0.06)	0.82 (0.08)	2.35ab
	1.5x	3.26 (0.26)	2.52 (0.39)	2.20 (0.26)	2.65	2.26 (0.18)	2.26 (0.26)	2.35 (0.20)	2.29	3.49 (0.27)	3.26 (0.10)	1.08 (0.17)	2.61a
	Mean	3.17a	2.51b	2.29b		2.24	2.05	2.15		3.30a	3.09a	0.82b	
Wheat	0x	2.41 (0.09)	2.35 (0.16)	2.31 (0.11)	2.35d	2.11 (0.09)	2.70 (0.09)	2.05 (0.15)	2.32c	2.87 (0.34)	2.41 (0.43)	2.58 (0.53)	2.62
	0.5x	2.75 (0.09)	2.74 (0.09)	2.58 (0.05)	2.69c	3.30 (0.18)	3.02 (0.30)	2.84 (0.07)	3.05b	3.59 (0.20)	2.61 (0.43)	2.38 (0.18)	2.86
	1x	3.12 (0.09)	3.14 (0.17)	3.09 (0.13)	3.12b	3.67 (0.12)	4.14 (0.21)	2.98 (0.09)	3.59a	3.08 (0.29)	2.87 (0.43)	2.50 (0.16)	2.81
	1.5x	3.61 (0.12)	3.27 (0.04)	3.43 (0.07)	3.44a	4.24 (0.26)	3.92 (.037)	3.95 (0.45)	4.04a	2.74 (0.66)	2.95 (0.58)	3.32 (0.15)	3.00
	Mean	2.97	2.87	2.86		3.33ab	3.47a	2.95b		3.67	2.71	2.69	

Table 2.5. Mean of SOC at 0-15 cm soil depth, 2012-2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column or row and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started.

		Pre-study	**2012**				**2013**				**2014**			
		TCCP												
crop	compost	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean
		g kg soil^{-1}												
Corn	0x	19.7 (0.4)	20.1 (0.5)	22.1 (0.6)	21.9 (0.5)	21.3b	25.9 (1.1)	27.1 (2.8)	25.5 (0.7)	26.2	19.9 (0.8)	20.0 (0.3)	19.7 (0.4)	19.8
	0.5x		21.8 (0.4)	22.9 (0.8)	23.0 (0.5)	22.6ab	27.3 (1.3)	24.8 (0.7)	26.4 (0.9)	26.2	21.3 (0.6)	20.6 (0.7)	21.3 (1.1)	21.0
	1x		23.0 (1.1)	22.7 (0.9)	22.5 (0.7)	22.7ab	27.4 (0.8)	27.9 (2.2)	26.5 (1.1)	27.3	21.6 (1.4)	20.2 (0.7)	26.3 (4.6)	22.7
	1.5x		22.9 (0.3)	23.3 (1.4)	22.9 (0.4)	23.0a	27.6 (0.7)	27.9 (0.4)	28.4 (0.3)	27.9	21.2 (0.6)	20.3 (0.8)	20.8 (0.4)	20.8
	Mean		22.7	22.6	21.9		27.0	26.9	26.7		20.9	20.2	22.0	
Soybean	0x	22.2 (0.7)	21.0 (0.4)	22.3 (0.1)	20.6 (0.3)	21.3	23.4 (0.4)	25.2 (0.7)	24.3 (1.0)	24.3b	19.2 (0.4)	18.8 (0.6)	21.7 (0.5)	19.9ab
	0.5x		20.8 (0.4)	21.3 (0.5)	21.4 (0.6)	21.1	24.3 (0.6)	27.4 (1.2)	27.6 (0.6)	26.4ab	18.5 (0.3)	18.9 (0.3)	21.1 (0.7)	19.5b
	1x		21.1 (0.3)	22.1 (0.4)	21.3 (0.1)	21.5	27.2 (0.9)	24.9 (0.7)	27.8 (1.2)	26.8a	19.7 (1.0)	19.9 (0.9)	21.7 (0.5)	20.5ab
	1.5x		20.5 (0.4)	22.7 (0.6)	21.2 (1.5)	21.4	24.1 (0.6)	28.1 (1.2)	26.1 (0.7)	26.2ab	20.8 (0.1)	21.0 (0.7)	21.7 (0.8)	21.2a
	Mean		20.8b	22.1a	21.1b		24.8	26.5	26.4		19.5b	19.6b	21.5a	
Wheat	0x	19.8 (0.5)					23.3 (0.4)	26.5 (0.2)	26.5 (1.3)	25.4	22.2 (0.9)	20.8 (0.6)	22.8 (1.4)	21.9
	0.5x						24.8 (0.1)	26.5 (0.9)	27.9 (1.2)	26.4	21.2 (1.3)	21.5 (0.2)	21.8 (0.8)	21.5
	1x						26.0 (1.0)	28.1 (0.9)	26.0 (1.0)	26.7	22.3 (0.7)	21.7 (0.5)	22.4 (0.8)	22.1
	1.5x						25.1 (1.0)	27.8 (0.4)	28.3 (0.9)	27.1	21.6 (0.4)	22.0 (0.7)	22.7 (0.5)	22.1
	Mean						24.8b	27.2a	27.2a		21.8	21.5	22.4	

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CHAPTER THREE

SOIL QUALITY IN CONVENTIONAL TILLED AND NO-TILL ORGANIC SYSTEMS

Abstract

Organic crop production is heavily dependent on tillage for weed control, but because tillage can lead to decreased levels of soil organic matter and changes in soil structure, alternative management needs to be explored. The effect of cover crops in conjunction with different tillage systems on soil quality indicators was examined in this research. Organic no-till utilizes a crimped cover crop residue for weed control and was compared to a system where a cover crop was used for winter weed suppression then mowed and incorporated into the soil, and to a system using no cover crop and tillage for weed control. This study site was located in central Missouri on Mexico silt loam soil (fine, smectitic, mesic Vertic Epiaqualfs) from 2012 to 2014 and included grain crops and cover crops in a three year rotation, consisting of corn (*Zea mays* L.), cereal rye cover crop (*Secale cereale* L.), soybean (*Glycine max* L.), winter wheat (*Triticum aestivum* L.), a summer cover crop, and cereal rye/hairy vetch (*Vicia villosa* L.) cover crop. Main plot treatments were tillage/cover crop practice (TCCP) combinations: tillage without cover crop (TNCC), tillage with cover crop (TCC), and no-till with cover crop (NTCC). Sub-plots were turkey litter compost rates relative to the recommended rate (0x, 0.5x, 1x, 1.5x). Soil quality indicators included aggregate stability (AgStab), β-glucosidase (BG) activity, permanganate oxidizable carbon (POXC), total organic carbon (TOC), total nitrogen (TN), PLFA biomass and soil P and K levels. A soil quality index was determined for each treatment using the Soil Management Assessment Framework

(SMAF). AgStab, TOC and BG were generally less in TNCC than in cover crop treatments. Increased compost rates led to greater TN, P and K levels and to improved SQ index scores. PLFA biomass was not affected by compost rate but was greater in treatments with high amounts of residue from crops or from cover crops. POXC was impacted by compost rate and crop residue but not by TCCP. All soil quality indicators showed differences between years, with highest levels in 2013, the year with the highest and greatest distribution of precipitation. Differences in SQ index between treatments were significant but minor, which may be a result of the short-term nature of the study. Cover crops tended to mitigate the negative effects of tillage on soil in this study and cover crops impacted soil quality more when grown in conjunction with soybean than with corn or wheat.

Keywords: organic grain production, organic no-till, corn, soybean, wheat, soil health, soil quality, aggregate stability, active carbon, β-glucosidase, cover crop, rye, hairy vetch, PLFA, soil organic carbon, SMAF.

Abbreviations: TCCP, tillage/cover crop practice; NTCC, no-till with cover crop; TCC, tillage with cover crop; TNCC, tillage without cover crop; SOC, soil organic carbon; C, carbon; N, nitrogen; POXC, permanganate oxidizable carbon; P, phosphorus; K, potassium; SQ, soil quality; AgStab, aggregate stability; BG, β-glucosidase; DM, dry matter; SMAF, Soil Management Assessment Framework; PLFA, Phospholipid Fatty Acid.

Introduction

An established standard of the USDA National Organic Program is the maintenance or enhancement of soil quality on organic certified cropland (USDA-AMS, 2011). To assess how management affects soil properties, soil quality can be quantified using biological, physical and chemical indicators (Wienhold et al., 2004). Although many studies have compared soil quality indicators in conventional production to organic production, few studies have examined the effects of different management practices within an organic production system (Carr et al., 2013a). For a manager of an organic system, a pertinent question may not be how organic practices compare to conventional production, but rather how to improve organic practices to best protect natural resources, maximize ecosystem services, and produce the highest yields. Organic agriculture is a growing industry in the United States (Greene et al., 2009) so organic managers are often not looking for reasons to produce organically, but rather are likely looking for the best practices to produce organically and to achieve economically sustainable yields and environmental health.

Soil quality is often considered at the heart of organic practice. The use of green manures, cover crops and animal manure that is fundamental to organic production can lead to improvements in soil quality (Wander et al., 1994, Fließbach et al., 2007). Although organic production has been found to result in improved levels of soil quality compared to conventional production, including conventional no-till, those comparisons often show reduced yields in organic production (Teasdale et al., 2007, de Ponti et al., 2012, Seufert et al., 2012) relative to conventional production practices. Reduced organic yields are often attributed to increased weed interference (Posner et al., 2008) and decreased soil fertility (Cavigelli et al., 2008b). Some authors have also found yields in organic production to equal those of conventional systems (Delate and Cambardella, 2004), especially when greater resiliency to climatic variation is a factor (Lotter et al., 2003). This is often attributed to improved SOC levels from greater C inputs in organic management leading to improved soil structure, increased soil water holding capacity, and enhanced nutrient cycling (Cavigelli et al., 2013).

Although long-term organic research provides evidence that tilling organic matter into the soil may more effectively increase SOC than eliminating tillage (Cavigelli et al., 2013, Teasdale et al., 2007), typically a no-till system will have improved soil quality when compared to a tilled system with similar inputs (Karlen et al., 1994, Lal, 1993). Recently, organic producers and researchers have begun using organic no-till (ONT) in an attempt to capitalize on the benefits of reduced tillage (Bernstein et al., 2011, Teasdale et al., 2012, Mischler et al., 2010a, Delate et al., 2012, Mirsky et al., 2013). In this system, a cover crop is grown to a reproductive stage, after which it is terminated using a roller crimper. A grain or oilseed crop is then no-till planted into the cover crop mat that remains on the soil surface. While results with ONT have thus far been varied and mainly focused on weed control and yield, greater understanding of the processes controlling production success may eventually bring ONT into the mainstream of organic production practice (Mirsky et al., 2012).

Although it may be assumed that ONT will combine the soil quality benefits of no-till and organic practices, there has been very limited research to help ascertain the validity of this assumption. In a review on soil quality under ONT, Carr et al. (2013) found only 14 articles specific to organic conservation tillage and only one that included data from ONT. Most commonly the tillage methods compared were moldboard plow and chisel plow with shallow tillage such as rototilling or rotary harrow used for seed bed preparation in both systems (Gadermaier et al., 2012, Lehocká et al., 2009). The one study that examined a soil quality indicator in ONT found that earthworm abundance and biomass were greater in ONT than in tilled systems (Peigné et al., 2009).

In addition to no-tillage, a key component of an ONT system is the cover crops used for weed control. The positive effects of cover crops on soil quality in conventional no-till systems has been well studied (Amado et al., 2006, Mullen et al., 1998). With the majority of research focusing on weed control and termination methods (Creamer and Dabney, 2002), there is less known about soil quality effects when cover crops are crimped and remain on the soil surface. In a study examining three legume and two non-legume cover crops that were crimped and left on the soil surface compared to a no cover crop control, the cover crop treatments had greater extractable SOC and N than the control (Zhou et al., 2012). Calegari et al. (2008) found a 64.6% increase in SOC at 0-10 cm soil depth when cover crops were crimped in a no-till system compared to cover crops being incorporated in a conventional-till (CT) system. However, the CT system increased SOC storage at 10-20 cm soil depth.

For ONT to be successful, it will need to provide a suite of services including sufficient weed control, increased soil quality and improved yields. The objective of this study was to determine the effects of ONT on biological, physical and chemical soil quality indicators. An ONT system was compared to an organic system where the cover crop was mowed and incorporated into the soil and to an organic tilled system where no cover crop was utilized. The effect of sub-plots of four rates of composted turkey litter on soil quality indicators was also examined. To determine soil quality under the different production systems, the Soil Management Assessment Framework (SMAF) was utilized. The SMAF was developed jointly by the USDA- NRCS and ARS and is a quantitative soil quality evaluation method that uses measured physical, chemical and biological soil indicators to assess management effects on soil functions (Andrews et al., 2004). Scoring curves that consist of interpretative algorithms transform soil indicator values into unitless soil quality scores (Stott et al., 2011). These scores can be used to compare management practices on a given soil type or to monitor management effects over time (Wienhold et al., 2009).

Materials and Methods

Research Site and Design

This research was conducted from 2012-2014 at the University of Missouri Bradford Research Center, located in Boone County 8 kilometers east of Columbia, MO. Soils at this site are primarily Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualfs) and are on the central glacial till claypan plain. This site has an argillic horizon, which is a claypan subsoil horizon, typically 25 cm below the soil surface. This research site had previously been managed as a conventional row crop field until 2011 when organic management practices were initiated. Land used in this study was certified in organic transition by Quality Certification Services (QCS, Gainesville, FL). The research area was split into three sections (27 m x 67 m) for the three grain crops in the rotation. The crop rotation was a wheat (*Triticum aestivum* L.)-corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation. Winter cover crops included cereal rye (*Secale cereale* L) and hairy vetch (*Vicia villosa* L.).

Each crop section was in a randomized complete block split-plot design with main plot treatments of tillage/cover crop practice (TCCP), including TNCC, TCC, and NTCC. TNCC treatments were tilled plots with no winter cover crops between grain crop sequences. TCC treatments utilized a winter cover crop that was mowed and tilled into the soil. NTCC utilized a winter cover crop that was crimped and planted using no-till practices. Sub-plot treatments consisted of compost rates of zero compost (0x), half the recommended rate (0.5x), the recommended rate (1x), and 1.5 times the recommended rate (1.5x). A poultry compost product (Early Bird, Central Missouri Poultry Producers, Inc, High Point, MO) was applied at amounts based on the soil-test P recommendation (Buchholz et al., 2004) and the compost P content to prevent potential P loss. Amounts of compost, total P, and total N are displayed in table 3.1. Each crop section had four replications for a total of 48 plots (4.6 m x 6.1 m). The TCCP and compost treatments were located in the same plot positions for the three years of the study.

Weather

Due to extreme drought in 2012, irrigation of approximately 2.5 cm of water was applied five times on 6 June, 6 and 20 July, and 3 and 17 August. The average temperature from May through September in 2012, 2013 and 2014 was 23.3 C, 21.3 C, and 21.3 C and the total rainfall from May through September in those years was 177.3 mm, 440.9 mm, and 516.7 mm, respectively. The annual cumulative rainfall for 2012-2014 is shown in Figure 3.1 and is plotted against the 30-year average for Boone County, MO.

Crop Management

Composted turkey (*Meleagris gallopavo*) litter was applied by hand once annually each spring at Zadoks growth stage 2.4 (Zadoks et al., 1974) in winter wheat and just after winter cover crop destruction in other treatments. In tilled plots, the compost was incorporated into the soil and in no-till plots the compost remained on the soil surface. Pre-plant tillage in TNCC and TCC plots was conducted using a 1.5 m wide plot disk and weed control was done using a Danish S-tine 4-row cultivator. Management dates and processes are shown in Table 3.2. Cover crops in NTCC plots were terminated at Zadoks growth stage 61 for corn (Mirsky et al., 2009) and Zadoks 68 for soybean using three passes with a roller-crimper (I&J Mfg, Gap, PA). Cover crops in TCC were first mowed and then disked into the soil at the same growth stage. The organic corn (Welter Seed hybrid WS2292) and soybean (Blue River Hybrids 389F.Y) were planted using a 4-row John Deere 7000 planter (Moline, IL) with 76 cm wide rows at 86,400 and 385,300 seeds ha^{-1}, respectively. Due to the dense residue established by the cover crop in the NTCC treatments, the no-till coulters were removed and spiked closing wheels (Schoup Mfg., Kankakee, IL) were installed on the planter to effectively close the seed-row furrow in 2013 and 2014.

The winter cover crop (Table 3.3) was cereal rye (CR) planted before soybean and a mixture of cereal rye and hairy vetch (CR-HV) planted before corn. All cover crops and the organic wheat (variety “Bess”) were planted using a Tye (AGCO, Duluth, GA) no-till drill at 19 cm row spacing. Wheat was planted at 100 kg ha^{-1}. In 2012, a summer cover crop of buckwheat (*Fagopyrum esculentum* Moench) was planted in the wheat section after harvest and in 2013-2014 a cover crop mix of sunn hemp (*Crotalaria juncea* L.) and cowpea (*Vigna unguiculata* (L.) Walp.) was planted after wheat (Table 3.3).

Soil Analyses

Soil was collected just prior to harvest each fall using a soil probe with a 19.05 mm diameter to a depth of 15 cm. Eight samples were taken in a grid pattern in each plot and were composited and homogenized using a 6.35 mm sieve. Sub-samples of soil for aggregate stability, pH_s and macronutrient testing were air dried while all other samples were frozen at 0 C prior to lab analysis.

Analysis of pH_s and macronutrients was performed by the University of Missouri Soil and Plant Testing Laboratory using the methods described in Nathan et al. (2006). Potassium was extracted using ammonium acetate then levels determined using flame emission. A 0.01 M $CaCl_2$ solution was added to 5 g of soil to determine pH_s using a benchtop pH meter. Phosphorus was determined using Bray I extract, filtered, then ascorbic acid was added and the resulting color was read in a spectrophotometer set at 660 nm.

Wet aggregate stability was determined using the method of Nimmo and Perkins (2002). After air drying, a soil sample was passed through a 2 mm sieve and retained on a 1 mm sieve. Pre-weighed sieves of 0.5 mm were placed in plastic dishes filled with two liters of deionized water and 3.00 grams of the >1 to <2 mm soil fraction was evenly dispersed on the sieves and left to soak for 16 hours. Samples were agitated using 20 up and down strokes then sieves and soil were removed from water, placed on pre-weighed metal plates, and dried at 110° C for one hour. After the dry weight was recorded, samples were returned to a bowl of deionized water and sand and iron-manganese nodules were separated from soil aggregates by adding a solution of sodium hexametaphosphate (35.7 g L^{-1}) and sodium bicarbonate (7.94 g L^{-1}) then triturating the dispersing solution with fingers to remove soil particles left on the sieve. The samples and sieves were again dried at 110° C and the resulting dry weights of the remaining particles were recorded and subtracted from the aggregate sample weights to determine the total amount and percentage of water stable soil aggregates.

Phospholipid fatty acid analysis was determined using the method of Buyer and Sasser (2012). In brief, samples were placed in test tubes and dried overnight. After a Bligh-Dyer lipid extraction was performed the extract was dried, dissolved in chloroform, and placed into a 96 well extraction plate. Phospholipids were then eluted into vials, dried and transesterified. The fatty acid methyl esters produced by this process were then analyzed in a GC using MIDI Sherlock software (MIDI Inc., Newark, DE). PLFA markers used for analysis are listed in Table 3.4

Activity of β-glucosidase was determined by mixing 1 g of soil with 4 mL of modified universal buffer at pH 6.0 and 1 mL of *p*-Nitrophenyl-β-D-glucoside (PNG) substrate solution and incubated at 37° C for 1 hour (Eivazi and Tabatabai, 1988). To stop the reaction, 1 mL of 0.5 M $CaCl_2$ and 4 mL of 0.1 M THAM buffer (pH 12) were added. The resulting solution was filtered through Q2 filter paper (Fisher Scientific, Waltham, MA) and measured in a spectrophotometer at 410 nm (Ultrospec 2100 pro uv/visible, Amersham Biosciences). The amount of *p*-nitrophenol released was determined using the following equation:

(a x Abs +b) x volume/dry soil mass (g)/ hours incubated

Where a = slope of the standard curve, Abs = the absorbance of the sample, b = the intercept of the standard curve and volume = the total volume of the reagents.

Total soil organic carbon (TOC) and total nitrogen (TN) were determined on sieved (< 2 mm), air-dried, ground soil samples by dry combustion at 900° C using a LECO® Tru-Spec C/N Analyzer (Nelson and Sommers, 1996).

The permanganate oxidizable soil carbon fraction (POXC) was analyzed colorimetrically using the method of Weil et al. (2003) and modified by Culman et al. (2012). A 2.5 g soil sample was added to 2.0 ml of potassium permanganate ($KMnO_4$) and 18.0 ml of DI water then shaken for 2 minutes. After settling for 10 minutes, a 0.5 ml sample of the supernatant was extracted, added to 49.5 ml of DI water and read at 550 nm on a spectrophotometer (Pharmacia LKB Ultrospec). The following equation was used to determine POXC:

$$\text{POXC (mg kg-1)} = [0.02\ \text{mol/L} - (a+b \times \text{Abs})] \times (9000\ \text{mg C/mol}) \times (0.02\ \text{L solution/Wt})$$

Where initial solution concentration = 0.02 mol/L, a = the intercept of the standard curve, b = the slope of the standard curve, Abs = absorbance of the unknown, 9000 = milligrams of carbon oxidized by 1 mole of MnO_4 changing from Mn^{7+} to Mn^{2+}, 0.02 L = volume of stock solution reacted, Wt = weight of air dried soil sample in kg.

Statistical Analysis

Statistical analysis was completed with SAS Enterprise Guide 6.1 (SAS, Cary, NC). Results were analyzed using PROC MIXED at α=0.05 by crop and year with the ANOVA run as a RCBD split-plot design. The fixed effects in the model were TCCP, compost (sub-plot factor) and TCCP*compost. The random effects were block and block*TillCC (whole plot factor). All mean separation differences were tested using Tukey's HSD. Crop and year were included as fixed effects in the soil analyses to evaluate seasonal and vegetative effects on soil quality indicators. Visual inspection of frequency distributions showed that normality assumptions were valid.

Soil Management Assessment Framework

Soil quality indicator levels for each plot were considered in the SMAF soil quality index scores. Statistical analysis was then performed on individual scores to derive treatment means (PROC MIXED at α=0.05). The soil quality indicators used in the SMAF scoring include aggregate stability, pH, soil P and K, β-glucosidase activity and total organic C. Additionally, SMAF scoring used soil texture, soil suborder, slope, crop rotation, climate and minerology. SMAF indicators that were common to each treatment were as follows: silt loam soil texture, aqualf soil suborder, 2-5% slope, high degree days, high average precipitation, and smectitic mineralogy. Soil quality indicators that were monitored but not included in the SMAF evaluation include permanganate oxidizable carbon (POXC), microbial PLFA biomass and total N.

Results and Discussion

Soil Physical Indicator

Soil aggregate stability (AgStab), a common measurement used to express soil structure, is an important aspect of soil quality due to the impact of structure on plant available soil moisture, nutrient cycling, erosion, crusting, and crop yield (Bronick and Lal, 2005, Six et al., 2000). In contrast to findings that showed improvement in soil aggregation after applying compost (Whalen et al., 2003, Annabi et al., 2011), compost additions in this study did not affect aggregate stability (Table 3.5, Table 3.6). The improvement of aggregate stability from organic matter addition is attributed largely to microbial generated polysaccharides and soil particle entwinement by roots and fungal hyphae (Tisdall and Oades, 1982). Organic matter that is more recalcitrant has little effect on aggregate stability indicating that decomposition activity plays a role in stabilizing aggregates (Abiven et al., 2009). With an average C/N ratio of 11/1, the poultry litter compost used in this study would have been amenable to microbial decomposition under optimum environmental conditions. However, although total N increased with increasing compost addition, SOC (Table 3.6) and soil PLFA biomass (Table 3.7) were not affected by compost rate. This lack of microbial response was the likely reason that compost addition did not affect aggregate stability. Slow decomposition rates that may have been weather induced could lead to a lack of response in SOC levels to increasing compost rates.

Although there were no TCCP effects on AgStab in 2012, in 2013 the NTCC and TCC treatments had greater AgStab than the TNCC treatment and in 2014 in soybean NTCC had greater AgStab than either TCC or TNCC (Table 3.8). The higher summer rainfall and more steady autumn precipitation in 2013 (Figure 3.1) likely had a positive effect on soil microorganism population growth and activity (Schnurer et al., 1986), leading to improved levels that year in all microbe-mediated soil quality indicators tested (Table 3.9). Although tillage has been shown to decrease aggregate stability (Six et al., 1999), that result was not consistently seen in this study, possibly due to the low number of tillage events that were used for field preparation and in-season weed control. Weed control was a minor issue in the two tilled treatments due to the weed-free status of the fields when the study began and to summer drought that kept weed germination minimal in 2012. Because AgStab in the TCC treatment did not show a significant decrease from NTCC when averaged across years (Table 3.10), it is likely that organic matter provided by the cover crop residue aided in maintaining soil structure in the presence of tillage. This was consistent with other studies that have shown that winter cover crop use can mitigate tillage-induced soil structural change (Hermawan and Bomke, 1997, Benoit et al., 1962). Positive effects of cover crops on soil structure are often attributed to physical, biological and chemical effects of root growth (Benoit et al., 1962, Angers and Caron, 1998), thus a living cover crop may have a greater effect on soil quality indicators than addition of organic matter in the form of compost. AgStab was significantly less in TNCC treatments (Table 3.10), which is consistent with many studies showing that tillage is damaging to soil structure (Six et al., 1999, Wright et al., 1999, Hajabbasi and Hemmat, 2000). When examined by crop, wheat had the highest AgStab (Table 3.11), which was likely due to reduced summer tillage in the wheat-summer cover crop rotation.

Soil Biological Indicators

Soil Carbon

When analyzed by individual crops and years, POXC levels were effected by compost in corn in 2012 and soybean in 2014 and by TCCP in corn in 2012 (Table 3.12). When analyzed across all years and crops, POXC was less at the 0 compost rate (Table 3.6) and in corn and soybeans compared to wheat (Table 3.11). This somewhat minimal response of POXC to tillage and to compost and cover crop additions was in contrast to several studies that have shown that POXC can be reduced by tillage or increased by organic matter additions, and that the $KMnO_4$ reaction can detect changes in management in a short period of time (Culman et al., 2012, Weil et al., 2003, Lewis et al., 2011, Plaza-

Bonilla et al., 2014). The most significant difference in POXC was found between years (Table 3.9), where 2012, the extreme drought year, had only 45% of the POXC as 2013. This implies that seasonal differences may affect POXC levels more than production differences in a short-term study. Culman et al. (2012) also concluded that environmental factors can have a significant effect on measured POXC. Because moisture was limiting throughout much of this study, slow breakdown of compost and cover crop residue likely led to slow accumulation of organic material that is readily oxidized by $KMnO_4$.

Edaphic factors may also lead to low response of POXC to management. In validation testing for portable kits for measuring POXC, soils with a high fraction of smectitic clays, like those present at our experiment site, were found to potentially interfere with the $KMnO_4$ reaction due to high surface activity (Stiles et al., 2011). The presence of clay and silt particles accounted for 82% of variability in soil POXC in ten rice field soils in another study, which led researchers to conclude that physical protection for oxidizable lignin groups by soil clay particles can affect the results of POXC testing (Tirol-Padre and Ladha, 2004).

Although POXC was not significantly impacted by TCCP across years and crops, total organic carbon (TOC) was found to be significantly lower in the treatment with no cover crop than the treatments with cover crops (Table 3.10). TOC was also affected by year but not by compost rate or crop (Tables 3.6, 3.9 and 3.11). POXC is a component of TOC and generally considered to be more sensitive to short-term management changes than TOC. However, because TOC is determined by combustion of the total amount of organic matter in the soil, it might be less affected than POXC by slow breakdown of organic matter additions caused by dry climatic conditions. In this case, TOC is a direct reflection of the amount of organic material added in each treatment.

In the NTCC treatment, much of the cover crop residue was slow to decompose and a significant amount remained on the soil surface still attached to the crimped plants at the end of each cropping season. In the TCC treatment, the mowed and incorporated cover crop residue decomposed more rapidly and was not visible by midway through the growing season. It could be assumed that the total level of SOM found in a subsurface soil sample would be higher in the treatment where more residue was incorporated into the soil because at the time of soil sampling much of the cover crop residue in the NTCC plots was moved aside for placement of the soil probe into bare ground. Because TOC levels were equal in the two cover crop treatments but lower in the tilled treatment with no cover crop (Table 3.10), this is an indication that no-till conserved TOC and the presence of cover crop residue in the tilled system helped mediate the loss of TOC from tillage. This confirms previous work showing that SOC can be higher in a tilled organic system that utilizes animal-based fertilizer and cover crops than in both tilled and no-till conventional systems that do not utilize organic inputs (Wander et al., 1994, Teasdale et al., 2007). Because of the importance of SOC in many soil quality processes and parameters, it may be that in both organic and conventional production systems the addition of cover crops can more greatly impact soil quality than tillage reduction.

PLFA

Phospholipid fatty acid (PLFA) analysis can indicate the community composition of soil microorganisms. PLFAs in this study were not affected by compost rates (Table 3.7), which is different from other studies where microbial community structure and diversity were enhanced with compost amendments (Treonis et al., 2010, Bastida et al., 2008, Bossio et al., 1998b). Saison et al. (2005) found that activity, size and composition of soil microbial communities were impacted in the six months after compost application, but the changes did not persist past six months. The relatively dry conditions during our study coupled with PLFA soil sample collection after harvest, which was six months after compost application, possibly contributed to the lack of PLFA response to compost additions. Treonis et al. (2010) tested soil that was collected in June and August after a May compost application. Bossio et al. (1998) used soil sampled at six dates from just following compost application up to four months after and found significant variation in PLFA biomass between dates. Bastida et al. (2008), who worked in a semi-arid climate, sampled soil for PLFA analysis two years after compost was added to a perennial vegetation site. Although they did not report if there was a concomitant increase in plant growth from compost addition, that may have affected soil properties two years later.

Several microorganism functional groups did respond to tillage and cover crop practice. Actinobacteria, AMF fungi, and gram-negative and gram-positive bacteria were all significantly higher in treatments that used cover crops compared to the tilled treatment with no cover crop (Table 3.13), indicating that these functional groups may be more influenced by fresh residue from cover crops than by compost amendment. This supports previous findings by Carrera et al. (2007) and Jokela et al. (2009) who also found significant increases in microbial biomass from cover crop use but little or no effect from manure or compost application.

Our PLFA results are similar to Buyer et al. (2010) who reported biomass increases in all microbial groups under cover cropping except gram-negative bacteria, which increased in our study while anaerobes, eukaryotes and total fungi did not. Another study using a hairy vetch cover crop showed higher PLFA levels of fungi, protozoa and aerobic bacteria, demonstrating the variability in responses of microorganisms to cover crop species, soil or climatic conditions from study to study (Carrera et al., 2007). Several differences exist between compost source and contents and cover crops that could affect the composition, function and growth of the soil microbial community. As living entities, cover crops roots not only deposit rhizosphere-C into the soil that may play a greater role in SOM stabilization than residue-C, but the rhizosphere is also the preferred habitat of soil microorganisms due to root exudates that are a major nutrient source for microbial metabolism (Kong and Six, 2012). Composted animal litter is generally more aged and chemically stabilized than fresh plant residue (Goyal et al., 2005), thus it may be either less attractive for microbial activity or provide fewer nutrients for soil microorganisms than cover crop residue. Rhizosphere processes can also contribute to the formation and stabilization of macroaggregates, which have been found to contain higher levels of microbial biomass than microaggregates (Miller and Dick, 1995).

As with TOC results, the higher levels of PLFA in the tilled cover crop treatment compared to the tilled with no cover crop highlights the importance of utilizing cover crops to mediate negative changes to soil quality caused by tillage and demonstrates that cover crop use may have more impact than tillage reduction when addressing soil quality issues. Decreased biomass levels of some PLFA functional groups in the tilled plot with no cover crop confirms other studies that have also found negative impacts to soil microbial populations from tillage. Possible causes for this included moisture loss during tillage (Frey et al., 1999), a faster turnover rate of macroaggregates with tillage (Six et al., 1999), increased organic matter decomposition in tillage that limits longevity of microorganisms (Helgason et al., 2009), and vertical stratification of nutrients in no-till that may lead to greater microbial community growth (Franzluebbers, 2002).

Significant differences in PLFA biomass were also found between crop species with higher levels in corn than in soybean of all PLFA functional groups except eukaryotes (Table 3.14). Although wheat was also significantly higher than soybean, soil samples in that treatment were taken after a summer cover crop had been grown. Thus, it was not possible to determine the direct effect of the wheat crop. Because soil samples were taken just after corn and soybean physiological maturity and would not yet have been affected by above-ground residue decomposition, PLFA results in corn and soybean are likely due to below-ground plant growth differences between crop species. Crop specific differences that could lead to variable microorganism community growth include the composition of root exudates that differ by plant species, which can affect the relative abundance of microorganisms in the vicinity of the root (Berg and Smalla, 2009), and root structure differences between corn and soybean. Root biomass for crops grown on Missouri soils was estimated at 3.7 t ha^{-1} for corn and 1.4 t ha^{-1} for soybean (Buyanovsky and Wagner, 1986), with corn having a greater density of fine roots than the tap root-forming soybean (Gardner et al., 2003). This high production of root biomass by corn can lead to higher levels of soil microorganisms fed by nutrients provided by root decomposition (Haynes and Francis, 1993). Because soybean production may not result in increased levels of soil microorganisms, soil quality may particularly benefit from a winter cover crop grown prior to soybean cultivation. The winter cover crop, especially if it is a grass species, may contribute to increased residue biomass, increased and more varied root exudates, and improved levels of soil quality indicators over soybean grown without a cover crop.

β-Glucosidase

Tillage and cover crop practice impacted β-glucosidase (BG) activity after soybean (2012-2014) and wheat (2013) with a general trend showing higher activity in the NTCC and TCC treatments than in TNCC (Table 3.8). Because BG hydrolyzes degradation products of cellulose, it was expected that higher activity would be found where higher levels of plant biomass were produced by cover crops and by higher residue crops (Stott et al., 2010, Bandick and Dick, 1999). While the BG level was generally lower in soybean (Table 3.11), it responded more to the cover crops planted in the soybean system than to cover crops grown in conjunction with corn or wheat. This is further evidence that some indicators of soil quality may be more greatly impacted by the addition of a winter cover crop in conjunction with soybean than with corn and wheat. Soybean total residue biomass is generally about 37% of corn (Buyanovsky and Wagner, 1986) and contains about 78% of the cellulose level of corn residue (Broder and Wagner, 1988).

Compost rates had no effect on BG activity in individual crops and by TCCP treatment (Table 3.8). However, when analyzed for all years and crops, BG activity decreased at lower compost rates (Table 3.6). This could be due to increased cover crop growth in treatments with higher compost levels. Other studies have found a response in BG from compost addition; however, differences in compost composition may account for these differences. For example, the wood chip bedding used in our compost product may have a higher lignin:cellulose ratio than the straw bedding used in many poultry compost products (Bastida et al., 2008, Atkinson et al., 1996, Jones et al., 2006). While some studies have found a correlation of BG with increased organic C (Eivazi and Tabatabai, 1990, Leon et al., 2006), others have found a poor correlation with total C (Bandick and Dick, 1999, Acosta-Martínez et al., 2003). A previous study at the Bradford Research Center in 2001-2002 showed significant increase in BG levels when a wood chip-based poultry litter was applied (Pengthamkeerati et al., 2011), thus indicating that climatic or temporal conditions may be the primary factor impacting our results. Although seasonal variations are reported to have little impact on BG (Stott et al., 2010), significant seasonal differences were found in this study (Table 3.9). The extremely dry weather experienced during this study period could have resulted in lower compost decomposition and lower concomitant microbial and enzyme activity.

Soil Chemical Indicators

Chemical soil quality indicators investigated include pH, Bray 1 P, extractable K and total N. The pH of the soil was not affected by any treatments. P and K (Table 3.15) and total N (Table 3.6) increased as the amount of compost applied to each treatment increased. Because a lower level of compost was added to soybean, total N was lower in soybean than in wheat or corn (Table 3.11). There were no differences in P, K or total N by TCCP although tillage has been shown to reduce total N in a compost-amended soil (Laudicina et al., 2011). SPAD readings taken at VT stage in corn showed that NTCC corn had a significantly lower reading of 32 SPAD units compared to 39 in TNCC corn and 40 in TCC corn. Although total N in the soil was not significantly different at the time of fall soil sampling, these SPAD results show that N availability and tissue uptake were affected by TCCP during the growing season. Our data confirms previous work by

Wells et al. (2013) that nitrogen tie-up can result from a crimped rye cover crop. The cover crop residue that remained on the soil surface in NTCC was likely immobilizing nutrients compared to the cover crop in TCC that was disked into the soil, which leads to more rapid microbial transformation and availability of nutrients assimilated by the cover crop during its growth.

SMAF Soil Quality Index

Chemical, physical and biological indicators were included in the development of a soil quality (SQ) index for each treatment using the Soil Management Assessment Framework (Table 3.16). Although we expected that treatments with tillage would negatively affect the SQ index compared with no-till, this was only found in soybean and may have been more influenced by the presence of additional residue from cover crops than from tillage alone. In soybean, the SQ index was highest in the NTCC treatment in 2013-2014, which was a result of the improved β-glucosidase activity score (Table 3.7) in the SMAF index.

We expected that cover crops would lead to a greater SQ index than treatments with no cover crops. This was found to a small extent in soybean. In the case of corn and wheat, which are higher residue crops than soybean, cover crops did not lead to improved SQ index scores. Soil quality indicators in treatments with rolled cover crops and no-till were not significantly different from treatments with mowed cover crop and tillage except for the high index rating for aggregate stability in soybean in 2014. The additional N, P and K added at higher compost rates (Table 3.15) both directly led to higher SQ index scores and indirectly increased scores by improving crop biomass production, thereby increasing POXC and β-glucosidase activity.

Our results compare to a study in a corn silage production system that found soil quality scores were very similar in cover crop and no cover crop systems, but were lower in a manured system compared to a corn crop fertilized with inorganic N (Jokela et al., 2009). Also working in a Mexico silt loam soil in Missouri, Veum et al. (2015) found improved soil quality scores in the top 0-5 cm of soil in a system that had been no-till corn and soybean for 17 years compared to one that had been mulch-tilled during the same time period. However, in the 5-15 cm soil depth, the mulch-tilled soil had 7% greater overall soil function than the no-till soil. Because our soil was sampled from the 0-15 cm depth, we would not have been able to differentiate between surface and subsurface responses of soil quality indicators to the different production systems. We chose to sample from 0-15 cm to represent the primary crop rooting zone and to match soil fertility sampling recommendations for producers.

Although differences in the SQ index scores were statistically significant by year (Table 3.9), compost rate (Table 3.6) and crop (Table 3.11), the actual differences in scores may be too small to be evidence of clear trends in production system impact on soil quality in this study. In a comparison of five Midwestern watersheds, Karlen et al. (2014) also found SQ scores to be numerically close (82-89%) amongst differing applications of tillage, manure and crop rotations. Greater differences in SMAF scores were found in a comparison of 12 production systems in Missouri, with perennial systems ranking much higher than annual systems and unfertilized wheat and corn production at the extreme low end of the ranking (Veum et al., 2014). It is likely that large differences in SMAF scores between tillage and cover crop treatments will not be evident in a short term study that was also confounded by yearly weather extremes, but they may become more significant as increased SOM from sustainable management practices begins to exert a greater influence on biological, physical and chemical soil quality indicators.

Conclusions

Although there have been many studies on the effects of organic management on soil quality (Wander et al., 1994, Liebig and Doran, 1999, Carr et al., 2013a, Fließbach et al., 2007, Delate et al., 2015), SMAF soil quality index scores for organic production systems have not been conducted. This paper serves as a starting point for examining how SMAF soil quality scores are affected by organic practices such as tillage, cover crops and compost addition. We recommend conducting further studies to examine production effects in contrasting organic systems with less emphasis placed on comparing organic to conventional agriculture. With the advent of research on organic no-till, new possibilities now exist to address soil degradation within the confines of organic production. Further research is needed to elucidate the role of cover crops in a tilled organic system, control of weeds and management of cover crop under organic no-till, and determination of the long-term feasibility of organic no-till and its effect on soil quality, yield and profitability.

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Figure 3.1. Cumulative Precipitation from 2012-2014 compared to 30-year average cumulative precipitation for Boone County, MO.

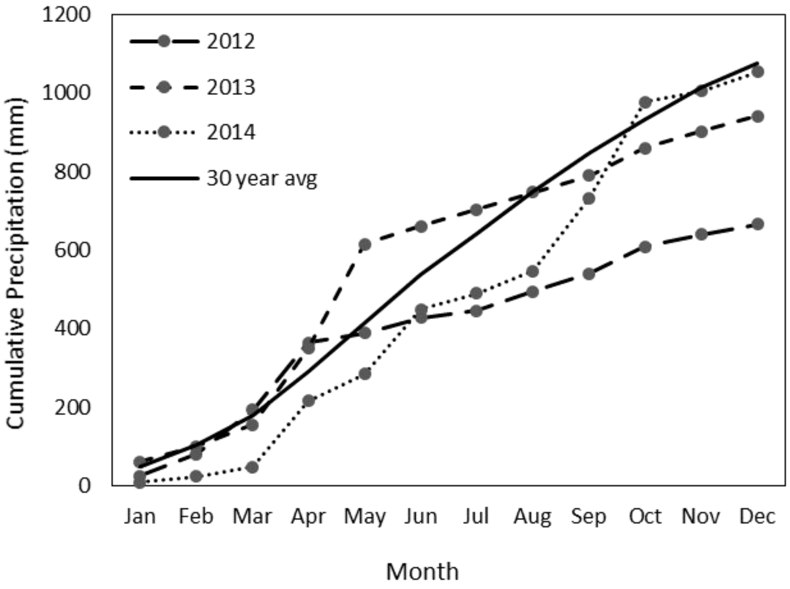

Table 3.1. Compost applied per compost treatment (0x, 0.5x, 1x, 1.5x recommended rate) for corn, soybean, and wheat from 2012-2014. Compost application was based on yield goal, soil test P fertilizer recommendations and P content of compost.

Crop	Year	Compost treatment	Compost applied	Total P	Total N
			———kg ha^{-1} yr^{-1}———		
Corn	2012	0x	0	0	0
		0.5x	3528	71	106
		1x	7000	140	211
		1.5x	10528	211	316
	2013	0x	0	0	0
		0.5x	3714	71	74
		1x	7368	140	148
		1.5x	11082	211	222
	2014	0x	0	0	0
		0.5x	4341	83	122
		1x	8681	165	243
		1.5x	13022	248	365
Soybean	2012	0x	0	0	0
		0.5x	2520	50	76
		1x	5040	101	151
		1.5x	7560	151	227
	2013	0x	0	0	0
		0.5x	2652	50	74
		1x	5305	101	148
		1.5x	7958	151	222
	2014	0x	0	0	0
		0.5x	2713	52	76
		1x	5426	103	152
		1.5x	8139	155	227
Wheat	2012	0x	0	0	0
		0.5x	2240	45	67
		1x	4480	90	134
		1.5x	6720	134	202
	2013	0x	0	0	0
		0.5x	2358	45	66
		1x	4716	90	131
		1.5x	7074	134	197
	2014	0x	0	0	0
		0.5x	2035	39	57
		1x	4070	77	114
		1.5x	6105	116	171

Table 3.2. Planting, fertilizing, cultivation, harvest, and termination dates for corn, soybean, wheat, and cover crops from 2012-2014.

Crop	Year	Planting Date	Compost Application Date	Cultivation Date	Harvest or Termination Date
Cover Crops	2011	8-Oct			
	2012	19-Oct			22-May (corn), 28-May (soybean)
	2013	17-Oct			3-Jun (corn), 11-Jun (soybean)
	2014				4-Jun (corn), 16-Jun (soybean)
Wheat	2011	8-Oct	27-Mar		8-Jun
	2012	19-Oct	25-Apr		3-Jul
	2013	14-Oct	16-Apr		30-Jun
Corn	2012	23-May	22-May	21-Jun	16-Oct
	2013	4-Jun	5-Jun	28-Jun	17-Oct
	2014	5-Jun	3-Jun	19-Jun, 2-Jul	8-Oct
Soybean	2012	29-May	29-May	21-Jun	17-Oct
	2013	12-Jun	11-Jun	11-Jul	14-Oct
	2014	16-Jun	15-May	2-Jul, 29-Jul	21-Oct

Table 3.3. Seeding rates, seasons and varieties of cover crops. VNS= variety not stated.

Crop	Season	Variety	Seeding rate
			kg ha^{-1}
Winter cover crop mix			
Crimson clover (*Trifolium incarnatum* L.)	winter	VNS	17
Hairy vetch (*Vicia villosa* Roth)	winter	VNS	11
Cereal rye (*Secale cereale* L.)	winter	VNS	100
Austrian winter pea (*Pisum sativum* L. subsp. Arvense)	winter	VNS	17
Buckwheat (*Fagopyrum esculentum* Moench)	summer	VNS	67
Summer cover crop mix	summer		40
Sunn hemp (*Crotalaria juncea* L.)	summer	VNS	17
Cowpea (*Vigna unguiculata* (L.) Walp.)	summer	Iron and clay	67

Table 3.4. Phospholipid fatty acid markers by microbial group.

Microbial Group	Markers			
AM Fungi	16:1 w5c			
Gram Negative Bacteria	10:0 2OH	10:0 3OH	12:1 w8c	12:1 w5c
	13:1 w5c	13:1 w4c	13:1 w3c	12:0 2OH
	14:1 w9c	14:1 w8c	14:1 w7c	14:1 w5c
	15:1 w9c	15:1 w8c	15:1 w7c	15:1 w6c
	15:1 w5c	14:0 2OH	16:1 w9c	16:1 w7c
	16:1 w6c	16:1 w4c	16:1 w3c	17:1 w9c
	17:1 w7c	17:1 w6c	17:0 cyclo w7c	17:1 w5c
	17:1 w4c	17:1 w3c	16:0 2OH	17:1 w8c
	18:1 w8c	18:1 w7c	18:1 w6c	18:1 w5c
	18:1 w3c	19:1 w9c	19:1 w8c	19:1 w7c
	19:1 w6c	19:0 cyclo w9c	19:0 cyclo w7c	19:0 cyclo w6c
	20:1 w9c	20:1 w8c	20:1 w6c	21:1 w8c
	20:1 w4c	20:0 cyclo w6c	21:1 w9c	21:1 w3c
	21:1 w6c	21:1 w5c	21:1 w4c	22:1 w5c
	22:1 w9c	22:1 w8c	22:1 w6c	24:1 w7c
	22:1 w3c	22:0 cyclo w6c	24:1 w9c	
Eukaryote	15:4 w3c	15:3 w3c	16:4 w3c	16:3 w6c
	18:3 w6c	19:4 w6c	19:3 w6c	19:3 w3c
	20:4 w6c	20:5 w3c	20:3 w6c	20:2 w6c
	21:3 w6c	21:3 w3c	22:5 w6c	22:6 w3c
	22:4 w6c	22:5 w3c	22:2 w6c	23:4 w6c
	23:3 w6c	23:3 w3c	23:1 w5c	23:1 w4c
	24:4 w6c	24:3 w6c	24:3 w3c	24:1 w3c
Fungi	18:2 w6c			
Gram Positive Bacteria	11:0 iso	11:0 anteiso	12:0 iso	12:0 anteiso
	13:0 iso	13:0 anteiso	14:1 iso w7c	14:0 iso
	14:0 anteiso	15:1 iso w9c	15:1 iso w6c	15:1 anteiso w9c
	15:0 iso	15:0 anteiso	16:0 iso	16:0 anteiso
	17:1 iso w9c	17:0 iso	17:0 anteiso	18:0 iso
	19:0 iso	19:0 anteiso	20:0 iso	22:0 iso
Anaerobic Bacteria	12:0 DMA	13:0 DMA	14:1 w7c DMA	14:0 DMA
	15:0 iso DMA	15:0 DMA	16:2 DMA	17:0 DMA
	16:1 w9c DMA	16:1 w7c DMA	16:1 w5c DMA	19:0 cyclo 9,10 DMA
	18:2 DMA	18:1 w9c DMA	18:1 w7c DMA	18:1 w5c DMA
Actinobacteria	16:0 10-methyl	17:1 w7c 10-methyl	17:0 10-methyl	18:0 DMA
	18:1 w7c 10-methyl	18:0 10-methyl	19:1 w7c 10-methyl	20:0 10-methyl

Table 3.5. Mean of % aggregate stability at 0-15 cm soil depth, 2012-2014, as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5 x= 1.5x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column, row and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started.

		Pre-study	2012				2013				2014			
		TCCP												
crop	compost	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean
		% stable aggregates												
Corn	0x	42.1	54.2 (4.2)	55.5 (3.7)	63.1 (5.2)	57.6	71.5 (3.6)	75.4 (2.5)	77.0 (1.4)	74.6	64.1 (3.8)	65.4 (1.5)	72.1 (2.3)	67.2
	0.5x		56.9 (1.2)	64.7 (2.3)	60.9 (4.2)	60.8	66.3 (5.1)	69.2 (2.6)	75.0 (2.1)	70.2	67.7 (2.8)	68.3 (3.0)	70.2 (1.7)	68.7
	1x		61.9 (2.8)	68.5 (1.9)	59.0 (2.5)	63.1	67.5 (4.1)	73.3 (4.3)	72.1 (5.1)	70.9	61.9 (4.5)	60.9 (5.6)	65.3 (2.1)	62.7
	1.5x		59.6 (3.5)	64.0 (5.7)	57.6 (1.9)	60.4	69.8 (2.5)	74.9 (2.7)	76.3 (1.5)	73.7	65.0 (2.5)	67.9 (5.6)	68.8 (2.7)	67.2
	Mean		58.1	63.2	60.1		68.8b	73.2ab	75.1a		64.7	65.6	69.1	
Soybean	0x	50.4	57.2 (3.2)	56.5 (5.8)	58.2 (5.4)	57.3	61.8 (4.0)	74.4 (4.2)	71.3 (3.7)	69.2	61.8 (3.5)	60.4 (4.2)	72.8 (1.4)	65.0
	0.5x		54.8 (3.6)	57.0 (2.9)	62.1 (1.4)	57.9	61.3 (4.2)	76.4 (2.3)	80.6 (1.7)	72.8	48.8 (2.2)	65.3 (3.0)	70.6 (1.1)	61.5
	1x		46.6 (7.7)	64.7 (2.6)	52.8 (1.6)	54.7	63.5 (2.0)	70.0 (5.0)	86.1 (1.2)	73.2	55.3 (3.0)	60.0 (2.3)	68.4 (2.2)	61.3
	1.5x		54.1 (4.2)	53.5 (5.3)	62.8 (4.1)	56.8	68.3 (5.4)	75.9 (6.5)	82.8 (1.5)	75.7	61.8 (2.7)	64.3 (3.6)	65.3 (0.9)	63.8
	Mean		53.1	57.9	58.9		63.8b	74.2a	80.2a		56.9c	62.5b	69.3a	
Wheat	0x	47.7	65.3 (4.7)	58.4 (2.5)	61.9 (6.2)	61.9	66.9 (5.1)	80.8 (3.0)	81.3 (2.4)	76.3	63.9 (8.1)	67.3 (3.0)	66.8 (2.7)	65.9
	0.5x		59.3 (2.6)	53.9 (2.1)	54.4 (5.4)	55.9	69.1 (3.5)	76.1 (2.9)	83.3 (2.8)	76.2	61.2 (4.5)	67.1 (2.7)	68.4 (1.8)	65.6
	1x		60.2 (3.1)	58.3 (2.3)	53.4 (8.5)	57.3	70.5 (6.7)	76.1 (4.7)	77.5 (5.7)	74.7	68.3 (2.6)	69.0 (1.4)	69.5 (1.4)	68.9
	1.5x		60.9 (2.4)	57.7 (3.2)	70.3 (3.9)	62.9	73.5 (3.4)	76.7 (2.8)	80.3 (1.9)	76.8	67.1 (1.7)	62.9 (4.6)	69.1 (3.1)	66.4
	Mean		61.5	57.1	60.0		70b	77.4a	80.6a		65.1	66.6	68.4	

Table 3.6. Mean % of aggregate stability (Ag Stab), β–glucosidase activity, permanganate oxidizable carbon (POXC), total N, total organic C, and soil quality index (SQI) from 0-15 cm, 2012-2014, as impacted by compost application. Compost applications were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

	Ag Stab	β–glucosidase	POXC	Total N	TOC	SQ index
	------%------	µg PNP g soil^{-1} hr^{-1}		g kg soil^{-1}		
0x	61.2 (1.1)	5.8 (0.2) b	0.60 (0.02) b	2.2 (0.0) b	22.0 (0.2)	0.71 c
0.5x	60.8 (1.1)	6.3 (0.2) ab	0.62 (0.02) ab	2.2 (0.0) b	22.4 (0.3)	0.73 b
1x	60.6 (1.1)	6.6 (0.2) a	0.63 (0.02) a	2.3 (0.0) ab	22.9 (0.3)	0.74 ab
1.5x	62.0 (1.1)	6.7 (0.2) a	0.64 (0.02) a	2.3 (0.1) a	22.8 (0.3)	0.75 a

Table 3.7. Mean biomass of soil PLFA (0-15 cm) from 2012-2014 as impacted by compost application. Compost applications were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Standard errors are stated in parentheses. ACT=actinobacteria, AMF=arbuscular mycorrhizael fungi, ANAER=anaerobic bacteria, EUK=eukaryotes, GNEG= gram negative bacteria, GPOS= gram positive bacteria.

	0x		0.5x		1x		1.5x	
	picomoles g soil^{-1}							
ACT	15758	(245)	15828	(227)	16110	(242)	16154	(236)
AMF	6038	(181)	6113	(150)	6173	(168)	6093	(147)
ANAER	1512	(39)	1529	(43)	1548	(43)	1514	(45)
EUK	2248	(124)	3385	(556)	3010	(466)	2847	(479)
FUNGI	2138	(139)	2180	(111)	2473	(137)	2287	(127)
GNEG	40622	(815)	42209	(882)	42767	(842)	42520	(655)
GPOS	29077	(569)	29772	(551)	30138	(617)	30086	(548)

Table 3.8. Mean of β–glucosidase activity at 0-15 cm soil depth, 2012-2014, as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each row and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started.

		Pre-study	2012				2013				2014			
		TCCP												
crop	compost	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean
		µg PNP g soil^{-1} hr^{-1}												
Corn	0x	5.3	4.9 (0.6)	5.7 (0.7)	7.9 (1.4)	6.1	5.9 (0.6)	7.4 (2.0)	6.4 (1.3)	6.6	6.6 (0.7)	5.4 (0.5)	5.8 (0.7)	6.0
	0.5x		6.9 (0.4)	7.3 (1.0)	6.0 (0.5)	6.7	7.7 (0.8)	6.6 (1.1)	8.6 (1.8)	7.6	5.7 (0.3)	6.4 (0.6)	7.1 (0.8)	6.4
	1x		6.7 (1.3)	8.7 (1.3)	8.0 (1.3)	7.8	9.3 (1.0)	8.7 (0.3)	7.1 (0.7)	8.3	7.0 (0.7)	7.6 (1.3)	7.3 (1.1)	7.3
	1.5x		7.6 (1.0)	7.1 (0.7)	8.3 (0.8)	7.7	7.6 (1.1)	9.4 (1.3)	8.8 (0.9)	8.6	6.5 (0.8)	8.0 (0.7)	7.2 (1.4)	7.3
	Mean		6.5	7.2	7.6		7.6	8.0	7.7		6.5	6.9	6.8	
Soybean	0x	5.5	5.1 (0.3)	6.3 (0.4)	5.6 (0.7)	5.6	5.0 (0.3)	7.4 (1.3)	5.7 (1.1)	6.0	4.9 (0.9)	4.2 (0.8)	5.2 (0.2)	4.7
	0.5x		5.8 (0.9)	6.7 (0.5)	5.4 (0.5)	5.9	4.5 (0.7)	7.3 (0.5)	8.7 (0.4)	6.8	4.0 (0.4)	4.5 (0.4)	5.5 (0.2)	4.6
	1x		5.2 (0.6)	7.1 (0.3)	6.1 (1.5)	6.1	6.1 (0.7)	8.1 (1.9)	8.0 (1.4)	7.4	5.1 (1.1)	4.8 (0.5)	7.1 (1.0)	6.7
	1.5x		5.2 (0.4)	6.6 (0.2)	5.7 (0.5)	5.9	4.6 (1.6)	9.4 (1.6)	8.1 (1.2)	7.4	4.8 (0.2)	6.8 (0.6)	6.4 (0.5)	6.0
	Mean		5.3b	6.7a	5.7ab		5.1b	8.1a	7.6a		4.7b	5.0ab	6.0a	
Wheat	0x	4.6					6.6 (0.6)	7.9 (0.4)	9.0 (0.6)	7.8	4.3 (0.8)	4.5 (0.6)	7.4 (1.6)	5.4
	0.5x						7.8 (0.3)	9.7 (1.2)	9.3 (0.7)	8.9	5.9 (0.6)	6.5 (0.8)	8.2 (1.3)	6.9
	1x						8.2 (0.8)	10.5 (1.0)	7.8 (0.4)	8.8	5.7 (0.8)	6.6 (0.9)	5.8 (0.5)	6.1
	1.5x						8.4 (0.6)	10.4 (1.4)	8.1 (1.3)	9.0	6.8 (1.7)	5.7 (0.5)	7.2 (1.9)	6.6
	Mean						7.7b	9.6a	8.6ab		5.7	5.8	7.2	

Table 3.9. Mean % of aggregate stability (Ag Stab), β–glucosidase activity, permanganate oxidizable carbon (POXC), total N, total organic C, and soil quality index (SQI) from 0-15 cm, 2012-2014, as impacted by year. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

	Ag Stab	β–glucosidase	POXC	Total N	TOC	SQ index
	------%------	μg PNP g soil^{-1} hr^{-1}	------------------------	g kg soil^{-1}	------------------------	
2011	46.7 (0.9) d	5.1 (0.1) c		2.0 (0.0) c	20.5 (0.2) c	0.66 d
2012	58.9 (0.7) c	6.5 (0.2) b	0.38 (0.01) c	2.2 (0.0) bc	21.9 (0.1) b	0.76 b
2013	73.7 (0.7) a	7.8 (0.2) a	0.83 (0.01) a	2.5 (0.0) a	26.4 (0.2) a	0.79 a
2014	65.4 (0.6) b	6.1 (0.2) b	0.58 (0.01) b	2.3 (0.1) b	21.1 (0.2) c	0.74 c

Table 3.10. Mean % of aggregate stability (Ag Stab), β–glucosidase activity, permanganate oxidizable carbon (POXC), total N, total organic C, and soil quality index (SQI) from 0-15 cm, 2012-2014, as impacted by tillage/cover crop (TCCP). TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

	Ag Stab	β–glucosidase	POXC	Total N	TOC	SQ index
	------%------	μg PNP g soil^{-1} hr^{-1}	------------------------	g kg soil^{-1}	------------------------	
NTCC	62.7 (1.1) a	6.5 (0.2)	0.63 (0.02)	2.3 (0.0)	22.8 (0.3) a	0.74
TCC	62.3 (0.9) a	6.8 (0.2)	0.62 (0.02)	2.3 (0.0)	22.8 (0.2) a	0.73
TNCC	58.5 (0.9) b	5.7 (0.1)	0.62 (0.02)	2.2 (0.0)	21.9 (0.2) b	0.73

Table 3.11. Mean % of aggregate stability (Ag Stab), β–glucosidase activity, permanganate oxidizable carbon (POXC), total N, total organic C, and soil quality index (SQI) from 0-15 cm, 2012-2014, as impacted by crop. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

	Ag Stab	β–glucosidase	POXC	Total N	TOC	SQ index
	------%------	μg PNP g soil^{-1} hr^{-1}	------------------------	g kg soil^{-1}	------------------------	
corn	60.4 (1.1) b	6.7 (0.2) a	0.58 (0.01) b	2.3 (0.0) a	22.5 (0.3)	0.75 a
soybean	60.6 (0.9) b	5.9 (0.1) b	0.59 (0.02) b	2.3 (0.0) ab	22.4 (0.2)	0.73 b
wheat	62.5 (0.9) a	6.5 (0.2) a	0.74 (0.01) a	2.2 (0.0) b	22.7 (0.3)	0.72 c

Table 3.12. Mean of permanganate oxidizable carbon (POXC) at 0-15 cm soil depth, 2012-2014, as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

		2012				2013				2014			
		TCCP											
crop	compost	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean
		POXC g kg soil^{-1}											
Corn	0x	0.35 (0.04)	0.34 (0.01)	0.308 (0.03)	0.33b	0.78 (0.02)	0.79 (0.04)	0.78 (0.02)	0.78	0.56 (0.03)	0.52 (0.05)	0.54 (0.06)	0.54
	0.5x	0.40 (0.02)	0.41 (0.03)	0.372 (0.01)	0.39a	0.80 (0.03)	0.74 (0.03)	0.82 (0.01)	0.79	0.61 (0.03)	0.59 (0.04)	0.59 (0.03)	0.60
	1x	0.44 (0.05)	0.42 (0.03)	0.372 (0.01)	0.41a	0.80 (0.03)	0.80 (0.01)	0.71 (0.01)	0.77	0.58 (0.04)	0.53 (0.04)	0.57 (0.06)	0.56
	1.5x	0.44 (0.04)	0.38 (0.02)	0.360 (0.01)	0.39a	0.80 (0.03)	0.83 (0.03)	0.81 (0.04)	0.81	0.63 (0.04)	0.62 (0.03)	0.60 (0.04)	0.62
	Mean	0.41a	0.39ab	0.35b		0.80	0.79	0.78		0.60	0.57	0.57	
Soybean	0x	0.38 (0.05)	0.40 (0.03)	0.39 (0.03)	0.39	0.79 (0.07)	0.79 (0.05)	0.85 (0.00)	0.81	0.51 (0.04)	0.45 (0.02)	0.51 (0.01)	0.489b
	0.5x	0.35 (0.06)	0.38 (0.03)	0.37 (0.03)	0.37	0.85 (0.06)	0.89 (0.06)	0.85 (0.05)	0.86	0.42 (0.01)	0.56 (0.07)	0.57 (0.01)	0.515ab
	1x	0.37 (0.03)	0.40 (0.03)	0.34 (0.02)	0.37	0.94 (0.08)	0.86 (0.03)	0.87 (0.07)	0.89	0.51 (0.03)	0.53 (0.04)	0.55 (0.02)	0.529ab
	1.5x	0.34 (0.03)	0.36 (0.05)	0.44 (0.04)	0.38	0.78 (0.04)	0.89 (0.08)	0.86 (0.04)	0.85	0.59 (0.03)	0.54 (0.06)	0.62 (0.05)	0.580a
	Mean	0.36	0.39	0.38		0.84	0.86	0.86		0.51	0.52	0.56	
Wheat	0x					0.75 (0.06)	0.88 (0.03)	0.85 (0.03)	0.83	0.61 (0.04)	0.61 (0.02)	0.69 (0.05)	0.64
	0.5x					0.82 (0.02)	0.82 (0.01)	0.86 (0.03)	0.83	0.64 (0.01)	0.60 (0.01)	0.63 (0.04)	0.62
	1x					0.85 (0.04)	0.89 (0.04)	0.84 (0.04)	0.86	0.68 (0.02)	0.62 (0.05)	0.69 (0.03)	0.66
	1.5x					0.83 (0.04)	0.86 (0.03)	0.89 (0.02)	0.86	0.61 (0.04)	0.67 (0.05)	0.67 (0.02)	0.65
	Mean					0.81	0.86	0.86		0.63	0.62	0.67	

Table 3.13. Mean biomass of soil PLFA (0-15 cm) from 2012-2014 as impacted by tillage/cover crop (TCCP). TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. ACT=actinobacteria, AMF=arbuscular mycorrhizael fungi, ANAER=anaerobic bacteria, EUK=eukaryotes, GNEG= gram negative bacteria, GPOS= gram positive bacteria.

	NTCC			TCC			TNCC		
				picomoles g soil^{-1}					
ACT	16720	(175)	a	16172	(202)	a	14995	(208)	b
AMF	6571	(130)	a	6236	(141)	a	5506	(133)	b
ANAER	1539	(33)		1568	(41)		1470	(36)	
EUK	3273	(324)		3218	(557)		2128	(119)	
FUNGI	2345	(115)		2258	(110)		2205	(111)	
GNEG	44340	(616)	a	42618	(758)	a	39131	(631)	b
GPOS	31212	(437)	a	30300	(507)	a	27792	(491)	b

Table 3.14. Mean biomass of soil PLFA (0-15 cm) from 2012-2014 as impacted by crop. Values followed by a different lowercase letter within each row are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. ACT=actinobacteria, AMF=arbuscular mycorrhizael fungi, ANAER=anaerobic bacteria, EUK=eukaryotes, GNEG= gram negative bacteria, GPOS= gram positive bacteria.

	corn			soybean			wheat		
				picomoles g soil^{-1}					
ACT	16660	(179)	a	14981	(169)	b	16387	(255)	a
AMF	6480	(141)	a	5314	(96)	b	6727	(153)	a
ANAER	1631	(39)	a	1390	(29)	b	1572	(39)	a
EUK	2663	(305)		2918	(470)		3119	(259)	
FUNGI	2424	(96)	a	2028	(107)	b	2401	(139)	a
GNEG	43105	(633)	a	39649	(633)	b	43986	(808)	a
GPOS	31269	(461)	a	26549	(334)	b	32346	(562)	a

Table 3.15. Mean Bray 1 P and extractable K from 0-15 cm, 2012-2014, as impacted by compost application. Compost applications were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

	P		K	
	mg kg soil^{-1}			
0x	11.4 (0.6)	d	89.9 (2.3)	c
0.5x	16.7 (0.9)	c	98.9 (2.8)	bc
1x	22.9 (1.4)	b	109.2 (3.3)	bc
1.5x	28.5 (1.8)	a	125.2 (4.4)	a

Table 3.16. Mean of soil quality fractional index at 0-15 cm soil depth, 2012-2014, as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management included: TNCC= tillage no cover crop, TCC= tillage with cover crop, and NTCC= no-till with cover crop. Compost rates were as follows: 0x= zero compost, 0.5x= 0.5 x the recommended rate, 1x= recommended rate, and 1.5x= 1.5 x recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started.

		Pre-study	**2012**				**2013**				**2014**			
		TCCP												
crop	compost	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean
		SQI Fractional Score												
Corn	0x	0.69 (0.03)	0.74 (0.01)	0.75 (0.01)	0.74 (0.00)	0.74	0.79 (0.01)	0.79 (0.01)	0.79 (0.01)	0.78c	0.65 (0.01)	0.67 (0.02)	0.65 (0.01)	0.65c
	0.5x		0.78 (0.01)	0.78 (0.01)	0.79 (0.01)	0.78	0.81 (0.01)	0.79 (0.01)	0.81 (0.01)	0.80b	0.74 (0.00)	0.74 (0.02)	0.75 (0.02)	0.75b
	1x		0.79 (0.01)	0.77 (0.02)	0.79 (0.01)	0.78	0.82 (0.01)	0.82 (0.01)	0.81 (0.01)	0.81ab	0.78 (0.01)	0.77 (0.01)	0.77 (0.01)	0.77a
	1.5x		0.80 (0.01)	0.80 (0.01)	0.80 (0.01)	0.80	0.82 (0.01)	0.82 (0.01)	0.82 (0.01)	0.82a	0.78 (0.01)	0.79 (0.01)	0.79 (0.01)	0.79a
	Mean		0.78	0.77	0.78		0.81	0.81	0.81		0.73	0.74	0.74	
Soybean	0x	0.66 (0.03)	0.72 (0.01)	0.75 (0.02)	0.73 (0.01)	0.73c	0.78 (0.01)	0.78 (0.02)	0.78 (0.02)	0.77b	0.70 (0.01)	0.70 (0.01)	0.74 (0.02)	0.71b
	0.5x		0.75 (0.02)	0.75 (0.02)	0.74 (0.02)	0.74bc	0.79 (0.02)	0.79 (0.03)	0.81 (0.01)	0.79a	0.72 (0.01)	0.72 (0.02)	0.75 (0.02)	0.72b
	1x		0.75 (0.02)	0.76 (0.03)	0.77 (0.02)	0.76ab	0.79 (0.02)	0.79 (0.02)	0.81 (0.02)	0.79a	0.73 (0.01)	0.74 (0.03)	0.77 (0.02)	0.75a
	1.5x		0.76 (0.02)	0.77 (0.02)	0.77 (0.03)	0.77a	0.80 (0.02)	0.81 (0.01)	0.81 (0.02)	0.80a	0.76 (0.02)	0.74 (0.03)	0.77 (0.02)	0.76a
	Mean		0.74b	0.76a	0.75ab		0.78b	0.79ab	0.80a		0.73b	0.72b	0.75a	
Wheat	0x	0.65 (0.02)					0.75 (0.03)	0.76 (0.03)	0.75 (0.02)	0.75	0.73 (0.03)	0.71 (0.03)	0.72 (0.02)	0.72
	0.5x						0.76 (0.03)	0.77 (0.04)	0.78 (0.03)	0.77	0.72 (0.03)	0.73 (0.03)	0.73 (0.03)	0.73
	1x						0.77 (0.03)	0.79 (0.02)	0.78 (0.03)	0.77	0.73 (0.03)	0.73 (0.02)	0.73 (0.02)	0.73
	1.5x						0.76 (0.03)	0.78 (0.03)	0.79 (0.03)	0.78	0.73 (0.03)	0.74 (0.02)	0.74 (0.03)	0.74
	Mean						0.76	0.77	0.77		0.73	0.73	0.73	

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CHAPTER FOUR

EFFECT OF CROP ROTATION ON SOIL QUALITY AND THE WEED SEEDBANK DURING THE THREE YEAR TRANSITION TO CERTIFIED ORGANIC PRODUCTION

Abstract

The transitional period from conventional to organic row cropping can be the most important and the most challenging time for an organic producer because of the need to control weeds, decrease the weed seedbank, and improve soil quality and fertility. To determine the effect of crop rotation and tillage practices on weed control and soil quality during the transition into organic row cropping, we examined seven transitional rotational cropping systems. All rotations utilized a fall planted winter cover mix prior to spring planting and included the grain crops corn (*Zea mays* L.), soybean (*Glycine max* L.), winter wheat (*Triticum aestivum* L.), grain sorghum [*Sorghum bicolor* (L.) Moench] and the summer cover crops sorghum-sudangrass [*Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf.] and sunn hemp (*Crotalaria juncea* L.). The seven rotational systems were: 1) Cover crop only (CCO), which was established as three years of winter and summer cover crops with no intervening cash crop; 2) Modified cover crop treatment (MCC), which utilized one year of a sorghum-sudangrass summer cover crop followed by grain sorghum in year two and corn in year three; 3) Modified conventional tillage (MCT), one year of sorghum-sudangrass in the summer followed by winter wheat and a soybean double-crop in year two and corn in year three; 4-5) Conventional tilled corn/soybean (CONVCS) and sorghum/soybean (CONVSS); and 6-7) No-till corn/soybean (NTCS) and sorghum/soybean (NTSS). The study site was located in central Missouri on a Mexico silt loam soil (fine, smectitic, mesic Vertic Epiaqualfs) from 2012 to 2014. Soil quality indicators measured included aggregate stability (AgStab), β-glucosidase (BG) activity, permanganate oxidizable carbon (POXC), total organic carbon (TOC), total nitrogen (TN), PLFA biomass and soil P and K levels. Weed biomass and total weed seeds were also determined. Conventionally tilled soybean yield was a greater percentage of conventional, non-organic yield than wheat, corn or grain sorghum because soybean did not experience low fertility constraints following termination of synthetic fertilizer use and before compost began actively releasing N for crop nutrition and growth. Although CCO led to lower numbers of weed seeds, it did not significantly decrease weed biomass. Soil quality indicators were not significantly different in the CCO system compared to the other treatments. Organic no-till was difficult to manage and is not recommended for use when transitioning to organic production.

Keywords: organic grain production, organic no-till, corn, soybean, wheat, soil health, soil quality, aggregate stability, active carbon, β-glucosidase, cover crop, rye, hairy vetch, PLFA, soil organic carbon.

Abbreviations: SOC, soil organic carbon; C, carbon; N, nitrogen; POXC, permanganate oxidizable carbon; P, phosphorus; K, potassium; AgStab, aggregate stability; BG, β-glucosidase; DM, dry matter; PLFA, Phospholipid Fatty Acid; CONVCS, conventional tilled corn-soybean; CONVSS, conventional tilled sorghum-soybean; NTCS, no-till corn-soybean; NTSS, no-till sorghum-soybean; CCO, cover crop only; MCC., modified cover crop; MCT, modified conventional tillage.

Introduction

To gain organic certification in the U.S., a three year transitional period is required during which no prohibited materials, such as synthetic chemicals, fertilizers or genetically modified seeds, may be applied to the land. This transitional period from conventional to organic row cropping can be the most important and the most challenging time for an organic producer because of the need to control weeds, decrease the weed seedbank (Riemens et al., 2007) and improve soil quality and fertility (Delate and Cambardella, 2004). Soil quality is a composite view of the soil's physical, chemical and biological properties and processes that sustain productivity, environmental quality and support a fully functional biological system (Doran and Zeiss, 2000). Soil organic matter (SOM) and its primary constituent, soil organic carbon (SOC), are closely linked to soil quality and soil fertility, thus maintaining or increasing SOM is an important goal in organic transition (Wander et al., 1994, Clark et al., 1998).

Many studies have been reported on organic and conventional comparisons (Cavigelli et al., 2008a, Gomiero et al., 2011, Hepperly et al., 2006, Gunapala and Scow, 1998), but studies comparing the effects of different row-crop rotations and tillage practices during organic transition on soil quality are not common. Tu et al. (2006) compared transitional strategies using one fully organic strategy with four reduced-input strategies with varying reductions of synthetic fertilizers and herbicides. The fully organic system was most effective at increasing soil microbial biomass, but had the lowest yields. Partially reducing synthetic inputs during the transition led to higher soil microbial respiration rate and N mineralization than the conventional control. However, any use of synthetic inputs further delays organic qualification by another three years so other transitional strategies that can maintain a productive cropping system are usually sought by producers.

A study on several organic farms under a corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] rotation found that soil quality indices of SOC, total N, biologically active C and N, and P all increased under organic transition within three years (Delate and Cambardella, 2004). Furthermore, increased tillage in organic plots did not reduce soil organic carbon compared to conventional plot levels. To test if yield increases in organic production are due to gradual improvements in soil quality, Martini et al. (2004) compared identically managed organic and transitional plots under organic management for different time periods (>5 and < 1 year). They concluded that organic tomatoes (*Solanum lycopersicum* L.) yielded better than conventional tomatoes during organic transition due to beneficial effects of a winter annual legume cover crop and that previously reported yield increases during transition may be due more to improved management with increasing experience than from improved soil quality.

Some crops may be better suited for use during the transition years than others. Yields often decrease during organic transition due to increased weed interference and lower fertility, although high-N use crops such as tomato and corn usually experience greater yield decreases than low-N use crops such as soybean (Clark et al., 1999, Liebhardt et al., 1989). In a meta-analysis of 362 studies comparing conventional and organic crop yields, de Ponti et al. (2011) found that organic crops yield an average of 80% of conventional crops (21% StdDev). Corn yield averaged 89% of its conventional counterpart, wheat (*Triticum aestivum* L.) 73%, and soybean 92%. However, Delate and Cambardella (2004), comparing conventional corn-soybean in Iowa to three organic transitional rotations using corn, soybean, alfalfa (*Medicago sativa* L.) and oats (*Avena sativa* L.), with cereal rye (*Secale cereale* L.) used as a winter cover crop, found that yields of the organic crops met or exceeded yields of their conventional counterparts.

Weeds can be a significant factor in yield reduction in a system transitioning to organic production. Under mechanical and hand hoeing weed control strategies employed by Riemens et al. (2006), the size of the weed seedbank increased during the conversion from conventional to organic farming. This was attributed to the absence of weed inhibiting herbicides, suboptimal mechanical weed control while technicians were learning to use new weed control methods, and a decline in crop cover biomass as a result of diminished fertility during the organic transition. Significant hand hoeing had to be used to prevent crop yield loss. Transitional crop rotations that start with less competitive crops may also lead to increased total weed seed production while more competitive crops can cause a reduction in weed seeds (Albrecht, 2005). Delate (2011) examined organic no-till using a roller/crimper and found that broadleaf weed control in no-till soybeans following a cereal rye-hairy vetch (*Vicia villosa* Roth) cover crop was similar to tilled treatments, but weed density in no-till corn treatments was five to nine times higher than with tillage.

Crop rotation and crop type along with tillage type were found to be factors in weed seed reduction. No-till systems generally accumulate weed seeds near the soil surface while increased tillage causes declines in total weed seed numbers and greater distribution of weed seeds throughout the tillage depth (Bàrberi and Lo Cascio, 2001, Cardina et al., 2002). Farming systems that contain cereals in the crop rotations can reduce weed density (Doucet et al., 1999) although studies that utilize herbicides may find increased weed seed density when a crop with limited labeled herbicides, such as oats or hay crops are used in rotations (Cardina et al., 2002). When herbicide and inorganic fertilizer usage cease, weed cover may increase by 50%, with an accompanying increase of perennial weed species (Hill et al., 1989).

To determine the effect of crop rotation and tillage practices on weed control and soil quality during the transition into organic row cropping, we examined seven transitional cropping systems. All systems utilized fall planted winter cover crops or wheat prior to spring planting (Table 4.1). The cash crops were corn, soybean, wheat, and grain sorghum [*Sorghum bicolor* (L.) Moench] and the summer cover crops sorghum-sudangrass [*Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf.] and sunn hemp (*Crotalaria juncea* L.). The seven cropping systems tested are listed in Table 4.2. Cover crop only (CCO), was established as three years of winter and summer cover crops with no intervening cash crop. Sorghum-sudangrass was the summer cover crop in year one and two and sunn hemp, a tropical legume, was used in year three. Cover crops provided weed control through resource competition and allelopathic effects (Teasdale, 1996, Creamer et al., 1996). They can also improve soil nutrient cycling efficiency, reduce soil erosion, increase SOC, increase water infiltration and improve soil physical properties (Snapp et al., 2005, Dabney et al., 2001, Lundquist et al., 1999a). We hypothesized that the CCO system would provide the greatest weed control and soil quality building during the transition to organic.

A modified cover crop treatment (MCC), utilized one year of a sorghum-sudangrass summer cover crop followed by grain sorghum in year two and corn in year three. Sorghum species contain sorgoleone, an allelopathic chemical that has been found to reduce growth of weed seedlings (Einhellig and Souza, 1992), so we hypothesized that two consecutive years of sorghum species would lead to lower weed seed growth and seed production. Having grain sorghum in year two was expected to be more economically viable than two years of summer cover crop. In treatment MCT, modified conventional tillage, the transition began with one year of sorghum-sudangrass in the summer followed by winter wheat and a soybean double-crop in year two and corn in year three, with tillage as needed to control weeds

CONVCS, conventional tilled corn-soybean-wheat-double crop soybean rotation utilized pre-plant tillage for early weed control and between row cultivation for in-season weed control. NTCS, no-till corn-soybean, followed the same rotation as CONVCS but included a crimped winter cover crop for weed control without any soil tillage until year three when a soybean double-crop was planted following winter wheat. No-till can reduce the carbon footprint of organic farmers by using cover crops flattened and killed by a roller/crimper as a weed blocking mulch instead of relying on multiple tillage events for weed control (Carr et al., 2013a, Mirsky et al., 2013).

In treatments NTSS, no-till sorghum-soybean, and CONVSS, conventional tilled sorghum-soybean, both the no-till and conventional till rotations were replicated using grain sorghum as the second year cash crop instead of corn. Grain sorghum has a history of success in MO, and a majority of its fertility needs may be met through use of a winter legume cover crop (Reinbott et al., 2004). Genetically modified (GM) varieties are not available for grain sorghum and thus it cannot cross pollinate with GM varieties, which are prohibited by National Organic Program (NOP) regulations.

Materials and Methods

Research Site and Design

This research was conducted from 2012-2014 at the University of Missouri Bradford Research Center (BREC), located in Boone County 8 kilometers east of Columbia, MO. Soils at this site are primarily Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualfs) and are on the central glacial till claypan plain. This site has an argillic horizon, which is a claypan, typically 25 cm below the soil surface. This research site had previously been managed as a fescue (*Festuca arundinacea* L.) meadow until 2010 when the fescue was tilled under and the field was planted with a summer cover crop of buckwheat (*Fagopyrum esculentum* Moench) for two years. These conditions might be similar to land that is put into organic production after being in long-term conservation reserve (CRP).The experiment was conducted as a randomized complete block design with five replications of seven different cropping system treatments. Plots were 6 x 10 m.

Weather

Due to the extreme drought in 2012, irrigation was applied at approximately 2.5 cm of water on 6 June, 6 and 20 July, and 3 and 17 August. Although 2013 experienced moderate drought, irrigation was not used. The average temperature from May through September in 2012, 2013 and 2014 was 23.3 C, 21.3 C, and 21.3 C and the total rainfall from May through September in those years was 177.3 mm, 440.9 mm, and 516.7 mm, respectively. The annual cumulative rainfall for 2012-2014 is shown in Figure 4.1 and is plotted against the 30-year average for Boone County, MO.

Crop Management

A poultry compost product (Central Missouri Poultry Producers, Inc., High Point, MO) was broadcast surface-applied once annually each spring at Zadoks growth stage 2.4 in winter wheat and just after winter cover crop termination in other treatments (Zadoks et al., 1974). In tilled plots, the compost was incorporated into the soil and in no-till plots the compost was left on top of the soil surface. Applied compost amounts were based on the soil-test P recommendation (Buchholz et al., 2004) and the P content of the compost to prevent potential P loss. The amount applied annually was approximately 4480 kg ha^{-1} of compost, 86 kg ha^{-1} of P and 127 kg ha^{-1} of N.

Pre-plant tillage was conducted using a 1.5 m wide plot disk and weed control was done in crop plots using a Danish S-tine 4-row. Management dates and processes are shown in Table 4.3. Cover crops in no-till plots were terminated using a roller-crimper (I&J Mfg, Gap, PA). Cover crops in tilled treatments were first flail mowed and then incorporated into the soil. The organic corn (Welter Seed hybrid WS2292), soybean (Blue River Hybrids 389F.Y) and grain sorghum (VNS, Welter Seed) were planted using a 4-row John Deere 7000 planter (Moline, IL) using 76 cm wide rows at 86,450, 385,320 , and 276,640 seeds ha^{-1}, respectively. Due to the dense residue established by the cover crop in the no-till plots, the no-till coulters were removed and spiked closing wheels (Schoup Mfg., Kankakee, IL) were installed on the planter to effectively close the seed-row furrow in 2013 and 2014.

The winter cover crop (Table 4.1) was a mix of hairy vetch, cereal rye, Austrian winter pea (*Pisum sativum* L. subsp. Arvense), and crimson clover (*Trifolium incarnatum* L.). Shallow tillage before planting of cover crops (<4 inches) was done in all but the no-till systems. The cover crops and the organic wheat (variety “Bess”) were planted using a Tye no-till drill (city state) in 19 cm wide rows. Wheat was planted at 100 kg ha^{-1}.

To determine cover crop yields, a 0.25 m^2 quadrat was randomly placed in the plots and above-ground cover crop biomass was removed, dried in a forced air dryer, and weights were recorded. Crop treatments were harvested at physiological maturity using plot combines to harvest the middle two rows of corn, soybean and grain sorghum, and the middle 1.5 m of wheat. Corn was harvested with a two-row Kincaid research combine (Kincaid Equipment Mfg., Haven, KS) while the soybean, sorghum and wheat were harvested with a Wintersteiger research combine (Wintersteiger Inc., Salt Lake City, UT) with a 1.5 m standard reel header platform. Corn moisture was determined by the combine moisture sensor, and yield adjusted to 155 g kg^{-1} moisture. Grain moisture for soybean, sorghum and wheat were determined using a benchtop moisture meter, and yields adjusted to 130 g kg^{-1} moisture for soybean, and 135 g kg^{-1} for sorghum and wheat. Harvest dates are shown in Table 4.3.

Plant Analyses

Leaf samples from cereal and grain crops and plant samples from cover crops were taken at anthesis to determine C and N levels using a LECO® combustion analyzer (Leco Corp., St. Joseph, MI). To determine biomass of winter and summer cover crops, a quadrat measuring 0.25 m^2 was randomly placed at two locations in each plot and plants were removed and dried in a forced air dryer and dry weights were recorded.

Weed Analyses

Weed seeds were separated from a 100 g soil sample (collection described in soil analyses section) through addition of a solution of sodium hexametaphosphate (35.7 g L^{-}

^{1}) and sodium bicarbonate (7.94 g L^{-1}). Samples were shaken for 20 minutes then vacuum filtered through a Buchner funnel using small coffee filters. Remaining organic matter, sand particles and iron-manganese nodules (commonly found in claypan soils) were examined under a 10X microscope and weed seeds were counted and reported on a m^2 basis to a 15-cm depth. Due to time constraints, only total weed seed counts were performed and seeds were not identified by species. To determine weed biomass, a quadrat measuring 0.25 m^2 was randomly placed at two locations in each plot, plants were removed, dried and weighed. Individual weed species were visually noted at the time of sampling.

Soil Analyses

Soil samples were collected each fall just prior to harvest using a soil probe with a 19.05 mm diameter to a depth of 15 cm. Eight samples were taken in a grid pattern in each plot and were composited and homogenized using a 6.35 mm sieve. Sub-samples of soil for aggregate stability, pH_s, soil organic matter (SOM), cation exchange capacity (CEC), and macronutrient testing were air dried while all other samples were frozen at 0 C prior to lab analysis.

Analysis of CEC, pH_s, SOM, and macronutrients was performed by the University of Missouri Soil and Plant Testing Laboratory using the methods described in Nathan et al. (2006). CEC was estimated from the extractable K, Ca, and Mg results and the measure of neutralizable acidity. SOM was determined by loss-on-ignition. Potassium, Mg and Ca were extracted using ammonium acetate with K determined by flame emission and Ca and Mg concentration determined on an atomic absorption spectrophotometer. A 0.01 M $CaCl_2$ solution was added to 5 g of soil to determine pH_s

using a benchtop pH meter. Phosphorus was determined using Bray I extract, filtered, then ascorbic acid was added and the resulting color was read in a spectrophotometer set at 660 nm. Neutralizable acidity was determined using the New Woodruff Buffer method.

Wet aggregate stability was determined using the method of Nimmo and Perkins (2002). After air drying, a soil sample was passed through a 2 mm sieve and retained on a 1 mm sieve. Pre-weighed sieves of 0.5 mm were placed in plastic dishes filled with two liters of deionized water and 3.00 grams of the >1 to <2 mm soil fraction was evenly dispersed on the sieves and left to soak for 16 hours. Samples were agitated using 20 up and down strokes then sieves and soil were removed from water, placed on pre-weighed metal plates, and dried at 110° C for one hour. After dry weight was recorded, samples were returned to a bowl of deionized water. Sand and iron-manganese nodules were separated from soil aggregates by adding a solution of sodium hexametaphosphate (35.7 g L^{-1}) and sodium bicarbonate (7.94 g L^{-1}) then triturating the dispersing solution with fingers to remove soil particles left on the sieve. The samples and sieves were again dried at 110° C and the dry weights of the remaining particles were recorded and subtracted from the aggregate sample weights to determine the total amount and percentage of water stable soil aggregates.

Phospholipid fatty acid analysis was determined using the method of Buyer and Sasser (2012). In brief, samples were placed in test tubes and dried overnight. After a Bligh-Dyer lipid extraction was performed, the extract was dried, dissolved in chloroform, and placed into a 96 well extraction plate. Phospholipids were then eluted into vials, dried and transesterified. The fatty acid methyl esters produced by this process were then analyzed in a GC using MIDI Sherlock software (MIDI Inc., Newark, DE).

Activity of β-glucosidase, an enzyme that hydrolyzes degradation products of cellulose, was determined by mixing 1 g of soil with 4 mL of modified universal buffer at pH 6.0 and 1 mL of *p*-Nitrophenyl-β-ᴅ-glucoside (PNG) substrate solution and incubated at 37 C for 1 hour (Eivazi and Tabatabai, 1988). To stop the reaction, 1 mL of 0.5 M $CaCl_2$ and 4 mL of 0.1 M THAM buffer (pH 12) were added. The resulting solution was filtered through Q2 filter paper (Fisher Scientific, Waltham, MA) and measured in a spectrophotometer at 410 nm (Ultrospec 2100 pro uv/visible, Amersham Biosciences). The amount of *p*-nitrophenol released was determined using the following equation:

(a x Abs +b) x volume/dry soil mass (g)/ hours incubated

Where a = slope of the standard curve, Abs = the absorbance of the sample, b = the intercept of the standard curve and volume = the total volume of the reagents.

Soil organic carbon (SOC) and total nitrogen (TN) were determined on sieved (< 2 mm), air-dried, ground soil samples by dry combustion at 900 C using a LECO® Tru-Spec C/N Analyzer (Nelson and Sommers, 1996).

Ammonium-N and NO_3^--N were extracted by weighing 4 g soil into a 50 mL plastic tube with cap, adding 20 mL 2M KCl solution, then shaken for 30 minutes at 100 rpm (Griffin et al., 2009). The samples were allowed to settle before extraction and were then vacuum filtered through a Buchner funnel using grade Q2 filter paper. The final extract was stored in a 15 mL plastic tube and frozen until analysis. Extracted NH_4^+ and NO_3^- were analyzed using the Lachat Quickchem 8500 (Hach Company, Loveland, CO), a colorimetric method. Ammonium-N analysis was completed using Lachat method 12-107-06-2-A (Lachat, 1990b) and NO_3^--N analysis was completed using Lachat method 12-107-04-1-B (Lachat, 1990a).

The active soil carbon fraction was analyzed colorimetrically using the methods of Weil et al. (2003) and modified by Culman et al. (2012). A 2.5 g soil sample was added to 2.0 ml of potassium permanganate ($KMnO_4$) and 18.0 ml of DI water then shaken for two minutes. After settling for 10 minutes, a 0.5 ml sample of the supernatant was extracted, added to 49.5 ml of DI water and read at 550 nm on a spectrophotometer (Pharmacia LKB Ultrospec). The following equation was used to determine the permanganate oxidizable (POX) carbon:

POXC (mg kg-1) = [0.02 mol/L – (a+b x Abs)] x (9000 mg C/mol) x (0.02 L solution/Wt)

Where initial solution concentration = 0.02 mol/L, a = the intercept of the standard curve, b = the slope of the standard curve, Abs = absorbance of the unknown, 9000 = milligrams of carbon oxidized by 1 mole of MnO_4 changing from Mn^{7+} to Mn^{2+}, 0.02 L = volume of stock solution reacted, Wt = weight of air dried soil sample in kg.

Statistical Analysis

Statistical analysis was completed with SAS Enterprise Guide 6.1 (SAS, Cary, North Carolina). Results were analyzed using PROC MIXED at α=0.05. The ANOVA was run as a RCBD design. The fixed effect in the model was crop rotation treatment and random effect was block. All mean separation differences were tested using Tukey’s HSD. Analysis was separated by year because the experiment monitored effects of varying crop rotations over time.

Results and Discussion

Yield

Due to very poor stands from the environmental stress of high temperatures and low precipitation, biomass production of the cover crop in 2012 ranged from only 36 to 42% of the 8000 kg ha^{-1} that has been identified as the threshold for consistent suppression of annual weeds (Mirsky et al., 2013). This led to high summer annual weed biomass in all treatments (Table 4.4) and had strong adverse effects on NTCS and NTSS soybean yields, which averaged 87% lower than yields in the CONVCS and CONVSS soybean (Table 4.5). Because NTCS and NTSS soybean relied on cover crop residue to block weed growth, the reduced cover crop biomass provided little to no weed control throughout the growing season. Average yields of soybean in the CONVCS and CONVSS treatments were 86% of the average yield reported in the University of Missouri Variety Testing (UMVT) Columbia 2012 soybean trial (Wiebold et al., 2012b). This shows that full season soybean can be grown during organic transition without resulting in extreme yield loss. The UMVT tests include many GM varieties developed through concentrated breeding and yield testing while many of the organic crop varieties have received less testing and research attention due to no patent protection. Therefore, reductions in organic crop yields relative to conventional yields may be due more to varietal differences than production differences.

Drought conditions in 2012 also led to poor stands of sorghum-sudangrass in the CCO, MCC and MC treatments with an average cover crop biomass yield of 3625 kg ha^{-1} compared to 40,350 kg ha^{-1} in the CCO treatment in 2013 (Table 4.6), which had above average rainfall in the spring and early summer (Figure 4.1). Winter cover crop biomass levels were greater in 2013, but were still below the weed suppression threshold in all treatments except NTCS. However, summer weed biomass was significantly higher in the crop treatments, including NTCS, than the summer cover crop treatment, CCO, and MCT, where reduced weed biomass indicates that either the sorghum-sudangrass from 2012 and/or the grain sorghum in 2013 inhibited weed growth. Grain sorghum yield in the MCT treatment was significantly higher than in CONVSS, although both underwent the same tillage and cultivation (Table 4.5). MCT yield was still 81% less than the average yield of 7061 kg ha^{-1} determined by the UMVT state grain sorghum trials for 2007-2009 and 2014, the last 4 years that yield data was compiled (Wiebold et al., 2014b). Grain sorghum yield in NTSS was significantly less than CONVSS. It was observed that grain sorghum seedlings were not competitive against the weeds that were also emerging through the cover crop residue in NTSS treatments. Grain sorghum has demonstrated poor competitiveness against early season weeds (Burnside and Wicks, 1967).

Corn yield in NTCS was half of the CONVCS yield (Table 4.5), even though weed biomass in the two treatments did not differ significantly (Tables 4.4). Cover crop biomass in the NTCS was greater than the threshold for weed suppression and was 58% more than CONVCS biomass, indicating that weed control might not account for the differences in these two treatments (Table 4.6). It is possible that the higher cover crop biomass, which had a 59:1 C/N ratio, was immobilizing nitrogen in the NTCS treatment and suppressing growth of the corn. Although this is not supported by significant differences in spring and fall soil inorganic N levels (Table 4.7), several studies have shown that crop residue with a high C/N ratio can lead to N immobilization in the short term and reduced N uptake by subsequent crops (Kuo et al., 1997b, Ranells and Wagger, 1996). Additionally, the compost fertility treatment was applied to the field after cover crops were cut or crimped and before CONVCS was disked, allowing compost to remain on the soil surface in NTCS while it was incorporated in CONVCS, possibly leading to yield differences from N deficiency in NTCS due to reduced rate of compost decomposition and lower nutrient availability (Eghball and Power, 1999a). The small differences in soil inorganic N in 2013 and 2014 (Table 4.7) may be due more to the inconsistent nature of compost application rather than treatment effects. Our highest yielding corn in 2013 and 2014 yielded only 62% and 41% of the UMVT average corn yields for the same research farm (Wiebold et al., 2014a, Wiebold et al., 2013a).

Wheat was grown in year two in the MCT treatment and yielded 46% of the UMVT average for conventional wheat grown on the same farm (Wiebold et al., 2013b). Although weed counts were not taken, we observed that curly dock (*Rumex crispus* L.) occupied between 15 to 20% of the total land area in the CONVCS and CONVSS wheat treatments in both 2013 and 2014. Wheat yields in 2014 were higher in the CONVCS and CONVSS plots than in the NTCS and NTSS plots (Table 4.5) but were only 61% of the UMVT average for conventionally grown wheat on the same farm (Wiebold et al., 2014d). In 2014, curly dock and giant ragweed (*Ambrosia trifida* L.) were estimated to cover approximately 30% of the land area in the NTCS and NTSS wheat, which likely accounted for the decreased wheat yield in those treatments. Winter cover crop residue from previous years in NT plots might also be contributing to N immobilization in the soil, leading to decreased wheat yield. Due to relatively dry conditions in 2012 and 2013, winter cover crop residue did not decompose as rapidly in NT treatments as it did in treatments where it was mowed and tilled into the soil, thus N availability may be affected for a longer time period in NT plots. Double-crop soybean was grown after wheat in all treatments, but was not harvested for yield due to plants remaining extremely short and non-productive. In 2013, dry summer weather led to very poor double-crop soybean stands and growth. In 2014, higher moisture led to extremely rapid growth of giant foxtail (*Setaria faberi* Herrm) within the rows of double-crop soybean, which shaded out young soybean plants in spite of effective between-row cultivation.

Weed Suppression

Although it was hypothesized that weed growth would be reduced immediately by cover crops, weed biomass in 2012 was not significantly different in cover crops compared to crop treatments. This was due to the slow germination and poor growth of the sorghum-sudangrass from drought in 2012. In 2013, the CCO and the MCT treatments had significantly reduced weed biomass. In CCO, the sorghum-sudangrass cover crop grew extremely well (Table 4.6) and was highly competitive against weeds. The grain sorghum and/or the previous year’s sorghum-sudangrass residues provided weed control in the MCT treatment. In 2014, the MCT and MCC treatments both had high amounts of weed biomass. Because these two treatments both utilized corn as the rotation crop that year while all other treatments but CCO used soybean, the reduced weed control was likely a result of weed management problems in the corn and not that of past rotations. The cover crop in CCO during 2014 was sunn hemp, which has a more open canopy for light penetration for interception by weeds than sorghum sudangrass, but produced 63% less biomass per area than sorghum-sudangrass yielded in the previous year. We grew sunn hemp, a tropical legume, in year three because crops grown after sorghum-sudangrass were notably chlorotic and were likely experiencing N deprivation from the enormous amount of C that sorghum-sudangrass residue can introduce to the soil (Creamer and Baldwin, 2000).

Weed seed counts were conducted prior to establishing the different tillage and rotation treatments and were repeated at the conclusion of the study (Table 4.8). Pre-study weed seed counts were not significantly different between treatments and were extremely high when compared to other organic transitional studies (Riemens et al., 2007, Albrecht, 2005). This may have been because other studies were conducted in long-term cropland, which probably had low weed population densities prior to transition, whereas this study was conducted in a field that had previously been diverse meadow. Drought in 2012 may have also led to weed seed germination and subsequent desiccation, predation and decay (Gallandt, 2006). The total number of weed seeds was reduced in all treatments by the end of the study. Weed seed numbers in the CCO treatment in 2014 were significantly lower than in all other treatments, showing that a transitional strategy utilizing winter and summer cover crops can reduce the weed seedbank before beginning certified organic production. Although this approach may reduce immediate economic returns to near zero unless cover crops can also be utilized for hay or grazing, it may be a viable option in fields where weed populations are extremely high or herbicide-resistant weeds have proliferated before conversion to organic production.

Soil Quality

Although it was hypothesized that growing a three-year rotation of summer and winter cover crops would improve soil quality by increasing microbial biomass and community diversity, increasing active and total SOC, and improving aggregate stability, this was not found to be the case in this study. PLFA analysis, used to differentiate the soil microbial biomass into categories of AM fungi, anaerobic, gram negative and gram positive bacteria, eukaryotes, fungi and actinobacteria, did not reveal significant differences between treatments or years (Table 4.9). Because soil microorganisms are dependent on water for movement and metabolic function (Kieft et al., 1987), it was expected that PLFA numbers would increase after the 2012 drought when soil moisture levels became more conducive for microbial activity. However, the lack of response either shows that the drought did not have long-term effects on microorganisms in this soil, the small amount of irrigation water placed on the field had a positive effect on soil microorganisms, or that more than three years are required for the microbial components to recoup from an extreme drought. We have no pre-drought surveys for comparison to determine which of these processes was involved in affecting the microbial community response. A limited response of soil microorganisms to water stress may be due to the predominance of inactive or dormant microbes which survive short-term drought (Chen and Alexander, 1973) or due to the adaptive nature of soils and microbial populations in areas where climatic conditions routinely fluctuate (Lundquist et al., 1999b).

Several studies have shown that microbial biomass and community diversity can increase within a short time span when cover crops are utilized (Buyer et al., 2010, Bossio et al., 1998a) or when soil is not tilled (Mathew et al., 2012, Helgason et al., 2009). However, other studies have shown that seasonal PLFA variation may be greater than variation as an effect of tillage practice (Zhang et al., 2012, Spedding et al., 2004). Increased microbial biomass or community diversity can occur under conditions where soil C stocks may be increased or retained from production practices. Although the CCO, MCT and MCC treatments in this study added C to the soil in year one in the form of sorghum-sudangrass residue, the amount of residue was higher than the weed biomass in only the CCO treatment. It is possible that the high amount of weeds present in the field contributed to the lack of differences in PLFA between treatments as well as lack of significant differences in β-glucosidase activity (Table 4.10), POXC (Table 4.11) and TOC (Table 4.12). However, sorghum-sudangrass had very high biomass levels in 2013 and sunn hemp had greater biomass than the weed cover in 2014, yet there was not a change measured in any of these soil quality indicators. The study period may be too short to detect changes in soil quality related to the crop rotations and crop species used. Cover crop residue can be slow to break down under certain climatic conditions and may not always result in rapid changes to SOC levels, or residues might contribute to very rapid, temporary increases in microbial activity or active carbon (Hu et al., 1997) before stabilizing as the season progresses and SOC from the residue decomposition is mineralized.

SOC can affect aggregate stability, which is affected by crop rotation and tillage as well as soil microbial processes. Aggregate stability has generally been found to be higher in no-till systems (Karlen et al., 1994), but in this study we did not see a tillage treatment effect on aggregate stability between tilled and no-till plots in years one and two (Table 4.13). Significant differences in aggregate stability between treatments were observed in 2014 and values for all treatments increased from year one to year two then fell drastically in year three. In the spring of 2014, CONVCS and CONVSS were tilled as usual and NTSS and NTCS were tilled because organic no-till cannot be maintained after winter wheat because harvested wheat does not leave adequate residue for weed inhibition. MCC and MCT were tilled for improved weed control prior to planting corn, and CCO was tilled because residue buildup was so great it would have impeded germination of the subsequent crop. Although there was a large decrease in aggregate stability in all treatments from 2013 to 2014, this cannot all be attributed to tillage because there were no effects on aggregate stability by multiple disking and cultivation in the two previous years. Since the decrease in aggregate stability in year three cannot be entirely attributed to tillage, it is possible that heavy precipitation around the time of soil sampling (Figure 4.1) affected results.

Many studies that show changes in soil quality indicators from agricultural practices are conducted on soils that have been in very long-term row cropping systems. Because the field used in this study was in long-term (>50 years) tall fescue meadow, it may have shown few treatment effects from cover cropping and no-till because it was not a particularly degraded soil at the outset of the current study (Table 4.14). Although pH and Bray I P levels were under the desired range for good crop growth, the SOM average of 4.3% was relatively high for agricultural soil in central Missouri. The average SOM for cropped ground at the study site is 2%. Although there were no treatment effects on SOM, P and pH, there was an increase in P in year two from compost mineralization and a slight decrease in SOM from pre-study levels (2011) to year three. It could be expected that soils that start with levels of SOM and soil microbial communities conducive to good crop growth would respond slower to management changes than soils that are lacking in these soil system drivers.

Conclusions

Our results indicate that a system transitioning from conventional to organic production by establishing three years of continuous cover cropping in a high SOM soil had little effect on soil quality but significantly decreased the weed seedbank. This could have a significant impact on profitability of a new organic system. We do not recommend the use of organic no-till in a transitioning system as yields were severely reduced by weed interference and N immobilization. An organic no-till system may require more than the threshold of 8000 kg ha^{-1} of biomass to suppress weed emergence. Through accidental over-application of compost to a winter cover crop growing in a field alley one year, we observed that cover crop growth was improved more through improved fertility than increased planting rate. We observed weed emergence through the cover crop residue even in treatments with high biomass, thus we are currently engaged in a study to determine ways to control weeds that emerge in organic no-till. Conventionally tilled soybean yield was a greater percentage of conventional, non-organic yield than wheat, corn or grain sorghum in this transitional system because soybean did not experience low fertility constraints following termination of synthetic fertilizer use and before compost began actively releasing N for crop nutrition and growth. Double-crop soybean did not perform well in this system due to low mid-summer precipitation and weed competition. In the future, we will study the use of a summer cover crop mix planted after wheat. A combination of winter cover crops or wheat for early season weed control, SOC additions, and erosion control; summer cover crops for reducing the weed seedbank; and low N-requiring soybean (or other legume crops) are important tools for the transition from conventional to organic production methods.

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Figure 4.1. Cumulative Precipitation from 2012-2014 compared to 30-year average cumulative precipitation for Boone County, MO.]

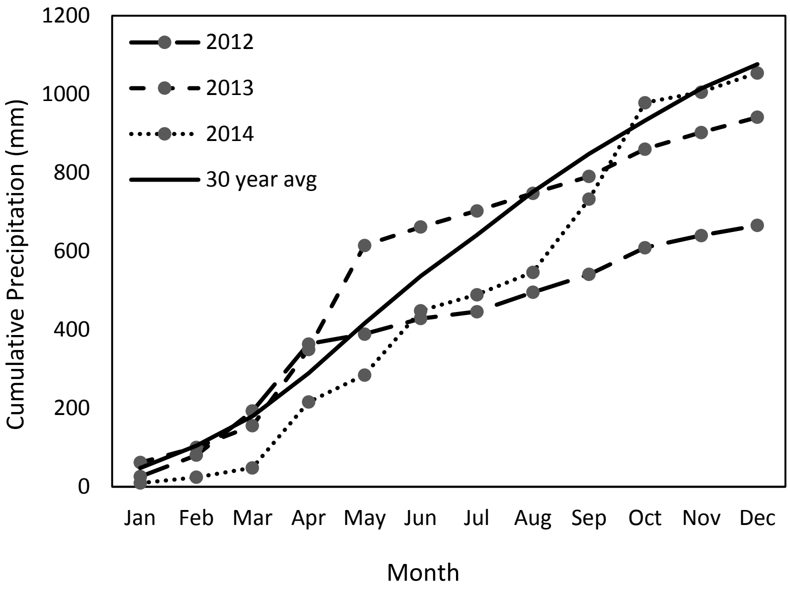

Table 4.1. Seeding rates and seasons of cover crops.

Crop	Season	Seeding rate
		kg ha^{-1}
Winter cover crop mix		
Crimson clover	winter	17
Hairy vetch	winter	11
Rye	winter	80
Austrian winter pea	winter	17
Sunn hemp	summer	30
Sorghum/sudangrass	summer	40

Table 4.2. Seven rotational systems used to transition from conventional to organic row crop production. DC soybean =double crop soybean.

Year		**Cover crop only (CCO)**	**Modified Cover Crop (MCC)**	**Modified Conventional (MCT)**	**Conventional Corn-Soybean (CONVCS)**	**Conventional Sorghum-Soybean (CONVSS)**	**No-Till Corn-Soybean (NTCS)**	**No-Till Sorghum-Soybean (NTSS)**
2012	winter crop	winter cover crop mix						
	tillage	minimal till	minimal till	minimal till	as needed	as needed	none	none
	summer crop	sorghum-sudangrass	sorghum-sudangrass	sorghum-sudangrass	soybean	soybean	soybean	soybean
2013	winter crop	winter cover crop mix		wheat	winter cover crop mix			
	tillage	minimal till	minimal till	as needed	as needed	as needed	none	none
	summer crop	buckwheat	sorghum-sudangrass	soybean	corn	grain sorghum	corn	grain sorghum
2014	winter crop	winter cover crop mix			wheat			
	tillage	minimal till	minimal till	tilled	tilled	tilled	tilled	tilled
	summer crop	sunn hemp	corn	corn	soybean	soybean	soybean	soybean

Table 4.3. Dates of production practices 2011-2014. DC SB= double crop soybean.

Management	2011	2012	2013	2014
Compost	-	4-Apr	25-Apr	16-Apr
Pre-plant crimping (NTCS, NTSS)	-	21-May	12-Jun	-
Pre-plant tillage	-	21-May CONVCS, CONVSS	12-June, CONVCS, CONVSS, MCC	16-June, CCO, MCC, MCT; 1-July NTCS, NTSS, CONVCS, CONVSS
Irrigation	-	6-June; 6, 20-July; 3, 17-Aug	-	-
Corn plant/harvest	-	-	12-June/17-Oct; 27-June replanted NTCS	18-June/24-Oct
Soybean plant/harvest	-	21-May/22-Oct	9-July DC SB	1-July DC SB
Grain sorghum plant/harvest	-	-	12-June/17-Oct 27-June replanted NTSS	-
Wheat plant/harvest	-	19-Oct/8-July, 2013	18-Oct/1-July, 2014	-
Summer cover crop plant	-	18-May	27-Jun	18-Jun
Cultivation	-	3, 14, 21,27-June	20, 28-June; 9, 16, 29-July	2, 11, 17, 29-July
Winter cover crop planting	8-Oct	22-Oct	17-Oct	-

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.4. Mean above-ground biomass of weeds from 2012-2014. Biomass was collected at the time most weed plants were at anthesis. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

Treatment	2012	2013	2014
		kg ha^{-1}	
CCO	5817 (903) a	93 (32) c	1778 (1238) c
CONVCS	3733 (983) a	2575 (286) ab	2728 (418) c
CONVSS	5210 (524) a	3122 (418) a	2908 (238) c
MCT	5652 (548) a	295 (58) c	11018 (1660) a
MCC	6585 (1409) a	2552 (348) ab	10316 (2761) ab
NTCS	4153 (342) a	3520 (1176) a	4085 (630) bc
NTSS	5244 (1179) a	3504 (350) a	4705 (1073) bc

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.5. Mean yield of cash crops from 2012-2014. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

Year	Treatment	Wheat	Maize	Grain sorghum	Soybean
		——— kg ha^{-1} ———			
2012	CCO				
	CONVCS				3010 (161) a
	CONVSS				2955 (46) a
	MCT				
	MCC				
	NTCS				396 (17) b
	NTSS				381 (102) b
2013	CCO				
	CONVCS		5175 (723) a		
	CONVSS			901 (68) b	
	MCT	1848 (336)			
	MCC			1328 (92) a	
	NTCS		2585 (523) b		
	NTSS			259 (118) c	
2014	CCO				
	CONVCS	2819 (57) ab			
	CONVSS	2939 (208) ab			
	MCT		3723 (519) b		
	MCC		5077 (442) a		
	NTCS	2129 (259) bc			
	NTSS	1979 (183) c			

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.6. Mean above-ground biomass of cover crops from 2012-2014. Biomass was collected at anthesis for each crop. Values followed by a different lowercase letter within each column and year are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

Year	Treatment	Winter cover crop	Sorghum sudangrass	Sunn hemp
		——— kg ha^{-1} ———		
2012	CCO	3229 (97) a	5477 (2025) a	
	CONVCS	2878 (183) a		
	CONVSS	2905 (187) a		
	MCT	2945 (321) a	3530 (676) a	
	MCC	3312 (256) a	1868 (449) a	
	NTCS	2906 (142) a		
	NTSS	3062 (141) a		
2013	CCO	5477 (455) ab	40350 (2959)	
	CONVCS	6148 (1177) ab		
	CONVSS	7919 (478) ab		
	MCT			
	MCC	4604 (364) b		
	NTCS	9757 (1825) a		
	NTSS	7020 (1050) ab		
2014	CCO	8775 (264) a		14957 (1056)
	CONVCS			
	CONVSS			
	MCT	8004 (873) a		
	MCC	9001 (698) a		
	NTCS			
	NTSS			

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.7. Mean of NH_4^+-N and NO_3^--N concentrations at 0-15 cm soil depth, 2012-2014. Values followed by a different lowercase letter within each column and section are significantly different (using Tukey's HSD) at α=0.05.. Standard errors are stated in parentheses. Spring samples were taken at planting and autumn samples were taken at harvest.

Treatment	2012	2013	2014
	——— mg kg^{-1} soil ———		
	Spring NH_4^+-N		
CCO	18.1 (5.8)	17.1 (3.7)	6.9 (1.1)
CONVCS	16.3 (5.0)	15.5 (1.6)	8.9 (2.9)
CONVSS	13.1 (1.5)	15.6 (2.4)	8.6 (1.4)
MCT	21.1 (6.6)	18.0 (2.8)	5.9 (0.2)
MCC	17.5 (5.1)	17.2 (3.4)	6.4 (0.8)
NTCS	18.1 (5.5)	19.3 (3.2)	6.1 (0.7)
NTSS	15.8 (5.0)	15.6 (3.1)	9.1 (1.6)
	Spring NO_3^--N		
CCO	17.8 (4.3)	9.3 (2.0)	1.9 (0.3) b
CONVCS	14.2 (1.8)	11.6 (1.3)	5.3 (0.7) ab
CONVSS	11.0 (2.8)	11.2 (3.7)	3.3 (0.3) b
MCT	17.2 (1.9)	22.9 (6.8)	2.0 (0.1) b
MCC	16.1 (3.1)	11.1 (2.0)	1.9 (0.2) b
NTCS	17.0 (3.1)	12.3 (4.1)	8.9 (3.6) ab
NTSS	17.4 (4.4)	13.2 (0.7)	10.9 (2.5) a
	Autumn NH_4^+-N		
CCO	7.1 (0.7)	6.0 (0.3) b	8.1 (4.9)
CONVCS	8.7 (1.0)	5.9 (0.6) b	3.2 (0.1)
CONVSS	7.5 (0.7)	7.4 (0.4) ab	8.6 (4.7)
MCT	7.8 (0.6)	6.4 (0.8) b	2.8 (0.3)
MCC	7.3 (0.9)	7.6 (0.6) ab	3.5 (0.5)
NTCS	8.2 (0.5)	10.3 (1.4) a	3.7 (0.5)
NTSS	6.4 (1.1)	8.1 (0.9) ab	3.4 (0.4)
	Autumn NO_3^--N		
CCO	29.6 (6.9)	10.3 (2.6)	50.6 (5.8)
CONVCS	35.2 (4.2)	16.1 (2.2)	43.8 (2.5)
CONVSS	30.6 (5.1)	13.8 (3.0)	45.8 (3.2)
MCT	32.4 (4.8)	14.3 (3.7)	39.0 (1.9)
MCC	23.9 (6.4)	9.6 (1.9)	47.2 (4.8)
NTCS	30.8 (3.1)	28.0 (16.2)	49.7 (3.7)
NTSS	32.9 (6.4)	25.4 (13.7)	46.5 (2.0)

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.8. Mean number of weed seeds in 0-15 cm soil depth. Soil was collected prior to start of experiment in 2011 and at harvest in 2014. Values followed by a different lowercase letter within each column are significantly different (using Tukey’s HSD) at α=0.05. Standard errors are stated in parentheses.

Treatment	2011	2014
	——— weed seeds m^{-2} 15 cm depth^{-1}———	
CCO	410670 (18484)	53084 (12791) b
CONVCS	470340 (45269)	209796 (38311) a
CONVSS	521040 (54612)	253396 (17431) a
MCT	457080 (37512)	170375 (27162) ab
MCC	521430 (41391)	224006 (38301) a
NTCS	617370 (84886)	236104 (29058) a
NTSS	488670 (42251)	228128 (24019) a

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.9. Means of microbial biomass by general type at 0-15 cm soil depth, 2012-2014. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses.

Treatment	2012	2013	2014
		picomoles g^{-1} soil	
		AM Fungi	
CCO	5605 (236)	6646 (463)	6380 (418)
CONVCS	5844 (141)	7007 (551)	5684 (412)
CONVSS	6095 (387)	7234 (519)	5882 (334)
MC	6198 (170)	6420 (242)	6077 (288)
MCC	6816 (446)	6801 (346)	6719 (502)
NTCS	5716 (324)	6264 (568)	6299 (320)
NTSS	6516 (597)	5766 (625)	5825 (179)
	NS	NS	NS
		Gram Negative	
CCO	47121 (1607)	55354 (3149)	50120 (3003)
CONVCS	49498 (985)	53155 (3195)	43734 (2751)
CONVSS	47258 (1207)	57505 (3138)	44999 (1985)
MC	48190 (563)	53201 (1603)	47442 (1792)
MCC	52289 (3062)	53249 (1106)	51268 (3086)
NTCS	47113 (1710)	51772 (1032)	49079 (1593)
NTSS	52818 (1977)	48058 (2370)	47171 (1976)
	NS	NS	NS
		Eukaryotes	
CCO	2325 (167)	2462 (201)	3314 (1175)
CONVCS	2328 (204)	2755 (427)	2042 (261)
CONVSS	2328 (229)	2490 (59)	1877 (171)
MC	2682 (345)	2067 (50)	2045 (110)
MCC	2852 (112)	2067 (99)	5318 (3003)
NTCS	2674 (249)	2452 (176)	2446 (90)
NTSS	2800 (191)	7602 (5575)	2079 (145)
	NS	NS	NS
		Fungi	
CCO	3307 (238)	2738 (354)	3879 (956)
CONVCS	3499 (597)	2885 (191)	1935 (88)
CONVSS	4172 (578)	4132 (531)	2111 (181)
MC	2736 (217)	3075 (193)	2997 (462)
MCC	3473 (690)	4081 (929)	5041 (1765)
NTCS	2726 (328)	2206 (212)	3758 (920)
NTSS	3768 (833)	3207 (967)	4072 (1442)
	NS	NS	NS
		Gram Positive	
CCO	31145 (1427)	39247 (1633)	35567 (1375)
CONVCS	33204 (1172)	38688 (2043)	33621 (1692)
CONVSS	30869 (945)	39601 (1805)	34447 (1648)
MC	31905 (432)	38012 (851)	34973 (1278)
MCC	33015 (1176)	38673 (1164)	37983 (1429)
NTCS	32327 (688)	36930 (1365)	36251 (1544)
NTSS	33094 (739)	34971 (1955)	33827 (1130)
	NS	NS	NS
		Anaerobic	
CCO	2108 (158)	2306 (170)	2007 (102)
CONVCS	2084 (106)	2303 (135)	1842 (152)
CONVSS	1992 (69)	2514 (103)	1922 (114)
MC	2064 (85)	2377 (163)	1922 (132)
MCC	2201 (193)	2309 (103)	2103 (167)
NTCS	2083 (93)	2407 (152)	2199 (124)
NTSS	2093 (74)	2148 (230)	1950 (80)
	NS	NS	NS
		Actino Bacteria	
CCO	18201 (637)	19938 (777)	19832 (689)
CONVCS	18885 (596)	20024 (633)	19528 (1132)
CONVSS	17342 (292)	19437 (634)	19979 (690)
MC	17782 (588)	19989 (600)	20061 (959)
MCC	18100 (900)	20452 (359)	20584 (844)
NTCS	17756 (456)	18904 (1043)	20039 (545)
NTSS	18874 (485)	18364 (1075)	19489 (715)
	NS	NS	NS

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.10. Mean of β–glucosidase reaction at 0-15 cm soil depth, 2012-2014. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses.

Treatment	2012	2013	2014
	——— μg PNP g soil^{-1} hr^{-1} ———		
CCO	11.4 (0.8)	13.1 (2.9)	6.8 (0.5)
CONVCS	9.5 (1.9)	10.7 (1.6)	4.9 (1.0)
CONVSS	8.9 (1.1)	11.9 (1.0)	4.7 (0.5)
MCT	10.0 (1.2)	11.9 (1.0)	8.5 (2.5)
MCC	11.0 (1.1)	11.8 (1.4)	6.5 (1.2)
NTCS	10.2 (1.0)	10.4 (0.7)	6.9 (2.1)
NTSS	10.4 (1.2)	10.8 (1.1)	5.3 (0.4)
	NS	NS	NS

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.11. Mean of permanganate oxidizable carbon (POXC) at 0-15 cm soil depth, 2012-2014. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses. Samples were taken at planting in spring and at harvest in autumn.

Treatment	2012	2013	2014
	——— g kg^{-1} soil ———		
	Spring POX Carbon		
CCO	0.32 (0.07)	0.61 (0.04)	0.69 (0.04)
CONVCS	0.39 (0.03)	0.56 (0.03)	0.72 (0.02)
CONVSS	0.34 (0.06)	0.61 (0.03)	0.74 (0.03)
MCT	0.39 (0.05)	0.67 (0.04)	0.75 (0.02)
MCC	0.42 (0.03)	0.61 (0.03)	0.71 (0.03)
NTCS	0.26 (0.04)	0.58 (0.02)	0.68 (0.04)
NTSS	0.36 (0.02)	0.56 (0.04)	0.75 (0.03)
	NS	NS	NS
	Autumn POX Carbon		
CCO	0.40 (0.06)	0.77 (0.03)	0.66 (0.04)
CONVCS	0.37 (0.04)	0.77 (0.03)	0.64 (0.03)
CONVSS	0.44 (0.05)	0.79 (0.05)	0.67 (0.03)
MCT	0.43 (0.03)	0.78 (0.01)	0.62 (0.02)
MCC	0.37 (0.03)	0.74 (0.05)	0.64 (0.03)
NTCS	0.41 (0.05)	0.75 (0.03)	0.70 (0.02)
NTSS	0.41 (0.06)	0.72 (0.02)	0.66 (0.04)
	NS	NS	NS

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.12. Mean of total organic nitrogen (TON), total organic carbon (TOC) and C/N ratio at 0-15 cm soil depth, 2012-2014. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses.

Treatment	2012	2013	2014
		g TON kg^{-1} soil	
CCO	2.2 (0.1)	2.7 (0.1)	2.0 (0.0)
CONVCS	2.1 (0.1)	2.6 (0.1)	2.1 (0.1)
CONVSS	2.0 (0.0)	2.8 (0.0)	2.1 (0.1)
MCT	2.1 (0.0)	2.7 (0.1)	2.2 (0.0)
MCC	2.1 (0.0)	2.7 (0.2)	2.7 (0.4)
NTCS	2.1 (0.1)	2.8 (0.2)	2.1 (0.1)
NTSS	2.2 (0.1)	2.7 (0.1)	2.2 (0.1)
	NS	NS	NS
		g TOC kg^{-1} soil	
CCO	20.9 (0.2)	27.6 (1.2)	21.3 (0.7)
CONVCS	20.4 (0.4)	24.8 (1.4)	21.0 (0.3)
CONVSS	20.0 (0.5)	27.6 (0.3)	20.6 (0.5)
MCT	21.7 (0.5)	26.7 (0.9)	21.8 (0.6)
MCC	20.5 (0.4)	25.2 (1.3)	22.4 (0.7)
NTCS	20.5 (0.4)	27.1 (1.3)	21.8 (0.7)
NTSS	21.2 (0.9)	24.5 (0.9)	22.1 (1.1)
	NS	NS	NS
		C:N Ratio	
CCO	9.5 (0.5)	10.1 (0.1) a	10.5 (0.4)
CONVCS	9.6 (0.3)	9.6 (0.2) ab	10.0 (0.2)
CONVSS	9.9 (0.2)	9.7 (0.1) ab	9.7 (0.2)
MCT	10.2 (0.2)	10.0 (0.1) a	10.0 (0.4)
MCC	9.9 (0.1)	9.5 (0.2) ab	8.8 (0.8)
NTCS	9.8 (0.2)	9.6 (0.1) ab	10.3 (0.2)
NTSS	9.7 (0.2)	9.3 (0.1) b	10.3 (0.3)
	NS	-	NS

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.13. Mean of aggregate stability at 0-15 cm soil depth, 2012-2014. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. NS signifies no significant difference in means between the seven treatments for each year. Standard errors are stated in parentheses.

Treatment	2012	2013	2014
	% Stable Aggregates		
CCO	55.9 (2.4)	77.7 (3.7)	24.0 (3.2) ab
CONVCS	51.3 (4.1)	66.6 (4.2)	14.4 (2.1) b
CONVSS	50.3 (4.2)	64.7 (2.5)	18.2 (2.4) ab
MCT	55.1 (5.6)	71.0 (4.5)	21.3 (1.7) ab
MCC	48.7 (3.3)	73.2 (1.9)	24.8 (2.2) a
NTCS	55.1 (4.9)	77.0 (3.6)	16.2 (1.4) ab
NTSS	56.9 (7.7)	74.6 (3.4)	15.0 (1.9) b
	NS	NS	-

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

Table 4.14. Results of soil fertility tests including means for pH(salt), soil organic matter (SOM), neutralizable acidity (NA), cation exchange capacity (CEC), Bray I phosphorus, calcium, magnesium, and potassium.

Year	Treatment	pHs	SOM	NA	CEC	P	CA	MG	K
			%	cmol g^{-1}		Kg ha^{-1}			
2011	CCO	5.4	4.3	1.7	12.1	50	3948	466	267
	CONVCS	5.5	4.2	1.5	10.9	45	3476	381	219
	CONVSS	5.5	4.3	1.7	11.9	46	3733	425	261
	MCT	5.5	4.2	1.6	12.7	43	4060	464	266
	MCC	5.4	4.3	1.8	12.5	44	3904	452	259
	NTCS	5.4	4.4	1.6	10.8	45	3334	390	248
	NTSS	5.4	4.4	1.9	12.4	43	3816	439	277
2012	CCO	5.9	3.8	2.3	14.7	64	4588	482	332
	CONVCS	5.9	3.9	2.0	14.2	79	4518	462	303
	CONVSS	5.8	3.8	2.1	14.0	79	4436	461	265
	MCT	5.9	3.8	2.1	14.7	65	4640	498	333
	MCC	5.8	3.7	2.5	14.1	65	4275	456	312
	NTCS	5.8	3.9	2.4	14.4	81	4360	497	366
	NTSS	5.8	3.8	2.4	14.3	81	4334	485	368
2013	CCO	6.1	4.3	2.0	13.4	126	4061	524	325
	CONVCS	6.2	3.9	1.4	13.3	119	4307	527	318
	CONVSS	6.1	4.2	1.9	14.5	126	4450	597	399
	MCT	6.0	4.2	1.9	13.9	114	4240	559	398
	MCC	6.1	3.8	2.0	13.3	100	4033	519	373
	NTCS	5.9	4.4	2.3	13.7	121	3926	552	482
	NTSS	6.0	3.9	2.0	13.7	120	4055	547	513
2014	CCO	5.8	3.6	2.0	14.7	95	4756	474	274
	CONVCS	6.0	3.5	1.7	14.0	120	4613	452	296
	CONVSS	5.9	3.7	1.8	14.9	123	4858	496	318
	MCT	6.0	3.6	1.9	13.8	105	4437	457	267
	MCC	5.9	3.9	1.8	14.3	113	4586	489	342
	NTCS	5.8	3.6	2.1	13.7	124	4255	460	319
	NTSS	5.8	3.8	2.1	15.1	123	4802	504	369

CCO=cover crop only; CONVCS=conventional till corn-soybean; CONVSS=conventional till sorghum-soybean; MCT=modified conventional tillage; MCC=modified cover crop; NTCS=no-till corn-soybean; NTSS=no-till sorghum-soybean

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CHAPTER FIVE

TIMING AND METHOD OF ORGANIC CORN PLANTING IN COVER CROPS

Abstract

To determine the effects of planting into a cover crop in organic no-till, a three year study was conducted from 2012-2014 to compare corn (*Zea mays* L.) germination and emergence rates at different planting times. A cereal rye (*Secale cereale* L) and hairy vetch (*Vicia villosa* L.) cover crop mix were terminated by either rolling/crimping or mowing. Corn was planted at four planting times in relation to cover crop termination: before cover crop termination into a standing cover crop (SCC), immediately after either rolling/crimping the cover crop (AT), one week after cover crop termination (1WAT) and two weeks after termination (2WAT). This research was conducted at the University of Missouri Bradford Research Center, located in Boone County, eight km east of Columbia, MO. Stand density counts were recorded as a measure of efficacy of each treatment. Germination and emergence of corn in an organic no-till system was significantly impacted by planting times and cover crop termination method. Population reduction in corn planted in the organic no-till ranged from 36% to 80% compared to the number of seeds planted. The likely cause of reduced plant density in organic no-till was due to difficulty of planting in cover crops. Plant population was highest in corn planted into a standing cover crop, then decreased as the time between termination and corn planting increased. Corn planted immediately after the cover crop was mowed showed a population decrease of 42% overall and 98% in 2012 when compared to corn planted immediately after crimping the cover crop. Delaying corn planting one or two weeks after cover crop termination showed no benefit and led to decreased corn plant populations.

Keywords: Organic no-till, cover crop, corn, crimped, population density, germination, rye, hairy vetch.

Abbreviations: Standing cover crop (SCC), after cover crop termination (AT), one week after cover crop termination (1WAT), two weeks after termination (2WAT), Mowing (M), Rolling/Crimping (R), carbon (C), no-till cover crop (NTCC), Planting times and cover crop termination method (PTCCT)

Introduction

The use of cover crops in annual organic cropping systems is integral to system function because of the ecosystem services they have been shown to provide. These services include inhibition of weed germination and growth (Mirsky et al., 2011), providing N from legume fixation (Ranells and Wagger, 1996), increases in soil organic C (Kuo et al., 1997a), improved soil and water quality (Dabney et al., 2001), and reduced erosion (Langdale et al., 1991). A relatively new area of research in organic production is organic no-till, which usually utilizes a cover crop that is rolled or crimped to provide a thick mulch that can potentially inhibit weed germination and growth during the early stages of annual cash crop production. Yields similar to conventional-tilled organic production can be achieved in organic no-till in years with low weed pressure (Teasdale et al., 2012). It is generally assumed that organic no-till can provide similar ecosystem services as conventional no-till, including improved soil structure (Blanco-Canqui and Lal, 2007), improved water holding capacity (Waddell and Weil, 1996), improved C retention (Duiker and Lal, 1999) and reduced erosion (McGregor et al., 1975).

In addition to crimping the cover crop in organic no-till, several studies have investigated terminating the cover crop through mowing. Both flail mowing (Wayman et al., 2014, Smith et al., 2011) and sickle mowing (Bernstein et al., 2011) are successful at terminating cereal rye (*Secale cereale* L) and hairy vetch (*Vicia villosa* L.) cover crops, although a healthy hairy vetch crop can wrap around a flail mower to the extent that management by mowing must be abandoned (Wayman et al., 2014). Smith et al. (2011) found that flail mowing can potentially provide as much weed control as crimping the cover crop and determined that mowed cereal rye residue did not decompose at a different rate than crimped residue. However, flail-mowed legumes have faster decomposition rates and are usually fully degraded during the growing season.

When crimping the cover crop, consistent control is best achieved when cereal rye has reached Zadoks growth stage 61 and hairy vetch has 60% flowering (Mirsky et al., 2009, Wayman et al., 2014, Mischler et al., 2010a). Cover crop residue is most effective at weed control when biomass levels are greater than 8000-9000 kg ha^{-1} (Smith et al., 2011, Mirsky et al., 2013). Increasing rye seeding rates from 90 to 150 kg ha^{-1} decreased weed biomass by 15% while an increase in seeding rate from 90 to 210 kg ha^{-1} decreased weed biomass by 31% (Ryan et al., 2011b). Several studies have investigated crimping the cover crop perpendicular to the direction of sowing with the cash crop planted the same direction as crimping (Mirsky et al., 2009, Ryan et al., 2011b) while others have not identified the direction of crimping (Smith et al., 2011, Bernstein et al., 2011, Wayman et al., 2014). At least one study reports making more than one pass with the crimper to achieve adequate cover crop termination (Wayman et al., 2014).

Although most studies report planting the cash crop immediately after crimping or mowing, Teasdale et al. (2012) found that rainfall caused planting delays of three to 17 days when they attempted to follow a protocol of planting seven days after cover crop termination. Because a thick layer of cover crop residue present on the ground before crop planting can have serious management consequences, it is vital to know the time period between planting and cover crop termination that is most beneficial to crop growth.

Possible management practices with cover crop use include planting into a standing cover crop as well as planting after the cover crop is terminated by crimping or mowing. Bernstein et al. (2011) found that soybean establishment in a standing rye cover crop averaged 80% compared to 58% in treatments where cover crop termination by mowing or crimping was completed before cash crop planting. This was attributed to the difficulty in maintaining good seed-soil contact when planting through a thick cover crop mulch. Surprisingly, they also reported no loss of soybean stand when the cover crop was crimped or mowed over soybean seedlings three weeks after soybean planting. Although they did not give a detailed description of the effect of crimping on weeks-old soybeans, they did report that this method did not decrease soybean yield. Additionally, weed biomass was not affected by planting into a standing cover crop compered to planting into a crimped or mowed cover crop and weed biomass in both systems were less than in the tilled soybean treatment.

To further elucidate the effects of planting into a cover crop in organic no-till, a three year study was conducted to compare corn germination and emergence rates at four different planting times. Corn (*Zea mays* L.) was planted into a standing cover crop and in crimped or mowed cover crops immediately following cover crop termination, one week after termination and two weeks after termination.

Materials and Methods

Research Site and Design

This research was conducted from 2012-2014 at the University of Missouri Bradford Research Center, located in Boone County, eight km east of Columbia, MO. Soils at this site are primarily Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualfs) and are on the central glacial till claypan plain. This site has an argillic horizon, which is a claypan, typically 25 cm below the soil surface. This research site had previously been managed as a conventional row crop field until 2011 when organic management practices were initiated. Land used in this study was certified in organic transition by Quality Certification Services (QCS, Gainesville, FL). A randomized complete block design was used with treatments of cover crop termination method (PTCCT) and planting timing. Cover crops were terminated by either rolling/crimping or mowing. Corn was planted at four different times in relation to cover crop termination: before cover crop termination into a standing cover crop (SCC), immediately after either rolling or crimping the cover crop (AT), one week after cover crop termination (1WAT) and two weeks after termination (2WAT). Each treatment had four replications for a total of 32 plots, each 3 x 12 m.

Crop Management

Management dates and processes are shown in Table 5.1. The study was treated as no-till both before cover crop and corn crop planting. The winter cover crop was a mixture of cereal rye (*Secale cereale* L) and hairy vetch (*Vicia villosa* L.) and was planted using a Tye no-till drill (AGCO, Duluth, GA) in 19 cm wide rows at a planting density of 110 kg ha^{-1} for rye and 33 kg ha^{-1} for vetch. Both were organic “Variety Not Stated”. The cover crop was planted at a high seeding density generally recommended for organic no-till production (Ryan et al., 2011b, Mirsky et al., 2012). The cover crop was terminated at Zadoks growth stage 61 (Mirsky et al., 2009) using three passes with a roller-crimper (I&J Mfg, Gap, PA) in the rolled treatments and one pass with a flail mower in the mowed treatments. The crimped cover crops were rolled parallel to the direction of sowing and the corn crop was planted in the same direction the cover crop was rolled. Organic corn (Welter Seed hybrid WS2292) was planted approximately 4 cm deep using a 4-row John Deere 7000 planter (Moline, IL) in 76 cm wide rows at 86,400 seeds ha^{-1}. Due to the dense residue established by the cover crop in the NTCC treatments, the no-till coulters were removed and spiked closing wheels (Schoup Mfg., Kankakee, IL) were installed on the planter to more effectively close the seed-row furrow in 2013 and 2014.

Data Collection

Stand density counts were recorded as a measure of efficacy of each treatment but yields were not collected because the field was not maintained throughout the growing season. When corn plants reached approximately 10 cm in height, stand counts were recorded by randomly placing a 3 m pole between the middle two rows of each plot so that plants next to the pole were counted in both rows. These stand counts were interpolated into number of corn plants ha^{-1}. Gravimetric soil moisture was determined from the 0-10 cm depth at each planting timing by collecting three random soil samples within each plot. Samples were weighed wet, then oven dried for 24 hours at 110 C and reweighed. Bulk density was determined gravimetrically to 7.65 cm depth using four samples per field and was multiplied by mass wetness to calculate volume wetness for each sample (Grossman and Reinsch, 2002).

Statistical Analysis

Statistical analysis was completed with SAS Enterprise Guide 6.1 (SAS, Cary, NC). Results were analyzed using PROC MIXED at α=0.05 with the ANOVA run as a RCBD design. The fixed effect in the model was planting times and cover crop termination method (PTCCT). The random effect was block. All mean separation differences were tested using Tukey's HSD. Soil moisture was similarly analyzed. Visual inspection of frequency distributions showed that normality assumptions were valid.

Results and Discussion

Germination and emergence of corn in an organic no-till system was significantly impacted by planting times and cover crop termination method. Data (Table 5.2) is presented both as the mean of all years combined and by individual year to highlight the greater reduction in plant population in 2012 compared to the subsequent two years. While this may be a result of reduced seed to soil contact while the no-till coulters were still attached to the planter, it may also be attributed largely to the extremely dry soil conditions in 2012. Although soil moisture at time of cover crop termination and corn planting was nearly the same in 2012 and 2014 and only 3% lower than in 2013, in the month following planting in 2012 there was only 3.9 cm of precipitation, while in 2013 and 2014 there was 18.4 cm and 16.2 cm, respectively. Conventional corn planted at the same farm averaged an 8% reduction from planting population to actual plant density (Wiebold et al., 2014a, Wiebold et al., 2013a, Wiebold et al., 2012a) while the reduction in corn population planted in the organic no-till ranged from 36% to 80%. While the likely cause of this greatly reduced plant density in organic no-till may be due to the difficulty of planting in cover crops, a contributing factor may also be that conventional corn was treated with fungicides and insecticides that are aimed at boosting germination while the organic corn in this study was untreated. However, warmer soil temperatures in late May when this corn was planted may have mitigated some germination issues that fungicides are used to treat in cooler, wetter soils.

Plant population was greatest in corn planted into a standing cover crop, then decreased as the time between termination and corn planting increased. One exception to this was corn planted immediately after the cover crop was mowed, which showed a population decrease of 42% overall and 98% in 2012 when compared to corn planted immediately after crimping the cover crop. The mowed cover crop treatment also had slightly reduced plant population compared to crimped when planted one week after cover crop termination, but was roughly equal at two weeks after termination. The reason for the decreased plant population in mowed treatments is likely due to interference of the macerated cover crop residue with the germinating corn seeds, which was a result of the dry cover crop residue entering the seed furrow and either causing a reduction of soil contact with the germinating crop seed or absorption of soil moisture by cover crop residue fragments. Several other studies have reported decreased seed to soil contact from similar residue hair-pinning (Carr et al., 2003; Kornecki et al., 2009; Luna et al., 2012).

Although planting into a standing cover crop provided the best corn germination and emergence, this method does change the way the cover crop provides soil cover and shading when subsequently mowed or crimped. Although data were not taken on weed control or soil cover, it was observed that cover crops pushed down by the tractor tires were more difficult to crimp or mow and may not cover bare soil as well as a cover crop that is crimped before planting. The stage of the cover crop as well as the moisture content of both the soil and the cover crop can also affect how a cover crop knocked down by tractor tires will respond. Although Bernstein et al. (2011) states that soil cover in the no-till rye treatments was 99%, variation in soil cover by planting times (standing cover crop vs. crimped cover crop) was not discussed. Because many researchers report problems with planting into a crimped cover crop mulch (Carr et al., 2013a, Delate et al., 2012, Bernstein et al., 2011, Teasdale et al., 2012), the results of this study and that of Bernstein et al. (2011) demonstrate that planting into a standing cover crop should be further investigated for its effects on weed control in organic no-till. This study shows that terminating the cover crop immediately after planting is a viable management decision but to gauge the weed control potential of both methods, this should be compared with the method of Bernstein et al. (2011) of crimping or mowing three weeks after planting.

Crimping a cover crop and then immediately planting into it was not statistically different from planting into the standing cover crop in this study, although the general trend was that of decreased plant population using this method. However, this management is the most tested in terms of weed control and planting practice (Mirsky et al., 2009, Mirsky et al., 2011, Smith et al., 2011) and should be further investigated. It was observed that planter modifications that increased weight on double disk openers and provided better seed furrow closure improved success with planting into a crimped cover crop.

Delaying corn planting one or two weeks after cover crop termination showed no benefit and led to decreased corn plant populations. Additionally, this time lapse gives weeds time to germinate and grow through areas where the cover crop mat does not provide perfect soil coverage. Because organic no-till requires that the rye cover crop be allowed to grow to a minimum of Zadoks growth stage 61 (Mirsky et al., 2009), this practice delays organic corn planting in the Midwest to mid- to late-May. Further pushing planting date into what are typically drier days in late May or early June can lead to decreased corn germination and fewer growing days to maximize yields (Lauer et al., 1999). Separating the timing of cover crop termination and crop planting can also lead to precipitation delays like that reported by Teasdale et al. (2012).

Conclusions

For organic no-till to become a viable management option for organic corn producers, it will likely have to offer comparable yields and weed control as conventional tilled organic management. Many questions still exist on how to achieve this and while studies like this can help determine best management practices, more research is needed on all aspects of the organic no-till system. One of the greatest difficulties in working with organic no-till is achieving adequate cover crop biomass to provide weed suppression. Further work to augment the findings of Ryan et al. (2011) is recommended on cover crop seeding densities and nutrient needs as well as research on how to manage weeds that come up through the cover crop residue. It will take time and perseverance to determine methods that will enable greater success and functionality in organic no-till but the same can also be said of other agricultural practices, such as conventional no-till (Grandy et al., 2006), that have seen improved success through research.

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Table 5.1. Production dates for cover crops and corn, 2012-2014.

Crop	Year	Treatment	Planting date	Termination date
Cover Crops	2011		8-Oct	
	2012		19-Oct	22-May
	2013		17-Oct	3-Jun
	2014			4-Jun
Corn	2012	SCC	16-May	
		AT	16-May	
		1WAT	23-May	
		2WAT	30-May	
	2013	SCC	21-May	
		AT	21-May	
		1WAT	28-May	
		2WAT	4-Jun	
	2014	SCC	20-May	
		AT	20-May	
		1WAT	27-May	
		2WAT	3-Jun	

SCC = standing cover crop; AT = after cover crop termination; 1WAT, 2WAT = 1 and 2 weeks after cover crop termination

Table 5.2 Plant density and volumetric soil moisture by treatment, 2012-2014. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05. Standard errors are stated in parentheses.

Treatment	2012			2013			2014			Mean 2012-2014			Mean soil moisture		
	———— plants ha^{-1} ————												cm^3 H$_2$O cm^3 soil^{-1}		
SCC-M	46265	(12281)	a	55411	(4921)	c	64018	(5442)	a	55231	(4836)	a	0.29	(0.01)	a
SCC-R	20846	(1829)	c	62942	(2690)	a	59714	(4842)	b	47834	(6030)	ab	0.29	(0.01)	a
AT-M	403	(403)	g	43575	(5982)	e	30126	(4026)	e	24702	(5858)	de	0.29	(0.01)	a
AT-R	18291	(4726)	e	56486	(4062)	b	52183	(8069)	c	42320	(5998)	abc	0.29	(0.01)	a
1WAT-M	30395	(5319)	b	24746	(9318)	f	32816	(4921)	e	29319	(3702)	cde	0.26	(0.01)	ab
1WAT-R	12239	(3341)	f	48417	(7882)	d	50569	(6243)	d	37075	(6190)	bcd	0.26	(0.01)	ab
2WAT-M	20308	(2122)	d	6994	(6994)	h	22057	(8212)	g	16453	(3886)	e	0.22	(0.01)	b
2WAT-R	9549	(2781)	f	22057	(13334)	g	25284	(1614)	f	18963	(4614)	e	0.22	(0.01)	b

SCC = standing cover crop; AT = after cover crop termination; 1WAT, 2WAT = 1 and 2 weeks after cover crop termination

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CONCLUSION

Although we saw potential in an organic no-till production system, its efficacy at weed suppression was heavily dependent on the health and growth of the cover crop. If soil fertility is low, cover crop growth will not be sufficient for weed suppression and yields will be negatively impacted. Cover crop growth was also highly dependent on climatic conditions. Additionally, the longer a system was in organic no-till the more likely that perennial weeds became problematic. Perennial weeds were not affected by the roller/crimper and if they emerge prior to or during cover crop growth, tillage to break their life cycle may be required. Hairy vetch used in the winter cover crop was difficult to kill with crimping and required three passes with the crimper to achieve adequate control. Planting through the cover crop residue was a significant production challenge and might require equipment modifications. Because soybean is planted at a much higher rate and is less affected by reduced plant population than corn, lower seed germination did not affect final yield as much as it did in corn, which was severely impacted by organic no-till production in this study. Delayed planting while waiting for the cover crop to reach the proper stage for crimping, coupled with reduced nitrogen availability to corn in organic no-till make it questionable that corn can successfully be integrated into an organic no-till system. Timing of cover crop crimping is better suited for a soybean production system. Wheat in an organic no-till system can be impacted by self-seeding of cover crops that are crimped after reaching reproductive growth stages. This may cause wheat to be unmarketable due to contamination of the harvested grain. Corn and wheat yields were reduced by basing compost application on P needs. Growing a cover crop at the biomass level needed for organic no-till may have repercussions for a producer who later decides to disk in the cover crop. High cover crop biomass would necessitate mowing before disking but mowing may lead to reduced soil to seed contact from physical interference from cover crop residue, which might be ameliorated with higher crop seeding rates. However, given the difficulty of attaining high cover crop biomass, this may be an unlikely scenario.

Although there have been many studies on the effects of organic management on soil quality, SMAF soil quality index scores for organic production systems have not been conducted. This paper serves as a starting point for examining how SMAF soil quality scores are affected by organic practices such as tillage, cover crops and compost addition.

Our results indicate that a system transitioning from conventional to organic production by establishing three years of continuous cover cropping in a high SOM soil had little effect on soil quality but significantly decreased the weed seedbank. This could have a significant impact on profitability of a new organic system. We do not recommend the use of organic no-till in a transitioning system as yields were severely reduced by weed interference and N immobilization. An organic no-till system may require more than the threshold of 8000 kg ha^{-1} of biomass to suppress weed emergence. Conventionally tilled soybean yield was a greater percentage of conventional, non-organic yield than wheat, corn or grain sorghum in this transitional system because soybean did not experience low fertility constraints following termination of synthetic fertilizer use and before compost began actively releasing N for crop nutrition and growth. Double-crop soybean did not perform well in this system due to low mid-summer precipitation and weed competition.

For organic no-till to become a viable management option for organic corn producers, it will likely have to offer comparable yields and weed control as conventional tilled organic management. Many questions still exist on how to achieve this and while studies like this can help determine best management practices, more research is needed on all aspects of the organic no-till system. One of the greatest difficulties in working with organic no-till is achieving adequate cover crop biomass to provide weed suppression. Further work is recommended on cover crop seeding densities and nutrient needs as well as research on how to manage weeds that come up through the cover crop residue. It will take time and perseverance to determine methods that will enable greater success and functionality in organic no-till but the same can also be said of other agricultural practices, such as conventional no-till, that have seen improved success through research.

We recommend that more studies be undertaken to examine production effects in contrasting organic systems and that less emphasis be placed on comparing organic to conventional agriculture. With the advent of research on organic no-till, new possibilities now exist to address soil degradation within the confines of organic production. Further research is needed to elucidate the role of cover crops in a tilled organic system, to control weeds and manage the cover crop under organic no-till, and determination of the long-term feasibility of organic no-till and its effect on soil quality, yield and profitability.

VITA

Kerry Clark attended the University of Missouri for her B.S. in Agricultural Journalism. Following her undergraduate education, Kerry served as a community development agent in the U.S. Peace Corps in Mali, West Africa for three years. She did her M.S. in Agronomy under the advisement of Dr. Robert Myers with the thesis “Legume-Cereal Intercrop Study: An evaluation of competitive and complementary effects of alternative crops in Missouri”. She also conducted research on trap cropping in alfalfa and amaranth, and researched Bambara groundnut and fonio production. She received a fellowship to study Bambara groundnut production in West Africa.

Following her M.S. in Agronomy, Kerry was the research associate at the University of Missouri Soybean Breeding Program for 19 years. Working with Dr. David Sleper, the program released twelve new soybean varieties, including the first glyphosate resistant varieties released by a public breeding program. In 2005, Kerry returned to school to fulfill educational requirements for becoming a licensed soil morphologist. Since 2007, she has operated her own consulting business for soil morphology tests for onsite wastewater and construction applications. She also trains wastewater professionals and regulatory personnel on soil capabilities. She is now completing her PhD in Soil Science under the advisement of Dr. Randall Miles and Dr. Robert Kremer.

In 2012, Kerry left Soybean Breeding to run the Organic Research Program at MU. She successfully brought in over two million dollars of funding for the program in four years. In 2014, Kerry developed and co-taught a statewide series of 16 workshops on soil health for farmers. She also speaks at many workshops, conferences and meetings on soil health and cover crops. In 2014, she joined the USAID-funded Soybean Innovation

Lab, part of the Feed the Future Initiative, as a project manager for seed quality in Ghana and Mozambique. Her work in those countries is helping to elucidate and strengthen the soybean value chain in sub-Saharan Africa and to help small-holder farmers gain access to seed, technology and information for successful soybean production.