DEVELOPING CROPPING SYSTEMS FOR ORGANIC GRAIN PRODUCTION IN TEXAS

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2019

Major Subject: Agronomy

ABSTRACT

Demand for organic products, including poultry and livestock, have increased over the past decade. With this increase in demand, an increased need for organic grain supply has developed. However, there is limited information currently available on organic production systems for grain production in Texas. Current practices for organic grain production in Texas rely on conventional tillage for weed control and manure application to meet crop N demand. Conservation tillage and use of cover crops are management practices that are expected to improve on current management practices and will be essential for sustainable production of organic grain.

A two-year study was initiated in Burleson County, TX to evaluate four management practices for three grain crops in rotation in an organic management system. Management practices evaluated include different tillage practices and cover crops treatment combinations of legume no-till (LNT), double cover no-till (DCNT), and double cover conventional till (DCCT) compared to current practices (CP).

Conventional tillage practices, with or without cover crops, produced better plant stands, greater biomass and leaf area for corn compared to corn planted into cover crop residue in the second year of the study. Both corn and grain sorghum grain yields were improved in one out of two years for CP compared to other management systems. Competition for resources (water, nutrient, light, etc.) by weeds and cover crops likely reduced grain yield. Cover crops, especially legume cover crops, as part of intensive rotations did improve N supply within the production system resulting in greater soil nitrate-N concentration after each year of organic management. However, logistics surrounding planting and terminating cover crops can pose problems within organic systems. Additional studies are needed to identify appropriate summer and winter cover crops species. Alternative tillage practices should be explored to improve crop establishment, especially when cover crops are present.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Ronnie Schnell, and my committee members, Dr. Nithya Rajan, Dr. Muthu Bagvathannian, and Dr. Clark Neely for their guidance and support throughout the course of this research.

I must also thank the student researchers for the countless hours spent processing samples and collecting field data. In addition, my fellow graduate students who would go above and beyond to make sure I had help when needed. I cannot fail to mention the departmental faculty and staff for making my graduate experience at Texas A&M University exceptional.

Finally, I would like to thank my family, especially my mother and father for their encouragement and to my beautiful fiancée for driving me forward when I was not sure I could continue, for her patience and for her unfaltering love.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Dr. Ronnie Schnell, Dr. Nithya Rajan, and Dr. Muthu Bagvathannian of the Department of Soil and Crop Sciences and Dr. Clark Neely of the Department of Soil and Crop Sciences MEPS.

Funding Sources

This work was supported by the Organic Transitions Program [grant no. 2016-51106-25710 project accession no. 1010355]. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the USDA National Institute of Food and Agriculture.

NOMENCLATURE

CP	Current Practice
LNT	Legume No-Till
DCNT	Double Cover No-Till
DCCT	Double Cover Conventional Till
NOP	National Organic Program
TAMU	Texas A&M University
LAI	Leaf Area Index
OMRI	Organic Materials Review Institute
USDA	United States Department of Agriculture
NASS	National Agricultural Statistics Service
MNG	Management
BR	Blue River
PH	Prairie Hybrids
GPS	Global Positioning System
N	Nitrogen
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
Na	Sodium

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CHAPTER I

INTRODUCTION

Demand for organic grain in Texas drives the need for development of sustainable cropping systems for organic grain crops, such as corn, sorghum, and soybean. The National Organic Program (NOP) requires use of cover crops and conservation tillage systems in addition to other guidelines for managing soil fertility and pests. Implementing required practices for grain production poses significant challenges for Texas organic producers. Conservation tillage has not been widely adopted in Texas. Furthermore, limited information is available to producers for incorporating cover crops into organic systems. Developing systems that enable successful use of cover crops and reduced tillage will be essential for managing fertility and weeds for sustainable organic grain production.

The number of organic farms in the U.S. has been increasing over the past decade, including Texas. A survey of certified organic producers in 2016 found continued increase in sales of certified organic products. U.S. farms and ranches produced and sold $7.6 billion in certified organic commodities in 2016, up 23% from 2015. During the same year, the number of organic farms in the U.S. increased 11% to 14,217 and the number of certified acres increased 15% to 5.0 million (USDA, Certified Organic Survey, 2017). Texas had 217 certified organic farms in 2016, a 62% increase from 2015 (Harmel, et al., 2006). Certified organic acreage in Texas increased from 86,665 in 2015 to 146,801 in 2016.

Organic corn (Zea mays), for grain or seed, in Texas was produced on 25 farms, with a total of 3,481 hectares (Morris and Maggiani, 2016). With, 64,355 metric tons of organic corn harvested in Texas during 2016, the average yield was 7.5 metric tons per hectare, valued at $6,827,023. For sorghum (Sorghum bicolor) grown for grain or seed in 2016 there were seven farms totaling 986 hectares with 7,230 metric tons harvested, which were valued at $793,701. There were three certified farms producing organic soybeans (Glycine max) in Texas during 2016. Texas had 170 harvested hectares in 2016 producing 1,435 metric tons valued at $419,360. In addition, there were 23 wheat (Triticum aestivum) farms, with 4,003 harvested hectares, that produced 27,654 metric tons valued at $2,722,43 (NASS, 2016).

Organic farms in Texas are subject to regulation under the NOP. The NOP is federal law establishing specific guidelines for production practices used for all commodities sold under the Organic label. The USDA's National Organic Standards Board determined a national standard that organic food must be produced without the use of conventional pesticides, petroleum-based fertilizers, sewage sludge-based fertilizers, herbicides, genetic engineering (biotechnology), antibiotics, growth hormones, or irradiation. Land must have no prohibited substances applied to it for at least three years before the harvest of an organic crop.

Guidelines for implementing organic practices for grain production in Texas are lacking. Current practices for organic grain production in Texas rely on conventional tillage for weed control and manure application to meet crop nitrogen (N) and other nutrient demand. The NOP mandates that farmers implement a crop rotation that maintains or builds soil organic matter, works to control pests, manages and conserves nutrients, and protects against erosion. Conservation tillage and use of cover may improve on current management practices, satisfy NOP requirements, and help improve sustainable production of organic grain. Little information is available about the combined effects of tillage, cover crops, and N fertilization rates on soil mineral N or N uptake and yield of corn, sorghum, and soybean.

Soils found along the Gulf coastal and central regions of Texas present unique challenges for organic producers that intend to implement cover crops and conservation tillage. Both practices are rarely used throughout the region. Common soils in the region are highly expansive clays with greater than 50% clay content that can remain wet for extended periods of time (Harmel, et al., 2006). Soil, topography and environmental conditions in coastal regions of Texas has led to the common management practice of shredding and disking previous crop residues and making raised beds before the end of the year to prepare for planting the following spring. In central regions of Texas, previous crops are shred and disked in the summer and generally planted without further tillage the following spring.

These common crop and tillage practices result in fields being susceptible to soil erosion and loss of nutrients. Watersheds with limited grassed areas and conventional tillage experienced a mean annual soil loss of 22,900 kg ha^{-1} from 1939 to 1961 compared with 2,700 kg ha^{-1} for a watershed with additional grassed areas, contour tillage, and terraces (Ralph, 1964). Soil erosion can be reduced when small grains are included during winter periods due to the presence of soil cover in both the spring and the fall during high precipitation periods (Harmel, et al., 2006). Likewise, use of winter cover crops in organic cropping systems may reduce offsite transport of sediment and associated contaminants and help farm plans align with NOP guidelines (Harmel, et al., 2006).

Compaction is another major concern given soil texture and environmental conditions in many farming regions in Texas. With large equipment and multiple passes over the same areas per year, the soil is susceptible to severe compaction. The extent of compacted soil is estimated worldwide at 68 million hectares of land from vehicular traffic alone (Flowers and Lal, 1998). Soil compaction is estimated to be responsible for the degradation of an area of 33 million ha in Europe (Hamza and Anderson, 2005). Compaction can be greatly reduced by working the soil at the proper moisture content, reducing the number of passes by heavy machinery, and not allowing animals to graze on wet soils. As cropping systems are intensified to include cover crops, the balance between field traffic and planting logistics should be managed closely to minimize the potential for compaction. Employing conservation tillage, minimal tillage, or no-till cropping systems has potential to improve overall soil health and condition, while also reducing the number of passes over the field per season.

In addition to the logistical challenges soils in the region pose, N management is expected to be a significant challenge for organic producers in Texas. A combination of conservation tillage with a mixture of legume and non-legume cover crops can be used to reduce soil erosion, limit leaching of N, and increase grain yield compared with conventional tillage with no cover crop and high rate of N fertilization (Sainju, et al., 2006). For organic systems, synthetic fertilizers are not permitted and producers are encouraged to use legumes and manures or compost as appropriate to meet nutrient requirements of crops. Including legume cover crops in rotation with grain crops not only provides biological N fixation for the system but ground cover for weed suppression, soil retention, and water capture. Management of soils to add organic matter leads to improved soil stability and resistance to water erosion compared to conventionally managed soils, due to higher soil C content and improved soil aggregation (Clark, et al., 1998).

While the benefits of leguminous cover crops are known, incorporating additional crops into sequences in south and central Texas is uncertain. Species, variety selection, and maturity will affect water use and productivity in Texas, especially when growing these crops outside of typical production windows. Studies have shown that organic cropping systems perform better than conventionally managed crop systems during climate extremes such as drought or flooding (Lotter, et al., 2003). Productivity of legume cover crops will determine the amount of N potentially cycled within the system. In addition, logistics of planting and termination will likely be affected by weather. Delayed planting or emergence could disrupt intensification of production systems that include multiple crop cycles within the calendar year.

Weed suppression is likely the greatest challenge for organic grain producers in Texas. The scale and economics of grain production limits the available tools for weed control in organic systems. Use of synthetic mulches or hand weeding are not practical for large-scale grain production. Therefore, many organic grain producers rely on cultivation as the primary method of weed control. Use of cover crops as mulches and no-till planting has gained considerable interest in organic and conventional production systems. Yet, limited information is available in Texas on the success of no-till systems and best practices for incorporating cover crops into no-till systems.

Literature Review

Demand for organic products has increased over the last decade with subsequent increase in organic grain production. The US National Organic Program (NOP) has established guidelines that organic producers must adhere to in order to receive certification as an organic production system. To achieve organic certification, you must develop a farm plan as outlined by the NOP. Key elements include establishing tillage and cultivation practices that will maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion. Producers must also manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials. The producer must implement a crop rotation including but not limited to sod, cover crops, green manure crops, and catch crops that provide function and are applicable to the operation (Saviozzi, Levi-Minzi, et al., 1993). Previous work in cover cropping, nutrient management, soil moisture and health, and tillage practices should be explored as organic grain systems are developed for Texas.

Cover Crops

The NOP mandates that cropping systems employ biological cycles to improve the physical, chemical, and biological condition of the soil. Cover crops will play a key role in the development of systems that comply with NOP mandates. Identifying appropriate species/varieties, optimum planting times, and termination methods will be essential for system development. Cover crops are grown to improve soil fertility, prevent soil erosion, enrich and protect soil, enhance nutrient and water availability, and improve quality of soil. Cover crops can increase and sustain microbial biodiversity in soils, improve the overall health of the soil and provide a sustainable environment for the main crops (Sharma, et al., 2018). (Karlen, 1994) found that maintaining or adding crop residue, even in the absence of tillage, improves several biological, chemical, and physical characteristics of silt loam soils. These improvements of soil chemical and physical properties enable the soil to resist water and wind erosion, to retain more water, and to retain essential plant nutrients.

In conventional farming systems, insufficient N supply is supplemented by application of synthetic N fertilizer or by introducing a nitrogen fixing legume into the system (THOMAS, 1992). Species selection can add value to cover crop production. Legumes contribute biologically fixed N to the system and can be used to supplement other nutrient sources, such as manure. When non-legumes are used, such as winter cereals, residual inorganic N can be cycled and may prevent loss of N from the system through leaching or denitrification. Cereals can capture and store residual N in aboveground biomass that remains from previous crops. A mixture of legumes and non-legumes may be needed to obtain the greatest benefit to soil. Legumes have the ability to provide supplemental N to the system, while non legumes have the ability to sequester residual N and prevent it from leaching beyond the root zone (Mendes, et al., 1999). In addition, cover crops sequester atmospheric carbon, converting it to soil organic matter for improved soil health and quality. Cover crops were shown to increase soil organic matter, macro-porosity, mean aggregate size, soil permeability, and crop yield in a 25-year study with cotton under conventional tillage (Patrick, et al., 1957).

Despite potential benefits of cover crops, water depletion from soil by non-cash crops is a concern, especially in rain fed regions. Use of stored soil moisture by cover crops can reduce yields of the subsequent crops in rain fed and semiarid regions (Creamer, 2006)This is less of a problem in humid areas with sufficient rainfall and where irrigation water is available to compensate for water deficits at planting time. Yet, cover crops may improve water capture and retention and potentially negate water use.

Similarly, a 7 year study using winter rye as cover crop in maize-soybean cropping system increased soil moisture and improved soil water table. Cover crops help to reduce evaporation from the soil surface, conserves moisture from the irrigation or rainfall, and can improve soil moisture availability to the subsequent crops (Sharma, et al., 2018). Cover crop residues returned to the soil surface play an important role in water conservation. Crop residue alters soil water balance by decreasing losses due to runoff and evaporation, and increasing soil water storage in the root zone. Crop residue mulch decreases evaporation rate during the first and second stages of evaporation and keeps the soil moist for a longer period than without the residue mulch (Lal, 1995).

Cover crops grown in organic systems require termination prior to planting grain crops. Termination can be challenging even in conventional systems where chemical termination is used. Some cover crop species, such as rye, are particularly competitive and vigorous. Killing fall planted rye with repeated mowing before spring seeding a clover may be able to reduce competitiveness of the rye, but the higher traffic could cause soil compaction leading to poor growth and yield (Bottenberg, et al., 1997). Other reports have found it difficult to terminate legume cover crops and suggest that the surviving mulches could reduce subsequent crop stands and early season growth (White and Worsham, 1990). Similar challenges are anticipated in organic grain systems in Texas.

Nutrient Management

Impact of manure on crop growth and soil properties is well documented. Application of manure or litter can enhance soil organic C and improved soil physical condition through better aggregation and infiltration and reduced soil resistance. Manure applications could be an effective practice of nutrient management and restoring the quality and productivity of eroded lands (Adeli, et al., 2017). Similar to improvements of soil properties, manure can improve grain yield and quality, including protein levels in cereals (Fredriksson, et al., 1997).

Manures or composts are often the primary nutrient source for organic grain systems. Organic sources of nutrients, particularly N, are released slowly and persist in the soil beyond the year of application (Adeli, et al., 2017). Manure and compost applications should be managed carefully to avoid non-point source loss of nutrients, including phosphorus (P). With manure applications, a threshold of phosphorous accumulation in the soil is used to minimize environmental loss of P. When using manures as a complete N source repeatedly, soil test P levels frequently increase beyond ranges considered optimal for most agronomic crops. The N:P ratio of most manures results in over-application of manure P relative to crop P needs (Miller, et al., 2011). Manure applications should be managed carefully to increase crop growth, grain yield and improve soil condition.

Considering manure should not be used meet used to meet total crop N requirements due to environmental concerns, supplemental N will be required to increase grain production. While Chilean nitrate or sodium nitrate ($NaNO_3$) is allowed within organic systems, it can only supply 25% of total crop N requirements. Sodium nitrate as 16% N and is known by several different synonyms, e.g. nitratine, soda niter, and nitrate of soda (Urbansky, et al., 2001). The combination of manure N and Chilean N is unlikely to meet N demands of grain crops. Therefore, including legumes in rotation as grain or cover crops is a logical method of increasing N supply to organic grain systems.

A mixture of rye and vetch is a popular choice for many organic systems in the U.S. In a study conducted by Vaughan (1999), he found that soil with vetch cover crops had consistently higher N concentrations than other treatments indicating more plant available N with vetch. Under no-till management conditions, Vaughan also found that soil N concentrations were significantly higher at 0-15 than 0-30 cm soil depth at two locations and for two years due to the concentration of plant residues near the soil surface (Vaughan and Evanylo, 1999). Hargrove (1986) found that a well-adapted legume such as crimson clover could replace as much as 120 kg fertilizer N ha^{-1}. The average amount of fertilizer N replaced by the legume was 72 kg N ha^{-1}. Since fertilizer N represents a sizeable portion of the fossil fuel energy required for non-leguminous row crop production, this represents a significant energy savings, enhancing the conservation value of a no-tillage production system (Hargrove, 1986).

There are other organically approved nutrient sources approved through the Organic Materials Review Institute (OMRI) that could be used as N sources. Products such as fish emulsion, pelletized chicken litter, soybean meal, or feather meal may be used in organic systems (Fernandez-Salvador, et al., 2015). The cost of these products may limit the percentage of needed N that can be applied to grain crops. Yet, alternative nutrient sources could serve as a component of total nitrogen requirements of grain crops when coupled with legumes, manures, and other approved N inputs.

Weed Control

Weeds are a concern for conventional and organic production systems and must be addressed to maintain high yield potential. Cover cropping can be a useful method of weed suppression by out competing, shading, or even allelopathy. Rye is a common winter cover crop used in many systems and it has been shown to have a reasonably strong allelopathic response to other plants. Creamer (1996) found lettuce germination was inhibited by unleached rye straw. These results demonstrated that allelochemicals were leached from rye residue and that the leached shoot residue can be used as a control for weed suppression (Creamer, 1996). Proper variety selection for cover crops is important for successful weed control and to avoid interference from the cover crop with grain crop production.

Cover crop suppression of weeds can be enhanced if cover crops are managed with no tillage than if tilled into the soil (Dabney, et al., 2001). Living cover crops (living mulches) have greater weed suppression capacity than terminated crops, but are often competitive with direct seeded crops for light, water, and nutrients. Weed suppression by cover crops has been a key element in the successful adoption of no-till systems in South America (Dabney, et al., 2001), which has reached 95% in some regions. Weed suppression by cover crops can be due to resource competition, niche disruption, and phytotoxic effects and is affected by cover crop species, planting date, seeding rate, kill method, and kill timing relative to subsequent crop planting (Liebman and Davis, 2000). To reduce herbicide requirements, cover crops must be competitive with native vegetation yet be easier to control as subsequent cash crop planting time approaches. Mechanical termination of cover crops with mowers or rolling choppers can be used in lieu of herbicides in organic systems although successful termination of the cover crop is uncertain.

Tillage Systems

Studies have estimated that about 80% of the world’s agricultural land is affected by moderate to severe erosion and 10% suffers slight to moderate erosion.(Pimentel, et al., 1995). Many farmers fear the depletion of soil water and nutrients if they were to implement the practice of cover cropping. In a study with 10 years of no-till corn Karlen (1994) found that maintaining or adding crop residue, even in the absence of tillage, improves several biological, chemical, and physical characteristics of silt loam soils. These improvements presumably enable the soil to resist water and wind erosion, to retain more water, and to retain essential plant nutrients. The overall soil quality assessment quantifies the benefits of maintaining or adding crop residues. They concluded that this approach can easily be adapted to other soils and types of evaluation (Karlen, 1994).

Plowing practices are not universal and can vary widely from producer to producer based or cultural practices, soil types, and equipment used. The type of plow used determines what will happen to the soil such as inversion (moldboard), just breaking the surface (chisel), etc. However, note that since conventional farming practices are continually evolving and vary geographically, the point of comparison must be typical of common practices for the time and location of the assessment. The relative gain from adopting conservation tillage will depend on the system from which the farmer switched (Uri, et al., 1998). As stated, there are several different forms of tillage in practice and there are certain parameters that define each.

Conventional tillage comprises all tillage types that leave less than 15% of crop residues on the soil surface after planting the next crop, or less than 1,100 kg ha^{-1} of small grain residue throughout a critical erosion period. Generally, such tillage techniques include plowing or intensive tillage. Conventional moldboard plowing followed by secondary tillage operations is still used as the preferred tillage option for soils with internal drainage problems, e.g., clay soils with poor structure or for pure sandy soils. Farmers can be locked into a cycle of continuous plow tillage. The justification for this common practice varies from yield security, residue-free soil-surface-improved seedbed preparation, and drilling (especially where precision drilling of crops is used), to weed control and burying weed seeds (El Titi, 2002).

Intensive and often excessive tillage practices result in decreased amounts of crop residues returned to soil, accelerated decomposition of organic matter (OM) and losses of OM-rich top soil by winds and water erosion. Excessive tillage also pulverizes the soil and exposes it to the sun, leading to increased soil degradation and loss of OM (Arshad, et al., 1990). Another study found a decrease in organic carbon content of 12 to 14% for the minimal tillage compared to conventional tillage treatments (Dick, 1983). Dick also found that the organic carbon concentration decreased from that observed at the beginning of the tillage experiment but the decrease was less for no-till (11%) than for minimal tillage (23%) and conventional tillage (25%). Contrary to studies citing loss of OM, some suggest other factors contribute to lower levels of measured soil OM. When bulk density is factored into calculations of soil organic carbon (SOC), it is concluded that tillage system does not affect SOC (Deen and Kataki, 2003).

No-till is an alternative to conventional tillage that can decrease soil erosion, reduce moisture loss and production inputs, and intensify land usage while maintaining comparable crop productivity (White and Worsham, 1990). Soil water retention is a key factor in deciding whether to implement a no-till practice or not. He et al. (2011) found that no-till improved soil water storage 19.3% over conventionally treated plots in an 11-year study conducted in Hebei province, North China Plain from 1998-2009. Additionally, benefits included significantly greater soil organic matter content and improved nutrient status, increased macro-aggregate stability, higher proportions of macro pores and mesopores, and enhanced soil water storage. Yields for the NT treatment were improved by 3.5% and 1.4% compared to the soils under conventional tillage management (He, et al., 2011).

Soils under no-till have greater soil surface residue, which results in moist soil and lower temperature with improved microbial activity, better aggregate structure and considerable improvement in soil properties. Soil properties improved include N content, soil organic matter and soil organic carbon content, CEC (Cation exchange capacity) and decrease the C:N ratio compared to conventional till soils (Soane, et al., 2012). Moreover, no-till greatly enhances carbon accumulation within micro aggregates, which in return form macro aggregates. Formation of stable aggregates provides benefits for soil physical and chemical properties.

While there are reported benefits for reduced tillage, tillage may be necessary in organic systems. Tillage is a primary tool for weed eradication in many organic systems. However, it poses problems for soil aggregation, structure, and moisture retention. To meet the demand for organic products in Texas, information on the interaction of cover crops and tillage systems is needed for grain producers to engage in organic production and adhere to the guidelines established by the NOP. The current project will address three major challenges for organic grain producers; tillage practices, cover crop practices, and nutrient management. The goal is to develop a system that could lead to successful establishment of a certified organic system that could aid local farms in making informed decisions on how to begin to transition into a certified organic system. Developing production guidelines for Texas producers is essential for sustainable production of organic grain.

CHAPTER II

DEVELOPING ORGANIC GRAIN CROPPING SYSTEMS IN TEXAS

Introduction

Demand for organic products by consumers has resulted in the emergence of organic agriculture in the United States. Based on a 2016 survey by the USDA, there were 14,217 organically certified farms in the United States. Furthermore, there is a growing demand and market for organic products in Texas with 217 certified organic farms registered in the state (NASS, 2016 #187). Yet, recommendations for organic practices in Texas are lacking. To enable expansion of organic farming in Texas to meet consumer demands, successful agricultural practices, and production systems need to be identified.

Organic practices developed for Texas producers must be developed within the confines of the National Organic Program (NOP). NOP guidelines determine definitions, applicability, organic production and handling requirements, labels, labeling and marketing information, certification, accreditation of certifying agents, and administration. To further break down these sets of guidelines, there are sub guidelines that more specifically explain what each category is defining. When implemented properly you are allowed to use regulated terms such as 100 percent organic, organic, or made with organic. The first and possibly the most critical step is creating and submitting an organic system plan. This plan lays out the strategy a farm will put in place to achieve or maintain certified organic status. The key components of this plan are production and handling, land requirements, soil fertility and crop nutrient management, crop rotations, and pest management practices. All of these parameters must be met in accordance with the NOP guidelines. For example, the producer must manage their crop nutrients and soil fertility through rotations, cover crops, and the application of animal materials. Therefore, based on this guideline alone monoculture farming practices are strongly discouraged. This provides a challenge for Texas producers implementing organic farming systems.

Limited information for cover crop management in Texas and no recommendations for managing cover crops in organic grain systems in Texas currently exist. Experiences in other regions of the U.S. suggests that mixtures of small grain and legume cover crops should be explored. Small grain cover crops are capable of taking up residual soil fertilizer N in the fall, winter, and spring when there can be significant levels of leachable N in the root zone. A legume such as hairy vetch helps to scavenge residual N and also fixes atmospheric N in the system (Clark, et al., 1997).

In addition to cover crops, tillage systems need to be identified that satisfy requirements of the NOP and lead toward sustainable production of organic grain under conditions encountered in Texas. No-till and conventional tillage practices could be employed in Texas. Yet, conventional tillage may provide options for managing crop and cover crop residues in intensive crop cycles.

All of the inputs into the system form a cohesive environment for the success of the system. The cover crops and especially the legume are an essential part of any sustainable organic system. The successful implementation of these management practices will in time lead to a system that is not only self-sustaining but also profitable.

Materials and Methods

Site Description

A replicated field study was established during the summer of 2016 in Burleson County, TX. The study was arranged into a split plot design with three replications. Main plots were rotations of corn, sorghum, and soybean (Grain Crops), each of the main plots were represented in each block during every year of the study. Within each grain crop, contrasting management practices served as sub-plots. Subplots included: 1) Current Practice - conventional tillage with summer fallow, winter fallow and spring primary crops; 2) Legume No-Till - summer cowpea, winter legume, no-till primary crops; 3) Double Cover No-Till – summer cowpea, cereal/legume mix, no-till primary crops; 4) Double Cover Conventional-Till – summer cowpea, cereal/legume mix, complete tillage before planting primary crops (Table 1). Subplots were 3 m wide and approximately 100 m in length.

Table 1. Sub-plot treatment descriptions. CP = current practice, LNT = legume no till, DCNT = double cover no till, DCCT = double cover conventional till

MANAGEMENT PRACTICES				
	CP	LNT	DCNT	DCCT
SUMMER	Fallow	Legume	Legume	Legume
WINTER	Fallow	Legume	Cereal/Legume	Cereal/Legume
SPRING	Grain Crop	Grain Crop	Grain Crop	Grain Crop

Cover Crop Management

Summer and winter cover crops were planted proceeding grain crop planting in 2017 and 2018. For grain crops produced in 2017, a summer cover crop was planted in September of 2016. Iron and clay cowpea were planted at a rate of 56 kg ha^{-1} (Table 2) using a John Deere 8300 grain drill with a 3-m drill width and with 18-cm row spacing. Cowpeas were inoculated with N-Dure inoculant (*Bradyrhizobium*) at a rate of 142 g inoculant per 23 kg of seed. Cowpeas were allowed to grow until November of 2016 and terminated by shredding disking. For LNT, cowpeas were not terminated and allowed to stand in the field until no-till planting of grain crops in March of 2017. Winter cover crops were established in November of 2016 for DCNT and DCCT management systems. A mixture of cereal rye and hairy vetch was seeded at 146 kg ha^{-1} as described for cowpeas (Table 2). Hairy vetch was inoculated with N-Dure inoculant (*Rhizobium leguminosarum biovar viceae*) at a rate of 142 g inoculant per 23 kg of seed.

Winter cover crops were terminated by crimping and rolling using a 3 m harrow as a roller within a week of grain crop planting.

Table 2. Cover crop management proceeding planting of grain crops in 2017. CP = current practice, LNT = legume no till, DCNT = double cover no till, DCCT = double cover conventional till

2017	**Cover Crop Management Prior to Grain Crop**			
	CP	**LNT**	**DCNT**	**DCCT**
Summer Cover Crop		Summer Legume	Summer Legume	Summer Legume
Variety	-	Iron & Clay Cowpea	Iron & Clay Cowpea	Iron & Clay Cowpea
Seed Rate (kg ha^{-1})	-	56	56	56
Planting Date	-	9/17/16	9/17/16	9/17/16
Winter Cover Crop			Cereal Legume	Cereal Legume
Variety	-	-	Rye/Vetch	Rye/Vetch
Seed rate (kg ha^{-1})	-	-	146	146
Planting Date	-	-	11/18/16	11/18/16

Similar to 2017 grain crops, summer and winter cover crops were planted proceeding grain crops in 2018. For grain crops produced in 2018, a summer cover crop was planted on 09/07/2017. Hurricane Harvey delayed the scheduled planting of cowpeas. Iron and clay cowpea were planted at a rate of 39 kg ha^{-1} (Table 3) using a John Deere 8300 grain drill and identical inoculation process as described previously. Cowpeas were allowed to grow until 11/07/2017 and terminated by shredding disking. For LNT, cowpeas were terminated and winter cover legume was planted. Failure of cowpea to provide adequate soil cover for grain planting the following spring necessitated including a winter legume (winter pea, 56 kg ha^{-1}). Winter cover crops were established on 11/07/17 for DCNT and DCCT management systems as well. A mixture of winter cereals (spring wheat, 97 kg ha^{-1}) and winter peas (56 kg ha^{-1}) was seeded at 146 kg ha^{-1} as described for cowpeas (Table 3). Winter peas were inoculated with N-Dure inoculant (*Rhizobium leguminosarum biovar viceae*) at a rate of 142 g inoculant per 23 kg of seed. Winter cover crops were terminated by crimping and rolling using a 3 m harrow as within a week of grain crop planting.

Table 3. Cover crop management proceeding planting of grain crops in 2018. CP = current practice, LNT = legume no till, DCNT = double cover no till, DCCT = double cover conventional till

2018	**Cover Crop Management Prior Grain Crop**			
	CP	**LNT**	**DCNT**	**DCCT**
Summer Cover Crop		Summer Legume	Summer Legume	Summer Legume
Variety	-	Iron & Clay Cowpea	Iron & Clay Cowpea	Iron & Clay Cowpea
Seed Rate (kg ha^{-1})	-	39	39	39
Planting Date		9/7/17	9/7/17	9/7/17
Winter Cover Crop	-	Winter Legume	Cereal/Winter Legume	Cereal/Winter Legume
Variety	-	Austrian Winter Pea	Spring Wheat/Austrian Winter Pea	Spring Wheat/Austrian Winter Pea
Seed rate (kg ha^{-1})	-	56	97/56	97/56
Planting Date	-	11/7/17	11/7/17	11/7/17

Cover crops were assessed for dry matter (DM) production and nutrient content at the time of termination or before planting grain crops. Cover crop DM was measured from a 1 x 1 m square dropped at two random locations within each plot. Biomass was cut at soil level with a set of electric hedge trimmers. The cut sample was bagged, weighed, dried, and then weighed again to estimate mean DM ha^{-1}. Dried samples were milled using a Wiley Mill (2 mm) and submitted to the TAMU Soil Water and Forage Testing Laboratory for analysis of N content using high temperature combustion analysis (McGeehan and Naylor, 1988). Biomass and N content (% N) was used to estimate N cycled by cover crops.

Grain Crop Management

Grain crops were planted in early March for corn and late March-early April for sorghum and soybean. All grain crops were planted on 76-cm row spacing with four rows per plot and a plot length of 97.5 m using a John Deer 1705 no-till planter. No-till components for the planter consisted of coulters and floating residue mangers (Yetter floating row cleaner with shark tooth wheel with a fluted no-till coulter model 2585-182, Colchester, Illinois).

Table 4. Grain Crop Management for years 2017 and 2018. CP = current practice, LNT = legume no till, DCNT = double cover no till, DCCT = double cover conventional till, RP= Re-plant

Crop	Year	Variety/ Hybrid	Seeds ha^{-1}	Planting Date	Harvest Date
Corn	2017	Blue River 70A47	75,600	3/31	7/31
	2018	PH7387	79,040	3/22 4/13 RP	8/16
Soybean	2017	Blue River 505K7	308,800	4/5	-
	2018	P4910	345,800	4/6 4/18 RP	-
Sorghum	2017	Blue River 63C5	172,900	4/5	7/31
	2018	SP7715	197,600	4/16	8/16

Corn hybrids planted each year varied due to availability of seed. In 2017, Blue River 70A47 (Ames, Iowa) was planted and has a relative maturity of 112 days and in 2018, PH7387 was used (Prairie Hybrid, Deer Grove, Illinois) (Table 4). Corn was replanted using PH7387 in 2018 due to excessive stand loss due to wireworm and seed maggot infestations. Seed rate for corn was 75,600 seeds ha^{-1} in 2017. Due to low plant stands in 2017, seed rates were increased to 79,040 seeds ha^{-1} in 2018.

Similar to corn, soybean varieties varied by year due to availability of certified organic seed. Blue River 505K7 was planted in 2017 at 308,750 seeds ha^{-1} and Progeny Seeds P4910 was planted at 345,800 seeds ha^{-1} in 2018. Blue River 505K7 is a group V maturity and P4910 is a group IV maturity (Table 4). All soybeans were inoculated at planting with N-Dure inoculant (*Bradyrhizobium japonicum*) at a rate of 142 g per 23 kg of seed. Similar to corn in 2018, initial soybean stands were not sufficient and required replanting. Seed delivery delayed replanting to April 18.

For grain sorghum, Blue River 63C5 was planted in 2017. Due to seed availability, Sorghum Partner SP7715 was planted in 2018. SP7715 is a medium-full maturity, with tolerance to the sugarcane aphid, which is a major pest in the study region. During 2017, a seeding rate of 172,900 seeds ha^{-1} was used and this was increased to 197,600 seeds ha^{-1} in 2018.

Plant stands (plants ha^{-1}) were determined from 3 m of the center two rows at two random locations within each plot two weeks after emergence. Seeding rates and plant populations were used to calculate plant stand (%). Leaf area was measured destructively at 5 different growth stages and LAI was measured using a Li-Cor leaf area meter model LI-3100C (Lincoln, Nebraska) from 10 plants of the center two rows. Measured leaf area was used to determine leaf area index (LAI). Grain crop biomass was determined at physiological maturity by harvesting above ground tissue, weighing, drying (60 C), and weighing to estimate DM ha^{-1}.

At harvest, grain crops were harvested using a John Deere 3300 combine equipped with a Harvest Master HM800 data collection system to measure plot weight, grain moisture and test weight. Yield was collected from the center two rows of each plot. Yield was adjusted to uniform moisture of 13% for soybean, 14% for sorghum, and 15.5% for corn. Excessive weed biomass can interfere with plot weight, moisture, and test weight measurements. If weed biomass precluded mechanical harvest, plots were considered to have zero harvestable yield.

Nutrient Management

Poultry manure or compost was applied as a surface broadcast prior to planting grain crops each year (Table 5). Rates were limited by soil test P levels and it was anticipated that manure or compost would provide 50 to 60 kg N ha^{-1}. Additional nutrient inputs were included as appropriate to obtain N levels needed for grain yield goals while balancing N and P ratios applied within each system. In 2018, fish emulsion was applied at 56.1 L ha^{-1} in the seed furrow at planting. The fish emulsion had an analysis of (5-1-1) providing 3.2 kg N, 0.28 kg P, and 0.53 kg K ha^{-1}. Fish emulsion is an OMRI approved fertilizer that can be applied at planting or as a foliar application. It is derived from hydrolyzed fish protein and bone meal. In 2018, Chilean nitrate (15-0-0, sodium nitrate) was applied to supply no more than 25% of crop N needs for corn and sorghum. Chilean nitrate is OMRI approved natural sodium nitrate from Chile. It was applied at 208 liters ha^{-1} to reach a N contribution of 28 kg ha^{-1}. Contribution of legume cover crops to system N inputs were estimated to determine maximum rates of supplemental N, as Chilean nitrate (25% maximum).

Table 5. Nutrient content and rate of litter or compost applied to grain crops in 2017 and 2018. * = Dry Weight Basis

Product	***N**	***P**	***K**	**Total**	**Application**
	---------------%---------------			***kg ha^{-1}**	**Date**
2017 Broiler Litter	2.52	1.23	3.87	1,936	3/3/2017
2018 Turkey Compost	1.11	0.18	0.35	4,694	3/13/2018

Additional Data Collection

Soil samples were collected prior to establishment of treatments in 2016 and prior to planting grain crops in 2017 and 2018 to determine soil concentration of nitrate-N and extractable nutrients. In 2016, experimental units had not been established. Therefore, four cores (15cm depth) were composited from each block. Prior to planting grain crops in 2017 and 2018, 4 cores were composited from each plot to the same depth. Soil cores were collected using a GSRPS Giddings Machine Company soil probe. The samples were sent to the Texas A&M Forage, Soil, and Water Testing Laboratory for analysis. Mechlich III was used to extract phosphorus, potassium, calcium, magnesium, sodium, and sulfur and concentration measured by inductively coupled plasma (ICP). A hydrogen selective electrode was used to determine soil pH in a 1:2, soil: deionized water extract. Nitrate nitrogen was extracted from the soil with 1 N KCL solution.

The weather data was collected for the two years of the study using a Watchdog 2000 Series data logger produced by Spectrum Technologies (Aurora IL). Solar radiation, relative humidity, temperature, precipitation, wind direction, wind speed, and dew point were recorded every 15 minutes. Data was acquired from the station several times per year. Data was then tabulated on a daily basis.

Data Analysis

Analysis of variance was assessed using PROC GLM procedures in SAS 9.4 (SAS, Cary, NC) partitioning as appropriate for measured variables. Primary crops served as main plot and management practices as subplots for variables analyzed as a split plot design. Split plot analysis was used to compare percent stand, LAI, dry matter biomass, population, and yield. When interactions were detected at $P<0.05$ level, analysis was performed on management practices within primary crops individually. Main effects were separated using Fisher's Protected LSD. Primary crop yield and biomass were analyzed as a randomized complete block design and management practices separated using LSD as appropriate. Block was assigned as a random variable while primary crops and management practices were treated as fixed effects.

Results and Discussion

Growing Conditions

Minimum and maximum monthly temperature, mean temperature, cumulative precipitation, and mean of solar radiation data are presented in Table 6. A combination of hot and dry conditions were observed in 2018 during periods when grain crops were sensitive. Delayed planting and required replanting of grain crops shifted developmental periods into periods of unfavorable environmental conditions. Supplemental irrigation was applied as necessary for grain crops during times of water stress (Table 7). Three irrigation events took place during the grain crop growing period. The irrigation system used for watering applied approximately 12.7 to 19.1 mm of irrigation water per run and it took two runs per block to complete one irrigation event.

Table 6. Weather data for 2017 and 2018 showing minimum and maximum temperature, mean temperature, cumulative precipitation, and mean solar radiation by month.

		TEMPERATURE			**PRECIPITATION**	**SOLAR RADIATION**
YEAR	**Month**	**Min**	**Max**	**Mean**	**Sum**	**Mean**
		°C			**mm**	**watt m^{-2}**
2017	Jan	0.05	26.94	14.5	96.0	293.93
2017	Feb	1.11	30.83	17.3	105.7	349.82
2017	Mar	2.89	30.33	19.28	44.7	402.43
2017	Apr	6.94	33.67	21.28	114.6	469.25
2017	May	8.56	33.61	23.58	142.8	465.67
2017	June	19.44	36.5	27.36	119.6	467.83
2017	July	20.56	40.78	29.91	55.9	518.73
2017	Aug	19.67	38.06	28.19	763.5	441.86
2017	Sept	13.44	35	25.79	24.9	478.86
2017	Oct	-0.44	33.61	20.4	17.6	427.27
2017	Nov	0.33	30.89	17.79	22.4	308.56
2017	Dec	-1.61	27.72	10.11	40.6	207.61
2018	Jan	-9.78	22.17	7.7	29.6	297.94
2018	Feb	-0.94	26.89	12.94	47.2	175.94
2018	Mar	1.89	29.72	18.34	156.5	397.45
2018	Apr	5.11	30.56	18.42	37.6	451.32
2018	May	13.22	37.28	26.15	52.8	475.59
2018	June	20.44	38.44	28.91	51.1	460.7
2018	July	16.11	42.83	28.94	40.6	477.82
2018	Aug	19.33	40.11	30.02	5.3	481.54

In August of 2017, the study site received 763.5 mm of rainfall during hurricane Harvey. This caused extensive delays in field activities resulting in reduced performance of cover crops the fall of 2017 and delayed planting of subsequent grain crops in 2018.

In some situations, it may be advised to not plant cover crops late and keep crop rotations on schedule.

Table 7. Irrigation event and quantity of irrigation applied in mm.

IRRIGATION DATES	APPROXIMATE IRRIGATION (MM)
03/18/2018	31.8
05/22/2018	63.6
06/18/2018	31.8

Soil Chemical Properties

At initiation of the study in 2016, soil samples were collected to obtain baseline soil fertility levels. Mean concentration of extractable NO_3-N, P and K are provided in Table 8. Concentration of extractable soil NO_3-N was low with means between 0.39 and 0.71 mg kg^{-1}. Site history indicates no synthetic fertilizers were applied since 2009. Low levels of extractable N were not unexpected. Concentration of Mehlich III extractable P ranged from 24.7 to 41.5 mg kg^{-1}. Although concentration appears to increase moving from west (block 1) to east (block 3), all measurements are below the P critical value for crop production in Texas. Extractable K ranged from 383 to 409 mg kg^{-1}, well above critical values (125 to 170 mg kg^{-1}) for crop production in Texas. High levels of extractable K in soil is common in Texas croplands.

Table 8. Extractable soil nutrient concentration from a sampling depth of 15 cm for each block prior to treatments being imposed in 2016. Standard deviation provided in parenthesis.

BLOCK	NO_3-N	P	K
		----------------------------mg kg^{-1}----------------------------	
1	0.39 (0.3)	24.7 (2.3)	409 (34.0)
2	0.71 (0.6)	32.7 (14.4)	389 (39.6)
3	0.51 (0.4)	41.5 (16.0)	383 (22.3)

Summer and winter cover crops were established within various management/tillage systems from the summer of 2016 through spring of 2017. Soil was sampled for analysis of extractable nutrients in 2017 prior to planting grain crops. Concentration of extractable NO_3-N, P, and K were used to determine manure rates and monitored to prevent accumulation of P within soil. Mean concentration of extractable nutrients are presented by crop and management practices (Table 9). Mean concentration of soil extractable NO_3-N increased 11.9-fold in 2017 compared to 2016. Given manure had not been applied yet, N fixation by cover crops and mineralization of N from cover crop residues likely contributed to greater levels of plant available N prior to grain crop production. There were no differences ($p > 0.05$) in soil extractable N with a mean of 6.9 mg kg^{-1} among management practices despite contrasting tillage and cover crop practices. This suggests mineralization of organic sources of soil N may have contributed to changes in soil N. While an increase of soil N concentration was observed, concentration on N in soil would likely not meet grain crop nutrient demands, specifically for corn and grain sorghum. Manure and other sources of N would be required to maximize grain production.

Table 9. Concentration of soil extractable NO_3-N, P and K by crop and management practice at 15 cm in 2017, prior to planting of grain crop. CP = current practice, LNT = legume no-till, DCNT = double cover no-till, DCCT = double cover conventional till Values followed by the same letter within columns and main factors (Crop or MNG) are not significantly different using L.S.D ($p < 0.05$).

	NO_3-N	**P**	**K**
Crop Rotation	---------------------------mg kg^{-1}------------------------------		
Corn	7.16	23.81	289.6 a
Sorghum	6.97	18.00	260.9 b
Soybean	6.70	18.53	258.9 b
Management (MNG)			
CP	6.88	18.95	256.8
LNT	6.97	22.80	285.6
DCNT	7.10	20.17	269.3
DCCT	6.82	18.54	256.8
P>F			
Crop	0.365	0.134	0.003
MNG	0.586	0.488	0.335
Crop x MNG	0.309	0.913	0.585

In contrast to concentration of extractable N in soil, concentration of Mehlich III extractable P and K decreased before grain crop planting in 2017 compared to initial soil test levels. Concentration of Mehlich III extractable P decreased 39% and decreased by 32% for extractable K compared to initial soil test values. However, there was no difference ($p > 0.05$) among crops or management practices. While nutrients may have been immobilized in cover crop residue at the time of sampling, no difference was observed between current practice and other management practices. This suggests the influence of cover crops was minimal.

Variation in soil extractable nutrient concentrations were detected in 2018. The CP management increased soil extractable NO_3-N by 39.6% compared to LNT, DCNT, and DCCT (Table 10). The current practice did not have a cover crop component, which may have precluded immobilization of N in cover crop residues. Overall, soil extractable NO_3-N was 16.6 fold greater than soil sampled before treatments were imposed in 2016. Increasing soil NO_3-N concentration over time is expected as cropping systems mature and nutrient cycling is enhanced by management practices.

Table 10. Concentration of soil extractable NO_3-N, P and K by crop and management practice at 15 cm in 2018, prior to planting of grain crop. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till Values followed by the same letter within columns and main factors (Crop or MNG) are not significantly different using L.S.D ($p < 0.05$). Grain crop in bold indicates the crop grown in the current year.

	NO_3-N	**P**	**K**
Crop Rotation	---------------------------mg kg^{-1}------------------------------		
Soybean - ***Corn***	10.7	22.9 b	297.9
Corn - ***Sorghum***	10.5	24.1 ab	305.1
Sorghum - ***Soybean***	10.5	25.5 a	318.4
Management			
CP	13.5 a	24.4	307.1
LNT	10.0 b	23.6	310.1
DCNT	9.3 b	24.3	310.7
DCCT	9.5 b	24.3	300.5
P>F			
Crop	0.645	0.035	0.072
MNG	<.0001	0.981	0.730
Crop x MNG	0.852	0.428	0.864

Variation in soil test P concentration was observed among crops prior to grain crop planting in 2018. Crop rotations proceeded as Sorghum-Soybean-Corn. Following soybeans from 2017, soil test P concentration in 2018 was 10.2% lower preceding corn planting compared to rotation from sorghum to soybean. Overall soil test P and K concentration was lower than initial soil test levels, 26% for P and 24% for K respectively. Yet, soil test P and K concentration were greater than levels observed in 2017. With limited grain removal, soil nutrient levels appear to be improving under management systems, but not to levels that warrant environmental concerns.

Cover Crop Production and Nitrogen Content

Cowpeas were planted in the summer of 2016 to establish contrasting management practices. Cover crop mean dry matter and N mean is provided in Table 11 for each management practice (pooled across grain crops). Cowpea dry matter production ranged from 729 to 764 kg ha^{-1}. Concentration of N in cowpea biomass was used to estimate N return to soil from aboveground biomass. Cowpea biomass returned 24.8 to 25.6 kg N ha^{-1}. Cowpea under LNT was allowed to stand over the winter for no-till planting of grain crops in 2017. Winter cover crops in DCNT and DCCT proceeding 2017 grain crops included a mixture of cereal rye and vetch. Cover crop dry matter production was from 709 to 790 kg ha^{-1} with no difference among grain crops ($p>0.05$). In contrast, management practices did affect winter cover crop productivity. DCNT had greater ($p = 0.001$) winter cover dry matter production (877.8 kg ha^{-1}) compared to

DCCT 599.2 kg ha^{-1} (Table 11). Winter cover N concentration data was missing. Therefore, N return to soil by winter cover crops is not presented.

Table 11. Nutrient concentration and dry matter in kg ha^{-1} from cowpea biomass and rye/vetch cover crops preceding planting of grain crops in 2017. Standard deviation provided in parenthesis. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till, DM = Biomass Dry Matter, N = Total Nitrogen in dry matter (kg N ha$^{-1)}$. Missing or incomplete data sets represented by (-). Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

	Summer Cover		**Winter Cover**	
	DM	**N**	**DM**	**N**
	------------------------------kg ha^{-1}------------------------------			
Crop Rotation				
Corn	-	-	717	-
Sorghum	-	-	790	-
Soybean	-	-	709	-
Management				
CP	-	-	-	-
LNT	735 (111.1)	25.6 (4.8)	-	-
DCNT	764(158.9)	24.8 (6.7)	878 a	-
DCCT	729 (99.8)	25.2 (5.3)	599 b	-
P>F				
Crop	-	-	0.633	-
MNG	-	-	0.001	-
Crop x MNG	-	-	0.553	-

Cover crops preceding grain crops in 2018 included summer and winter cover crops. Summer cowpea productivity was evaluated by crop and management practice. Cowpea dry matter yields ranged from 1,638 to 1,975 kg ha^{-1} across all grain crops, with grain crop sequence not affecting (p>0.05) cowpea productivity. Similarly, management practices did not affect cowpea productivity (p>0.05). However, cowpea biomass yield was 2.4 times greater in 2017 compared to 2016. As a result, mean N returned to soil by cover crop biomass was 35.5% greater in 2017 at a mean of 34.2 kg N ha^{-1} compared to 2016 cowpea (Table 11).

For winter cover crop proceeding 2018 grain production, Austrian winter pea was added to the LNT management system. It was apparent that cowpea biomass would not provide adequate ground cover for weed suppression from observations made during initiation 2016 through grain planting in 2017. Winter pea was added to LNT in an attempt to provide some level of weed suppression for this management system.

Similar to cowpea in 2017, winter cover crop dry matter yield did not differ among grain crop rotations or management practices ($p>0.05$). Winter cover crop biomass yield ranged from 2,389 kg ha^{-1} to 2,914 kg ha^{-1}. Corresponding levels of N return in winter cover crop biomass ranged from 59.7 to 71.4 kg N ha^{-1} across grain crop rotations. Winter pea DM yield under LNT was 2491 kg ha^{-1} and cereal legume mix under DCNT and DCCT averaged 2,750.5 kg ha^{-1} (Table 12). However, no difference in DM yield was found comparing management practices or grain crop rotations ($p>0.05$). Similar to dry matter yield, grain crop rotations or management practices did not affect N returned by winter cover crop biomass.

Table 12. Nutrient concentration and dry matter in kg ha^{-1} from cowpea biomass and cereal grain/Austrian pea cover crops preceding planting of grain crops in 2018. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till, DM = Biomass Dry Matter, N = Total Nitrogen in dry matter (kg N ha$^{-1)}$. Grain crop in bold is the crop planted in the current year. Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

	Summer Cover		**Winter Cover**	
	DM	**N**	**DM**	**N**
	-----------------------------kg ha^{-1}-----------------------------			
Crop Rotation				
Soy - ***Corn***	1,728	34.5	2,389	59.7
Corn - ***Sorghum***	1,975	39.7	2,689	66.1
Sorghum - ***Soybean***	1,638	32.4	2,914	71.4
Management				
CP	-	-	-	-
LNT	1,836	33.3	2,491	74.5
DCNT	1,760	33.9	2,734	62.6
DCCT	1,746	35.3	2,767	60.1
P>F				
Crop	0.051	0.078	0.214	0.220
MNG	0.804	0.575	0.262	0.073
Crop x MNG	0.457	0.422	0.618	0.908

Studies from the southeastern parts of the US have shown that hairy vetch can supply N amounts of approximately 90 to 100 kg N ha^{-1} fertilizer. Adequate N fixation by legume cover crops could offset supplemental nitrogen required by grain crops (Hargrove, 1986). Rye is also widely adapted and utilized as a cover crop in temperate regions (Dabney, et al., 2001).

Winter peas are usually grown as a winter annual and grown over a wide range of climates, soil types, and fertility levels. They are somewhat drought tolerant and grow well in temperate regions receiving moderate rainfall. If used for something other than a cover crop it provides a source of protein for both humans and livestock nutrition (Berg and Lynd, 1985).

Total Nitrogen Inputs

Litter or compost was applied proceeding planting of corn and grain sorghum each year. In 2017, the broiler litter was applied at 1,936 kg ha^{-1} (Table 5). Litter application provided 65.7% of the total nitrogen supplied to grain crops in 2017. N supplied by broiler litter was 48.8 kg N ha^{-1}, near the target rate of 50 kg N ha^{-1}. During 2018, turkey compost was applied at 4,694 kg ha^{-1} and supplied 52.1 kg N ha^{-1} for corn and sorghum production.

Total N input for 2017 is currently incomplete for the winter cover additions due to inconsistent data. However, with the manure inputs and the summer cover inputs into the system a mean of 74.0 kg N ha^{-1} is supplied in the management practices that implemented a summer cover crop (Table 13). The current practice with only the manure input totaled 48.8 kg N ha^{-1}.

Total N inputs were calculated for each crop and associated management practices independently in 2018. Total inputs include cover crop N, litter or compost and additional nutrient inputs (Table 14, 15, and 16). When statistics were run on total N inputs there were differences in corn and sorghum versus soybean, but those can be attributed to the lack of additional N inputs the other crops received. LNT provided 184.7 kg N ha^{-1}, compared to DCNT supplying 169.3 kg N ha^{-1}, DCCT supplying 168.3 kg N ha^{-1}, and CP supplying 72.8 kg N ha^{-1} for all crops ($p<0.0001$). The difference was largely due to the higher N input by winter cover crop legume (Austrian pea) alone rather than fallow or legume-cereal mixtures. Compost, fish emulsion and Chilean nitrate applications were made uniformly across all management practices. Therefore, cover crop N inputs contributed to variation in total N inputs. Total N input for corn ranged from 83.2 kg ha^{-1} to 194.1 kg ha^{-1}. Total N input for sorghum ranged from 83.2 kg ha^{-1}to 195.4 kg ha^{-1}. Variation of N input for soybean was observed although not as critical for grain production for legume grain crops.

Table 13. Nitrogen additions to system in kg N ha^{-1} from cover crops and manure/compost applications of grain crops in 2017. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till. Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

	2017 Total N Input			
	Summer Cover	**Winter Cover**	**Manure/ Compost**	**Total**
Management	-----------------------------kg N ha^{-1}-----------------------------			
CP	-	-	48.8	48.8 b
LNT	25.6	-	48.8	74.4 a
DCNT	24.8	-	48.8	73.6 a
DCCT	25.2	-	48.8	74.0 a
P>F				0.014

Table 14. Nitrogen additions to system in kg ha^{-1} from cover crops, fish emulsion, Chilean nitrate, and manure/compost applications of grain crops in 2018. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till. Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

2018 Corn						
	Summer Cover	**Winter Cover**	**Fish Emulsion**	**Chilean Nitrate**	**Manure/ Compost**	**Total**
Management	------------------------------kg N ha^{-1}------------------------------					
CP	-	-	3.2	28.0	52.1	83.2 b
LNT	40.8	70.0	3.2	28.0	52.1	194.1 a
DCNT	32.8	56.1	3.2	28.0	52.1	172.1 a
DCCT	29.7	53.0	3.2	28.0	52.1	165.9 a
P>F						0.001

Table 15. Nitrogen additions to system in kg ha^{-1} from cover crops, fish emulsion, Chilean nitrate, and manure/compost applications of grain crops in 2018. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till. Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

2018 Sorghum						
	Summer Cover	**Winter Cover**	**Fish Emulsion**	**Chilean Nitrate**	**Manure/ Compost**	**Total**
Management	------------------------------kg N ha^{-1}------------------------------					
CP	-	-	3.2	28.0	52.1	83.2 b
LNT	38.6	73.7	3.2	28.0	52.1	195.4 a
DCNT	38.5	66.7	3.2	28.0	52.1	188.4 a
DCCT	42.1	57.8	3.2	28.0	52.1	183.2 a
P>F						<0.001

Table 16. Nitrogen additions to system in kg ha^{-1} from cover crops, fish emulsion, Chilean nitrate, and manure/compost applications of grain crops in 2018. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till. Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

2018 Soybean						
	Summer Cover	**Winter Cover**	**Fish Emulsion**	**Chilean Nitrate**	**Manure/ Compost**	**Total**
Management	------------------------------kg N ha^{-1}------------------------------					
CP	-	-	-	-	52.1	52.1 b
LNT	32.6	79.8	-	-	52.1	164.4 a
DCNT	30.6	64.8	-	-	52.1	147.5 a
DCCT	34.1	69.6	-	-	52.1	155.7 a
P>F						<0.001

Grain Crop Production

Variation in grain crop establishment was assessed by measuring plant populations several weeks after planting each year (Table 17). During 2017, corn was planted at 75,600 and the seeding rate was increased to 79,040 seeds ha^{-1} in 2018. Mean plant population for corn after emergence was 53,079 plants ha^{-1} in 2017 and 47,152 plants ha^{-1} in 2018. Management practices did not affect plant population in corn.

Soybeans were planted at 308,750 seeds ha^{-1} in 2017 and 345,800 seeds ha^{-1} in 2018. Mean plant population for soybean after emergence was 170,942 plants ha^{-1} in 2018 and 175,376 for 2017 plants ha^{-1}. Similar to corn, management practices did not impact soybean plant population in either year. Sorghum was planted at 172,900 seeds ha^{-1} in 2017 and 197,600 seeds ha^{-1} in 2018. Mean sorghum plant population after emergence was 87,688 plants ha^{-1} in 2017 and 81,065 plants ha^{-1} in 2018 and did not differ among management practices.

Table 17. Plant populations for corn, sorghum, and soybean for grain crop years 2017 and 2018.

	CORN		SORGHUM		SOYBEAN	
YEAR	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
CP	53,079	60,000	101,855	120,305	191,516	158,734
LNT	45,906	38,275	73,881	53,201	177,887	163,944
DCNT	52,362	45,773	94,682	62,867	168,563	173,391
DCCT	60,969	44,560	80,336	87,890	163,542	187,702
MEAN	53,079	47,151	87,688	81,065	175,376	170,942
P>F	0.316	0.256	0.766	0.124	0.603	0.827

There were no differences in stand percentage in 2017 among crops or management practices. (p>0.05). Corn had the greatest stand at 68.2% and sorghum had the lowest at 41.03% in 2018 (Table 18). Corn stands in 2018 were 18.8% higher than soybean and 27.2% greater than sorghum (p=0.001). In addition to crop type, management practices played a vital role in plant stand success. Current practice had the greatest stand at 65.5% in 2018, a 28% stand increase over no-till practices (p=0.003). DCCT plant stand did not differ from CP in 2018.

Table 18. Percent stand for corn, sorghum, and soybean and by management practice for GC years 2017 and 2018. Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

	2017	**2018**
	----------------------% Stand--------------------	
Crop		
Corn	61.4	68.2 a
Sorghum	50.7	41.0 c
Soybean	56.8	49.4 b
Management		
CP	60.8	65.5 a
LNT	51.2	43.2 c
DCNT	56.6	49.4 bc
DCCT	56.7	54.4 ab
P>F		
Crop	0.246	0.001
MNG	0.446	0.003
Crop x MNG	0.620	0.066

Growth and Development

Leaf area was measured in and leaf area index (LAI) calculated for grain crops to compare crop growth and development under contrasting management systems. Management systems did not affect ($p>0.05$) LAI of any grain crop in 2017. Mean leaf area index at maturity was 0.97 in corn, 0.96 in sorghum and 0.19 in soybean (Table 19). LAI was much lower than reported for grain crops. This suggests that growing condition were not optimum for crop growth. Competition from weeds, including unsuccessfully terminated cover crops, likely reduced crop growth.

Table 19. Grain crop dry matter (kg ha^{-1}) and LAI for corn by treatment for 2017. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till.

	2017					
	Corn		**Sorghum**		**Soybean**	
	DM	**LAI**	**DM**	**LAI**	**DM**	**LAI**
	kg ha^{-1}		**kg ha^{-1}**		**kg ha^{-1}**	
CP	8,552	1.15	5,765	1.13	918	0.28
LNT	3,854	0.63	3,492	0.82	609	0.14
DCNT	8,236	1.04	5,143	1.07	607	0.14
DCCT	8,940	1.10	3,481	0.84	717	0.21
Mean	7,396	0.97	4,470	0.96	713	0.19
P>F	0.601	0.706	0.752	0.867	0.353	0.408

Table 20. Grain Crop dry matter (kg ha^{-1}) and LAI for corn by treatment for 2018. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till. Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

	2018					
	Corn		**Sorghum**		**Soybean**	
	DM	**LAI**	**DM**	**LAI**	**DM**	**LAI**
	kg ha^{-1}		**kg ha^{-1}**		**kg ha^{-1}**	
CP	2,526 a	1.14 a	5,967	3.20	739	0.46
LNT	577 b	0.18 b	2,947	0.90	419	0.22
DCNT	624 b	0.36	3,376	0.78	471	0.27
DCCT	1,106 b	0.53 b	6,102	1.90	1,123	0.44
Mean	1,208	0.63	4,598	1.70	688	0.35
P>F	0.023	0.021	0.443	0.110	0.261	0.160

In 2018, management systems affected dry matter and LAI for corn (Table 20). Variation in sorghum and soybean dry matter and LAI was not affected by management systems in 2018 (Table 20). Corn under current management practices had a 128% greater DM over DCCT, 304% greater DM compared to DCNT, and 337% greater DM compared to LNT ($p=0.023$). LAI showed a similar trend with 115% greater LAI increase over alternative management practices ($p=0.021$). Reduced plant growth for practices that included cover crops and no-till management practices compared to current practices indicates that cover crops may have competed with grain crops for resources. Moreover, weed populations were not effectively controlled by cover crops, exacerbating impacts on grain crop development.

Grain Yield

Grain yields were measured for each crop to compare management practices. Mean grain yield for corn was 1,417 kg ha^{-1} in 2017 (Table 21) with no difference observed between management practices ($p=0.357$). In 2018, mean corn yield was 160 kg ha^{-1}. There were no differences between management practices ($p=0.08$). Despite no significant differences in corn grain yield for 2018, current management practices produced the only harvestable grain with 641 kg ha^{-1}. Corn yield in 2018 was reduced by >88% from corn yield in 2017. Corn followed soybean in rotation and poor performance of soybean in 2017 may have contributed to higher weed pressure and lower corn yields in 2018.

For sorghum in 2017, mean grain yield was 641 kg ha^{-1} (Figure 21) with no differences between management practices (p=0.892). In 2018, sorghum grain yield improved significantly. In fact, sorghum was the only grain crop to produce harvestable grain for all management practices (Figure 21). The current practice improved yields by >5.7 fold compared to other management practices. Management under CP resulted in a grain yield of 2,931 kg ha^{-1} compared to LNT with 163 kg ha^{-1}, DCNT with 244 kg ha^{-1}, and DCCT at 438 kg ha^{-1}.

Soybeans performed poorly in every year of the study compared to other grain crops. Soybeans produced no harvestable grain in either year; harvestable grain was determined by whether or not it could be efficiently machine harvested. Low biomass production was due to an excessive weed population. Competition from weeds and cover crops that failed to terminate by roller crimping resulted in poor growth every year of the study.

Table 21. Grain yield by crop, management practice, and by year for 2017 and 2018. CP = current practice, LNT = legume no-till DCNT =double cover no-till, DCCT = double cover conventional till. Values followed by the same letter within columns are not significantly different using L.S.D ($p < 0.05$).

	Corn		**Sorghum**		**Soybean**	
	2017	2018	2017	2018	2017	2018
	------------------------------kg grain ha^{-1}------------------------------					
CP	2,060	641	550	2,931 a	0.0	0.0
LNT	94	0.0	599	163 b	0.0	0.0
DCNT	1,532	0.0	514	244 b	0.0	0.0
DCCT	1,983	0.0	901	438 b	0.0	0.0
Mean	1,417	160	641	944	NA	NA
P>F	0.357	0.080	0.892	0.027	NA	NA

Conclusions

Despite reported benefits of reduced tillage systems, conventional tillage generally performed better for grain production under a transitioning organic system. Plant stands, plant dry matter and LAI was significantly reduced for grain crops (corn, soybean and sorghum) under no-till management compared to conventional tillage. Reduction in grain crop performance was mostly due to competition from undesired cover crops or weeds. As a result, yield was reduced for grain crops under no-till management. Despite negative impacts of cover crops under no-till, cover crops did improve N cycling within organic systems. However, cover crop evaluation is needed to identify suitable cover crop species for the region. For intense crop rotations, timing of planting and termination will be critical for successful production of grain crops.

CHAPTER III

SUMMARY AND CONCLUSIONS

With the increasing demand for organic food products, demand for organic grain to feed organic livestock will continue to rise. Development of sustainable organic grain systems will be required to meet future organic food and feed demands. A two-year study was initiated in Burleson County Texas during 2016 to evaluate management practices for transitioning to production of organic grain. This study is the first study in Texas evaluated practices for organic production of corn, sorghum and soybean. Results revealed positive and negative impacts of cover crops and conservation tillage for organic grain systems in Texas. Results of the current study will provide a framework for future organic grain research in Texas and lead toward development of sustainable organic cropping systems in Texas.

From initiation of study in 2016, soil fertility conditions improved through the first two years of transition to organic production. Nitrate (NO_3-N) levels increased 11.9-fold from 2016 to 2017 and an additional 16.6-fold from 2017 to 2018. Increasing soil N concentration within the system was attributed to contributions from summer and winter cover crops. Despite increases in soil N, legume or legume-cereal cover crops did not return enough N for adequate grain crop production, requiring supplemental application of manure and alternative N sources. Cropping systems designed for continued use of manure, concentration of P in soil should be monitored to prevent accumulation of P. From 2016 to 2018, concentration of extractable P and K decreased by 26% and 24%

respectively. While progress toward optimum grain production is slower, the current approach for manure management appears to be sustainable.

Cover crop productivity is a critical component of organic cropping systems. Moreover, adequate productivity of legume cover crops is essential for grain cropping systems with high N requirements. Biomass production of summer cover and winter cover crops was initially low but did improve over time. For summer cover crops (cowpea), a 139% increase in biomass and a 36% increase in N return by residues was observed from 2017 to 2018. Winter cover crop biomass increased 2.6 fold for the same period and N returned by residues averaged 65.7 kg N ha^{-1}. Previous reports indicated that 72 to 100 kg N ha^{-1} can be returned to soil by legume residue N (Decker, et al., 1994, Hargrove, 1986). Combining cover crop, manure and other N sources, mean N input was 148.8 kg N ha^{-1} in the second year of transition to organic grain production. This was 104% greater than N inputs under current producer management practices. Total N inputs in year two for systems including cover crops were considered for grain crop production and should lead to acceptable yield given there are no additional yield limiting factors.

One potential yield limiting factor is plant stands. Plant populations for 2017 and 2018 were well below target plant populations, with stands from 52.8 to 56.3% over the two-year study. In addition, insect feeding (seed maggots and wireworms) on corn seed required replanting in 2018. Moreover, reduced tillage systems resulted in lower plant stands compared to conventional tillage systems. Stand failure and poor stands are a concern for organic systems where pests are managed primarily through cultural practices. Poor stands and required replants reduces seed efficiency, increases production cost and should be considered when evaluating economics of organic grain production (Benson, 1990).

Poor plant stands and inadequate levels of weed suppression by cover crops resulted in poor crop growth and development. Leaf area index as a measure of crop growth indicated poor productivity for corn, soybean and sorghum. During the first year, mean LAI was less than 1.0 across all crops and management practices. While corn and soybean growth continued to produce low levels of biomass and leaf area in the second year, sorghum did show some improvement over the first year. Mean LAI was 1.7 in 2018, which was expected to result in better grain yields. LAI of 3.0 is considered the minimum for adequate grain crop production (Hosseini, et al., 2015). The lack of vegetative growth overall was expected to produce low grain yields.

Grain yields were considered low for all crops and production systems in the current study. Over the two-year transition period, mean corn yields ranged from 640 to 1,417 kg grain ha$^{-1.}$ Corn yields did not differ among management practices during the first year. During the second year, cover crops and reduced tillage practices reduced corn yields. Similarly, management practices did not affect grain yields during the first year of sorghum production with mean grain yield of 640 kg ha^{-1}. Yet, reduced tillage and cover crops reduced sorghum yields 2,493 to 2,767 kg ha^{-1} during year two compared to current producer practices. Poor plant stands and weed pressure were major contributors to poor yields in both years, which could be alleviated to some degree by conventional tillage. Soybean yield was poor in both years of organic transition. In fact, no harvestable grain was produced in either year. Soybeans were unable to compete with early season weed pressure under any management system. Future research should evaluate narrow row spacing and planting rates for soybean to identify more competitive and productive practices.

In conclusion, cover crops included in organic systems can supplement tradition organic nutrient sources and increase N supply to grain crops. Utilizing summer and winter covers crops can potentially increase N supply, yet may result in logistical issues surrounding timely planting and termination. While conservation tillage has merits, conventional tillage practices may be required during organic transition periods to improve plant stands and reduce weed pressure. Despite struggles with crop establishment and productivity during transition to organic management, small improvements in productivity were observed in the second year. Improved pest management strategies, strategic tillage practices, and refined cover crop management is expected to lead toward more successful transition periods for organic grain production.

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