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By Dulani Woods

Entitled Organic and Conventional Agriculture: A Comparison of Conventional, Manure, and Legume Systems on Soil Carbon, Soil Nitrogen, Yield, and Economic Returns from a Long Term System in the Mid-Atlantic

For the degree of Master of Science

Is approved by the final examining committee:

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ORGANIC AND CONVENTIONAL AGRICULTURE: A COMPARISON OF CONVENTIONAL, MANURE, AND LEGUME SYSTEMS ON SOIL CARBON, SOIL NITROGEN, YIELD, AND ECONOMIC RETURNS FROM A LONG TERM SYSTEM IN THE MID-ATLANTIC

A Thesis

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of

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by

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For those nearest and dearest to me: Wendy and Alma. Your support, encouragement, and understanding leading up to this point have been the most precious thing in the world to me.

ამერიას და საქართველოს გაუმარჯოს!

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ABSTRACT

Woods, Dulani. M.S., Purdue University, August 2009. Organic and Conventional Agriculture: A Comparison of Conventional, Manure, and Legume Systems on Soil Carbon, Soil Nitrogen, Yield, and Economic Returns from a Long Term System in the Mid-Atlantic. Major Professors: Corinne Alexander and Gerald Shively

This thesis explores the effects and interactions of three systems of agricultural production: 1) conventional grain, 2) organic grain where fertility is supported by manure from dairy cows, and 3) organic grain where fertility is supported by leguminous crops. The data set included 28 years of comparative farming observations from the Rodale Institute’s Farming Systems Trial. Ordinary least squares (OLS) regressions were used to examine the effects of the cropping system on soil nitrogen and soil organic carbon. OLS regressions were used to examine the impact of the cropping systems on corn yield in conjunction with soil nitrogen and soil organic carbon. The manure and legume cropping systems were found to sequester more carbon than a conventional system.

Overall, corn yields in the manure and legume systems were found to be 92.7% and 91.0% of the conventional system respectively. Following a 5 year transition period, manure and legume system yields were 95.9% 93.8% of conventional yields respectively. Corn yield was also analyzed in conjunction with plant genetics, weed pressure, and weather using a model where the weather variables were constructed based on the corn plant's phenological stages of development. Conditional on these variables, the manure and legume systems were found to have 11.4% and 33.0% higher yields respectively, than the conventional system.

Three years of cost and revenue data were used to estimate the level of organic premium needed for the organic and conventional systems to have economically equivalent returns. A 47.4% and 44.0% price premium was needed for the manure and legume systems respectively to maintain economic equivalence with the conventional system. Significant differences between the cropping systems were detected with respect to soil fertility, productivity and economic profitability.

CHAPTER 1 – INTRODUCTION

Organic and sustainable agriculture is an important and growing segment of global agriculture (Walz, 2004; Escobar and Hue, 2007). In one sense, sustainable agriculture was the original form of agriculture (Pimentel et al., 2005b). In highly industrialized societies, it has been largely replaced by what is now called conventional agriculture, or agriculture that is dependent on off farm inputs for its productivity. Proponents of conventional agriculture point to higher yields and greater overall productivity as evidence of its superiority (Lotter, 2003; Power, 1999). Proponents of organic agriculture point to unaccounted for health and environmental externalities as disadvantages of conventional agriculture (Lotter, 2003; Power, 1999). Lotter believes that by investing more in research and development on organic methods, higher productivity can be attained while avoiding many of the negative externalities associated with conventional methods (2003).

Using data from the Rodale Institute's Farming Systems Trial® (FST), this thesis seeks to explain yield differences between conventional and organic systems. This thesis measures the minimum organic price premium that would be needed for the organic systems to be as profitable as the conventional systems. Finally, this study examines some of the other differences observed between conventional and organic systems in the FST including indicators of soil fertility and potential for carbon sequestration.

The Rodale Institute is a non-profit organization that is dedicated to investing in research and development of organic agriculture. Rodale has the United States' longest running side-by-side comparison of conventional and organic farming methods (Hepperly, 2003). This comparison began in 1981 and is called the Farming Systems Trial®. Prior to 2003, it achieved statistically equivalent yields for corn and soybeans in its conventional and organic systems (Hepperly, 2003). However, even with equivalent yields, the FST's organic systems produce fewer high value cash crops (corn and soybeans) per acre because they are rotating cash crops with other crops to maintain soil fertility. As such, organic farms typically have a lower output of high value cash crops or lower per acre yields, on average, than conventional farms (Lotter, 2003). To compensate organic farmers with an equivalent or higher level of economic returns for their time, labor, and resources, consumers typically pay a higher price, or premium, for organic foods (Oberholtzer et al., 2005; Power, 2007).

Because there is considerable interest from consumers in purchasing organic products, producers are interested in meeting this demand, but need more information to be able to make better decisions about what to produce (Walz, 2004; Cavigelli eg al. 2008). To help provide such information, this thesis compared fertility, productivity, and profitability differentials for one conventional and two organic cropping systems. In addition, due to concerns about greenhouse gas emissions on the environment, there is considerable interest in evaluating different methods to sequester carbon dioxide in the soil (Drinkwater et al., 1998; Escobar et al., 2002; Flessa et al., 2002; Mäder et al., 2002; Reganold et al., 2003; Lal, 2004; L-Baeckström et al., 2006; Quincke et al., 2007; Cavigelli et al., 2008; Stalenga et al., 2008). In response, this thesis also compared the carbon sequestration potential of two organic cropping systems to a conventional cropping system.

Objectives

This study uses the Farming Systems Trial data set obtained from the Rodale Institute for the period of 1981-2008 to answer the following questions:

1. Are differences in soil fertility and carbon sequestration observed between systems, and can these differences be attributed to different cropping systems?
2. Are there differences in corn yields between systems and can these be attributed to soil fertility and the cropping system?
3. What price premium, if any, would be required to make the organic systems as profitable as the conventional system?

Organization

The remainder of this thesis is organized into the following chapters: Chapter 2 presents a review of academic literature on soil fertility, carbon sequestration, yields and profitability for organic and conventional agriculture. Chapter 3 presents the data and methodology. Chapter 4 presents the results, and Chapter 5 presents discussion and conclusions.

CHAPTER 2 – LITERATURE REVIEW

A large body of research focuses on sustainable, alternative, and organic agriculture. Topics range from yields, net returns, and organic premiums to soil fertility (Hanson et al., 1990; Reganold et al., 1993; Hanson et al., 1997; Pimentel et al., 2000b; Pimentel et al., 2005a). Several previous studies have been published using data from the Rodale Institute's Farming Systems Trial to compare organic and conventional agricultural systems (Hanson et al., 1990; Hanson et al, 1997; Drinkwater et al., 1998; Pimentel et al., 2000b; Kramer et al., 2002; Pimentel et al., 2005a). This study repeats much of what was done in previous research and examines all available data through 2008.

A limited number of studies have measured the impact of organic farming methods on overall CO_2 emissions (Shepherd et al., 2003). These studies examine emissions directly related to crop and livestock production as well as emissions related to off farm inputs. Studies that examine sustainable agricultural systems' potential to sequester carbon include Drinkwater et al. (1998), Escobar and Hue (2007), Flessa et al. (2002), Mäder et al. (2002), Reganold et al. (2003), Lal (2004), and Stalenga and Kawalec (2008).

Comparison of Organic and Conventional Treatments on Soil Carbon and Nitrogen

Soil fertility, a part of which is based on soil organic carbon and nitrogen cycles, is complex and dynamic. There is a large body of research into soil fertility in organic and conventional systems. A study by Stalenga et.al (2008) used data from a 12-year period and found that organic farming systems increased soil organic carbon while conventional and integrated systems depleted soil organic carbon. Mäder (2002) found that increased diversity of soil microbes in organic systems break down organic matter more completely and result in higher soil organic carbon levels. Drinkwater et al. (1998) and Cavigelli et al. (2008) found that manure and legume organic systems have a significant positive impact on soil organic matter and soil organic carbon levels. Escobar and Hue (2007) found the same and concluded that soil nitrogen levels will necessarily increase as soil organic matter increases. Kramer et al. (2002) found no difference in the short term (single season) nitrogen uptake between the crops in conventional and organic cropping systems, but their analysis did not examine the impact of organic systems on soil nitrogen.

Drinkwater et al. (1998) compared the nitrogen leachate in Rodale Institute’s organic legume systems conventional and organic systems and found it to be 50% greater in conventional systems. This presents one explanation for the long term observed increases in soil nitrogen in organic systems. However, Pimentel et al. (2005b) did not find the same difference in the Rodale Institute’s conventional and organic legume systems and concluded that part of the reason for the excess nitrogen was that the legume cover crop was supplying double the amount of nitrogen needed to supply the following corn crop. Thus there was a significant amount of nitrate in the soil that was subsequently leached.

Clark et al. (1999) found that, given time, organic methods can produce tomato yields that are equivalent to conventional yields. But, because the source of soil nitrogen is different in conventional and organic systems, an equivalent amount of soil nitrogen has the potential to be less available for crop growth in organic systems. As such, Clark et al. concluded that organic nitrogen inputs should be high enough to compensate for the lower availability. Unlike conventional systems however, excess nitrogen in organic systems is not likely to be leached into runoff. This is because organic systems often have higher levels of soil organic carbon which contributes to building soil organic matter. Over time, soil organic matter levels will stabilize so that higher nitrogen inputs would no longer be necessary in organic systems (Clark et al., 1999).

Comparative Yields, Profitability, and Premiums

In addition to examining the agronomic literature on cropping systems, it is also important to review the research on the economics of such systems. In an early simulation model, Doering (1977) found returns to management in a rotation of corn, wheat, soybeans, and alfalfa could be 30-60% higher than several other systems including a continuous corn and a conventional corn-soybean-wheat rotation.

Lotter (2003) found that organic cropping systems typically yield 10-15% less than conventional cropping systems, but from a profitability perspective, such yield reductions are usually offset by lower input costs and higher gross margins. However, historical deviations from this finding exist and underscore that outcomes strongly depend on regional factors, soil quality, and the management skill of the conventional and organic farmers that are being compared (Drinkwater et al., 1995; Liebhardt, 2001; Herencia et al., 2007). As such, the yield differences between conventional and organic crops may be changing with time (Liebhardt, 2001).

Hanson et al. (1997) reviewed economic returns using Rodale Institute FST Data from 1982-1995 for the conventional and legume organic rotations. They did this for three distinct periods: 1) 1982-1984, 2) 1986-1990, and 3) 1991-1995. Organic rotations for the three periods were: 1) Oats/Clover – Corn – Oats/Clover – Soybeans, 2) Oats/Clover – Corn – Barley/Soybeans – Wheat/Clover – Corn, 3) Wheat – Hairy Vetch/Corn – Rye/Soybeans. They dropped 1981 from their data set to avoid including start-up problems that occurred at the beginning of the FST. Using Rodale's experimental yield data, they set their analytic yields at 80% of the actual FST yields to reflect the difference between experimental conditions and field conditions. With machinery times on an hour per acre basis from Doane's Agricultural Report, they adjusted direct machinery time data upward by 20% to simulate additional indirect labor time associated with maintaining and operating farm equipment. It is not clear whether organic premiums were included in the analysis. Hanson et al. state that crop prices for their analysis were "an average of those prices received by farmers for the period 1982-1994." It was not explicitly stated elsewhere if the conventional crop prices were the same or different from the organic prices. A summary of economic returns is presented in table 1. Total costs exclude labor and land and as such, the returns are returns to land, labor and management. The table shows slightly higher returns for the conventional system in the startup period (1982-1984) and then slightly higher returns for the organic systems for the remaining periods.

Table 1: Conventional v. Organic Returns for Hanson et al. (1997)

	1982-1984		1986-1990		1991-1995	
	Organic	Conv.	Organic	Conv.	Organic	Conv.
Revenue	$163	$237	$208	$236	$216	$245
Costs	$83	$139	$100	$141	$103	$138
Returns to land, labor, and management	$80	$98	$108	$96	$113	$107

Delate et al. (2002) examine economic returns in a long term agricultural experiment with two organic rotations (Corn-Soybean-Oats/Alfalfa and Corn-Soybean-Oats/Alfalfa-Alfalfa and one conventional rotation (Corn-Soybean). Yields were actual experimental plot yields. Input costs (seed, fertilizer, and chemicals) were actual local supplier costs and machinery costs were Iowa State University annual estimates. Conventional revenues were calculated using local conventional elevator prices and government subsidies. Organic prices included organic premiums and were annual average prices paid by the local organic elevator and a "local source." Returns were calculated both with and without organic premiums. Table 2 is a summary of the economic returns for this study. The Organic 1 and Organic 2 rotations were corn-soybean-oats and corn-soybean-oats-alfalfa respectively. The conventional rotation was corn-soybean. The returns were returns to land, labor and management both with and without organic premiums. Delate et al. found higher returns to land, labor and management for the organic systems both with and without organic premiums.

Table 2: Conventional v. Organic Returns for Delate et al (2002)

	1999-2001		
	Organic 1	Organic 2	Conventional
Revenue	$416	$405	$236
Costs	$130	$115	$163
Returns with organic premiums	$286	$290	$73
Returns without organic premiums	$96	$114	$73

Pimentel et al. (2005a) examined Rodale FST data and found that:

> "Corn grain yields averaged 4222, 4743, and 5903 kg per ha for the organic animal, organic legume, and conventional systems, respectively, with the yields for the conventional system being significantly higher than for the two organic systems. After this transition period, corn grain yields were similar for all systems: 6431, 6368, and 6553 kg per ha for the organic animal, organic legume, and conventional systems, respectively (Pimentel et al. 2005b). Overall, soybean yields from 1981 through 2001 were 2461, 2235, and 2546 kg per ha for the organic animal, organic legume, and conventional systems, respectively (Pimentel et al. 2005b)."

Pimentel et al. (2005a) also reviewed Rodale Institute FST net returns from 1991-2001 and concluded that an organic price premium of 2.3% was needed to produce returns equivalent to conventional returns.

Several other studies examine carbon sequestration in organic and conventional systems. Lal (2004) found that there is considerable untapped potential to sequester carbon in soil by modifying current cropping systems. Lal estimates that worldwide soils are only sequestering between 50% and 66% of their potential capacity. Some of the practices that Lal estimates would help agricultural soils both sequester carbon and improve fertility are practices that are often implemented in organic farming systems such as the use of cover crops, application of manures, and growing a diversity of crops.

Using Rodale Institute FST Data, Drinkwater et al. (1998) and Hepperly et al. (2007) found significant increases in retained soil organic carbon in the manure and legume systems for the periods 1981 to 1995 and 1981 to 2002 respectively. Flessa et al. (2002) compared total greenhouse gas (GHG) emissions (CO_2, CH_4, and N_2O) from conventional and organic farming systems in Germany. Both farm types maintained crops and cattle. Flessa et al. considered inputs such as fertilizer and fossil fuels and measured outputs such as animal waste and soil emissions. Flessa et al. found that on a per acre basis, the organic system farm had lower greenhouse gas emissions, but after yield differences were considered, emissions per kg of yield were not significantly different.

In analyzing data from a 21-year comparison of organic and conventional cropping systems in Central Europe, Mäder et al. (2002), found that the higher level of microbial activity in organic soils contributed to increased decomposition of plant material and larger microbial biomass (and thus higher soil organic carbon levels). Mäder et al. did not examine the impact of inputs or emissions on the overall carbon or GHG emissions balance. Reganold et al. (2003) examined a variety of organic and conventional farm types in New Zealand over a 4-year period. For the mixed farm type (livestock and row crops), they found higher soil organic carbon levels and lower economic returns for the organic farms.

Stalenga and Kawalec (2008) examined N_2O and CO_2 balances using a 12 year comparative experiment in Poland. In addition, they compared 20 organic farms to nearby conventional farms in Poland over a 2-year period and examined CH_4, N_2O emissions as well as CO_2 sequestration in soil organic matter. They found that the organic systems had significantly lower emissions on a per acre basis for both the experimental and real-world systems. They attributed this to the emissions differences in portion of fodder crops grown in organic systems (40% versus 7.6%). Also, they did consider the contributions of synthetic fertilizer inputs but didn't consider differences in equipment-related emissions between systems.

In this review of the literature one finds that organic yields and net returns can be competitive with conventional yields depending on soil quality, farmer skill, environmental, and market conditions. There has historically been a yield gap where organic systems lagged conventional systems. However, neither the yield nor revenue gaps appear to be immutable characteristics of organic systems relative to conventional systems. Further, there was evidence that this gap has been shrinking over time. Many of the differences between the two systems are dependent on soil fertility and soil fertility is extremely complex and difficult to evaluate. Overall fertility for a given season is impacted by the interaction of soil chemistry, soil biology, and climate not only during, but before and after the growing season. Finally, organic farming methods have demonstrated the potential to sequester carbon, but it is unclear what the steady state levels are and what the environmental impact is on a per acre or per kilogram of yield basis. Only a few studies have attempted to compare the observed differences in carbon sequestration and greenhouse gas emissions with the carbon generated by conventional inputs (fertilizer, pesticides) and the increased use of farm machinery in the organic systems (Flessa et al., 2002; Hepperly et al.; 2007; Stalenga and Kawalec, 2008).

CHAPTER 3 – DATA AND METHODS

The primary source of data for this research is the Rodale Institute's Farming Systems Trial® in Kutztown, Pennsylvania (Berks County). The location of the trial area is indicated in figure 1. This trial is an ongoing comparison of conventional and organic farming methods. The Farming Systems Trial (FST) consists of three systems: conventional, legume (organic), and manure (organic). I obtained the FST data for the period 1981-2008.

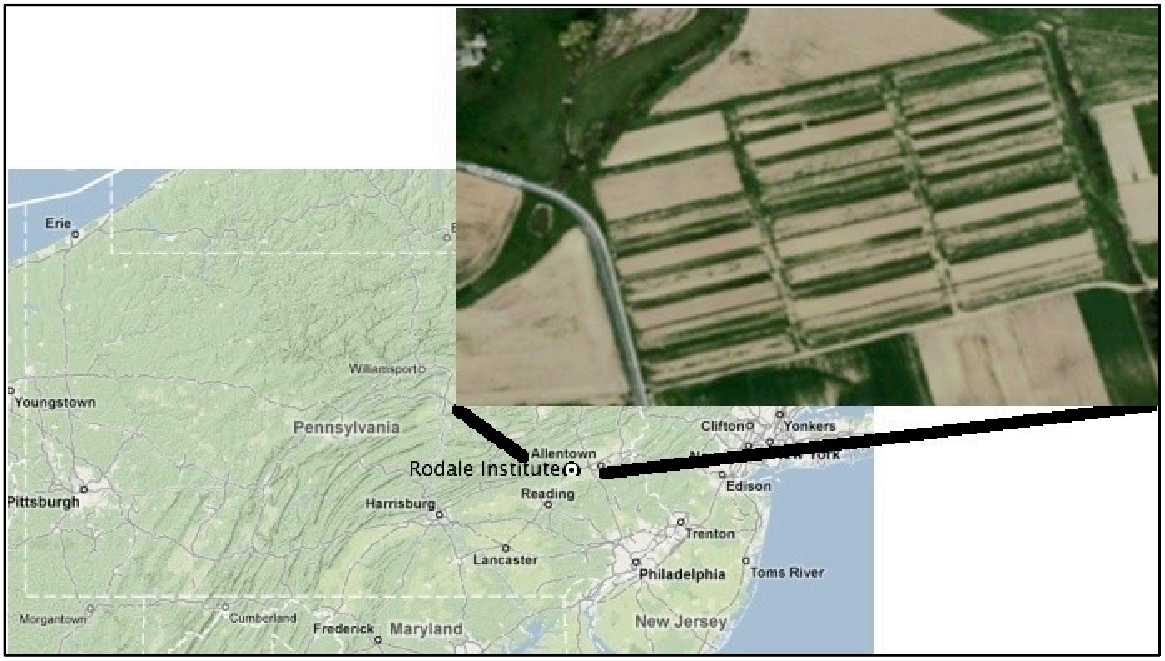

Figure 1: Geographic Location of Rodale Institute's FST

System Description

The Rodale Institute website describes the FST as the following:

> "The level field of mostly shale-y, somewhat compacted silt loam is broken into eight blocks, or replications, with each block containing three plots, 60 ft wide by 300 ft long[1], and each plot divided lengthwise into three subplots. Eight replications of each of the three cropping systems are randomized across the blocks; while the subplots allow each rotation to be started simultaneously at three points, so the effects of annual weather variations are distributed across different phases of the cropping cycle."

The data used for most of this analysis were collected at the subplot level. Figure 2 provides a graphical overview of the test area.

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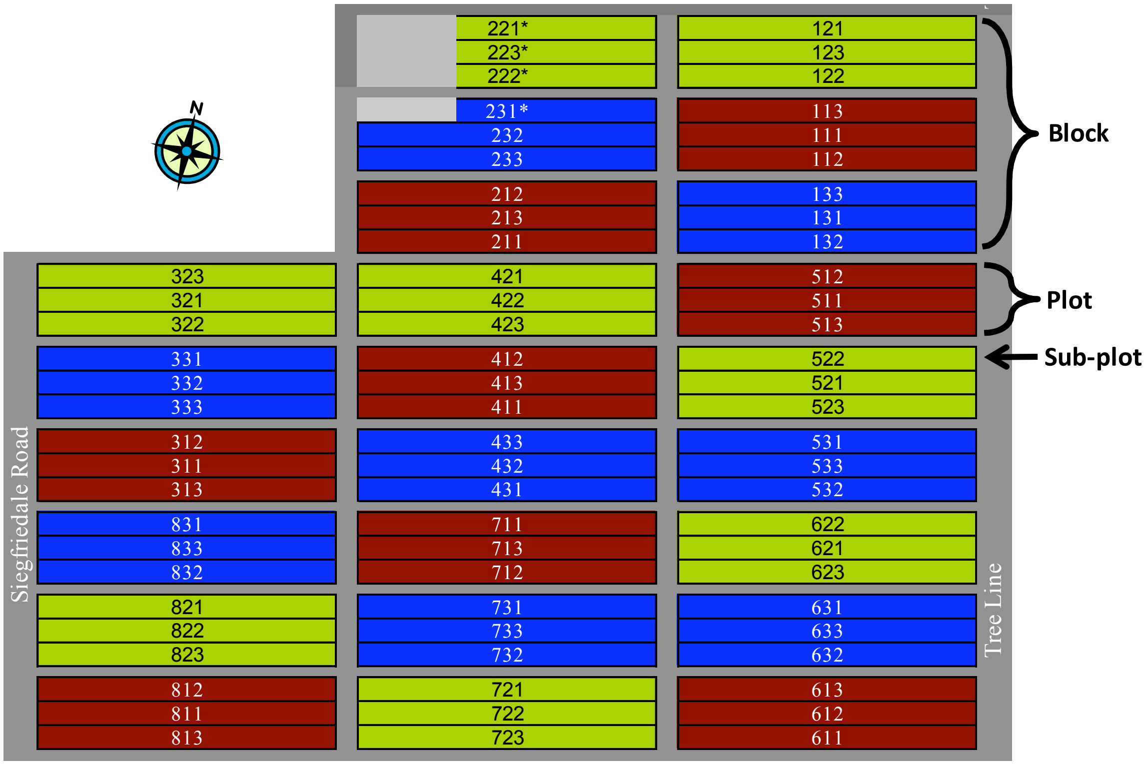
[1] Four of the 72 plots were subsequently shortened to 180 feet.

Rodale Institute Farming Systems Trial Field Layout



*Sub-plots 221, 223, 222, 231 were shortened to 180 feet

Figure 2: Farming Systems Trial Field Layout

During the period analyzed, 1981-2008, the conventional system consisted primarily of a 5-year rotation: corn-soybean-corn-corn-soybean. This rotation remained relatively consistent from 1981 to 2002. In 2003, the entire trial area was planted with oats to facilitate transitioning all three systems to a three-year rotation with corn, soybeans, and wheat being planted in each system each year. From 2004 to 2008, the conventional system was a three-year rotation: corn-soybean-wheat rotation with winter wheat following soybeans between the second and third year. The FST abandoned this matching 3-year rotation in 2008 and converted to a 2-year corn-soybean rotation for the tilled plots and a 3-year corn-soybean-wheat rotation for the no-till plots.

The manure organic system consisted mostly of a 5-year rotation for the cash crop: corn-soybean-silage corn-hay-hay, and an overlapping cover crop rotation: rye-rye-wheat-hay-hay. This remained relatively consistent until 2003 when the entire trial was planted with oats. From 2004-2007, the rotation was changed to corn-soybeans-wheat. In the fall of 2007 the manure system was converted to an 8-year rotation with crops that were typical of crop farms (cash crop grains, hay and corn silage).

The legume organic system consisted primarily of a 3-year rotation, corn-soybean-hay, from 1981-1991 when the rotation was changed to corn-soybean-wheat. This was maintained until 2008, interrupted only by the FST “reset” where oats were planted throughout in 2003 and on 2/3 of the plots in 2008. Throughout the period of analysis, the overlapping rotation consisted of hay, hairy vetch, or rye as a cover crop or barley as a relay crop. A relay crop is planted into an already growing crop. In this case, the barley was planted in early spring and the soybeans were planted in late spring in the same plot where the barley was already planted. Then, when the barley matured, it was harvested so as to leave the soybean plants alive and growing. When the soybeans matured, they were also harvested. Table 3, table 4, and table 5 report timelines of the manure, legume, and conventional system crop rotations.

Table 3: Timeline of Manure System Crop Rotations

System	Manure System		
Treatment	1	2	3
1981	Oats/ Hay	Short Corn	Short Corn/ Wheat
1982	Hay	Soybeans	Wheat/Hay
1983	Corn	Short Corn/ Wheat	Hay
1984	Soybeans	Wheat/ Hay	Corn
1985	Short Corn/ Wheat	Hay	Soybeans
1986	Wheat/Hay	Corn	Short Corn/ Wheat
1987	Hay	Soybeans	Wheat/Hay
1988	Corn	Short Corn/ Wheat	Hay
1989	Soybeans	Wheat/Hay	Corn
1990	Short Corn/ Wheat	Hay	Soybeans
1991	Wheat/ Hay	Corn	Short Corn/ Wheat
1992	Hay	Soybeans	Wheat/ Hay
1993	Corn	Short Corn/ Wheat	Hay
1994	Soybeans	Wheat/ Hay	Corn
1995	Short Corn/W*	Hay	Soybeans
1996	Oats/ Hay	Corn	Short Corn/ Wheat
1997	Hay	Soybeans	Wheat/Hay
1998	Corn	Short Corn/ Wheat	Hay
1999	Soybeans	Wheat/Hay	Corn
2000	Short Corn/ Wheat	Hay	Soybeans
2001	Wheat/Hay	Corn	Short Corn/ Wheat
2002	Hay	Soybeans	Wheat/Hay
2003	Oats	Oats/ Wheat	Oats
2004	Corn	Wheat/Hay	Soybeans/ Wheat
2005	Soybeans/ Wheat	Corn	Wheat/Hay
2006	Wheat/Hay	Soybeans/ Wheat	Corn
2007	Hay/ Corn	Wheat	Soybeans
2008	Oats	Corn	Oats/Hay

Table 4: Timeline of Legume System Crop Rotations

System	Legume System		
Treatment	1	2	3
1981	Oats/Hay	Soybeans	Corn
1982	Short Corn	Oats/Hay	Soybeans
1983	Oats/Hay	Short Corn/ Wheat	Oats/Hay
1984	Corn	Wheat	Short Corn
1985	Soybeans	Corn	Oats/Hay
1986	Oats/Hay	Relay Barley/ Soybeans/ Wheat	Short Corn/ Wheat
1987	Corn	Wheat/Hay	Wheat/ Soybeans/ Wheat
1988	Relay Barley/ Soybeans/ Wheat	Corn	Oats/Hay
1989	Wheat/Hay	Relay Barley/ Soybeans	Corn
1990	Corn	Spring Oats/Hay/ Wheat	Relay Barley/ Soybeans
1991	Soybeans/ Wheat	Wheat	Corn
1992	Wheat	Corn	Soybeans/ Wheat
1993	Corn	Soybeans/W	Wheat
1994	Soybeans/W	Wheat	Corn
1995	Wheat	Corn	Soybeans/ Wheat
1996	Corn	Soybeans/W	Oats
1997	Soybeans/ Wheat	Wheat	Corn
1998	Wheat	Corn	Soybeans/ Wheat
1999	Corn	Soybeans/ Wheat	Wheat
2000	Soybeans/ Wheat	Wheat	Corn
2001	Wheat	Corn	Soybeans/ Wheat
2002	Corn	Soybeans	Wheat
2003	Oats	Oats/ Wheat	Oats/Oats
2004	Soybeans/ Wheat	Wheat/Oats	Corn
2005	Wheat/Oats	Corn	Soybeans/ Wheat
2006	Corn	Soybeans/ Wheat	Wheat/Oats
2007	Soybeans	Wheat	Corn
2008	Oats	Corn	Oats

Table 5: Timeline of Conventional System Crop Rotations

System	Conventional System		
Treatment	1	2	3
1981	Corn	Soybeans	Corn
1982	Corn	Corn	Soybeans
1983	Soybeans	Corn	Corn
1984	Corn	Soybeans	Corn
1985	Soybeans	Corn	Soybeans
1986	Corn	Soybeans	Corn
1987	Corn	Corn	Soybeans
1988	Soybeans	Corn	Corn
1989	Corn	Soybeans	Corn
1990	Soybeans	Corn	Soybeans
1991	Corn	Soybeans	Corn
1992	Corn	Corn	Soybeans
1993	Soybeans	Corn	Corn
1994	Corn	Soybeans	Corn
1995	Soybeans	Corn	Soybeans
1996	Corn	Soybeans	Corn
1997	Corn	Corn	Soybeans
1998	Soybeans	Corn	Corn
1999	Corn	Soybeans	Soybeans
2000	Soybeans	Corn	Corn
2001	Corn	Soybeans	Corn
2002	Corn	Corn	Soybeans
2003	Oats/ Wheat	Oats	Oats
2004	Wheat	Soybeans/ Wheat	Corn
2005	Corn	Wheat	Soybeans/ Wheat
2006	Soybeans/ Wheat	Corn	Wheat
2007	Wheat	Soybeans	Corn
2008	Corn	Corn	Soybeans

Data Description

The data sets used for corn yield analyses include information on yield, crop variety, weed biomass, soil chemistry analyses, daily weather observations, and dates and quantities of inputs applied as well as the number of passes over each plot for planting, tillage, weed control, etc.

Constructed Variables

To conduct analyses on corn yield and soil organic carbon, several additional variables were constructed. Time variables included time and time squared as a proxy for technological improvement, if any (1981=1, 1982=2, etc.).

Doering (1977) identified the planting date as a critical factor affecting corn yields. Ramesh and Gopalaswamy (1991) point out that planting date can affect crop yields due to differences in solar radiation available at different times in a year. A planting-day-of-year variable (January 1 = 1, January 2 = 2, and December 31 = 365). I defined multiple sets of binary (0/1) indicator variables to represent the crop varietal, crop planted on the subplot in the prior year, cropping system (manure, legume, and conventional). An indicator for 1999 is included as that year was considered an anomalous growing season due to severe drought. These binary indicators are set to 1 if the condition holds and 0 otherwise. A complete set of descriptive statistics for these data are reported in table 10.

Weather Data

A range of weather data were used in the analysis. The weather data set contained daily temperature and precipitation observations. In some cases, weather data were missing due to equipment failure. Prior to 1985, a daily weather data set was not available for the FST. In two cases in which temperature data were missing, they were imputed based on the observed relationship between existing FST temperature data for National Weather Service (NWS) observation stations in Reading, PA (17.3 mi SW) and Allentown, PA (17.1 mi NE). Missing rainfall data were not imputed anywhere within the data set. To complete the daily temperature data set, 1,461 daily observations were imputed prior to January 1, 1985 when no weather data were available and 252 observations were imputed after January 1, 1985. I obtained the weather data for Reading and Allentown from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC). (NCDC is NOAA's data warehousing center for NWS data and for other NOAA agencies.) I estimated the statistical relationship of the daily maximum and minimum temperatures between Kutztown, Reading, and Allentown using the following two ordinary least squares models (Equations 1 and 2).

$$\begin{aligned} Kutztown\ High = {} & \beta_0 + \beta_1 j + \beta_2 j^2 + \beta_3 t + \beta_4 Reading\ H + \\ & \beta_5 Reading\ L + \beta_6 Allentown\ H + \\ & \beta_7 Allentown\ L + \epsilon \end{aligned} \qquad \text{Eq. 1}$$

$$\begin{aligned} Kutztown\ Low = {} & \beta_0 + \beta_1 j + \beta_2 j^2 + \beta_3 t + \beta_4 Reading\ H + \\ & \beta_5 Reading\ L + \beta_6 Allentown\ H + \\ & \beta_7 Allentown\ L + \epsilon \end{aligned} \qquad \text{Eq. 2}$$

Where:
j ≡ Day of year number where January 1 = 1, January 2 = 2, and December 31 = 365
j^2 ≡ Square of the day of year number
t ≡ Time variable where 1981 = 1, 1982=2, etc.
Reading H ≡ Daily High Temperature in Reading, PA
Reading L ≡ Daily Low Temperature in Reading, PA
Allentown H ≡ Daily High Temperature in Allentown, PA
Allentown L ≡ Daily Low Temperature in Allentown, PA

The regression results for these imputation equations are reported in table 6.

Table 6: Results for Imputing Temperature Observations

Coefficient Std. Error (p-value)	Kutztown High	Kutztown Low
Intercept	-0.04023	-0.40190
	0.243	0.253
	(0.869)	(0.113)
j	0.01398	-0.00117
	0.004	0.004
	(0.001)	(0.787)
j^2	-0.000045	0.00000826
	0.000011	0.000011
	(0.000)	(0.465)
t	0.22700	-0.44194
	0.038	0.040
	(0.000)	(0.000)
Reading H	0.06687	-0.12314
	0.014	0.015
	(0.000)	(0.000)
Reading L	-0.04864	0.22585
	0.017	0.018
	(0.004)	(0.000)
Allentown H	0.89097	0.16602
	0.015	0.016
	(0.000)	(0.000)
Allentown L	0.07437	0.71252
	0.017	0.018
	(0.000)	(0.000)
Adjusted r^2=	0.98	0.98
n=	1872	1871

Constructed Weather Variables

Based on a procedure similar to that used by Kaufmann and Snell (1997), I constructed 128 weather variables to assess the impact of temperature and water stress on crop growth potential. I used daily temperature data to calculate a measure of heat units called Growing Degree Days (GDD). The basic formula for GDD was Daily Average Temperature minus 50 degrees Fahrenheit. If the daily maximum was greater than 86 or the daily minimum less than 50, then prior to calculating GDD, then the maximum or minimum for that day was 86 or 50, respectively. Then, starting with the date the crop was planted, I used the GDDs to calculate the start dates for each development stage. Table 7 contains the GDD values used to predict crop development stages (Neild and Newman, 1990). For this analysis, the developmental stages were predicted based on a variety of corn bred to mature at 2,700 GDD.

Table 7: Developmental Stages for a 2,700 GDD Variety of Corn

Phase	Development Stage	Stage Number	GDD
Planted	Planted	0	0
	Two leaves fully emerged	0.5	200
Vegetative	Four eaves fully emerged	1	345
	Six leaves fully emerged (Growing point above soil)	1.5	475
	Eight leaves fully emerged (Tassel beginning to develop)	2	610
	Tenth leaves fully emerged	2.5	740
	Twelve Leaves Fully Emerged (Ear formation)	3	870
	Fourteen leaves fully emerged (Silks developing on ear)	3.5	1000
Reproductive	Sixteen leaves fully emerged (Tip of tassel emerging)	4	1135
	Silks emerging/pollen shedding (Plant at full height)	5	1400
	Kernels in blister stage	6	1660
	Kernels in dough stage	7	1925
	Kernels denting	8	2190
Maturation	Kernels dented	9	2450
	Physiological maturity	10	2700

After calculating the beginning and ending dates of the developmental stages, I calculated the following nine summary variables for each developmental stage: 1) total rain, 2) square of total rain, 3) maximum daily rain, 4) square of maximum daily rain, 5) maximum daily temperature, 6) square of maximum daily temperature, 7) average maximum temperature, 8) square of average maximum temperature, and 9) minimum daily temperature during the stage. In order to focus on the most relevant variables and minimize multi-collinearity, I checked all 128 variables for their correlation with corn yield. I then selected the 50 variables with the highest absolute value correlation with corn yield. From this subset of 50 variables, I selected the 21 variables that were the least correlated with each other using the criterion that the absolute value of all correlations with all other variables fell below a threshold of 0.80.

In order to preserve degrees of freedom, I dropped the variable “square of average maximum temperature” for stage 9. Since 2,700 GDDs weren’t always achieved in a growing season, this variable contained fewer observations than most other variables. This was typically the result of a later planting date. At the end of the selection process, I selected the weather variables in table 9 for use in the regression. Table 8 presents the cross-correlations of the 20 selected weather variables.

Table 8: Weather Variable Cross-Correlations

	TempMaxSquared56	TempMax005	RainMax67	TempAverageMaxSquared67	TempMaxSquared354	TempMin89	TempMaxSquared335	TempMaxSquared67	TempMaxSquared45	TempAverageMaxSquared335	TempAverageMaxSquared45	RainMax225	TempMin56	RainSquared225	RainMax56	TempMin45	Rain89	RainMax45	TempMaxSquared115	TempMin354	RainMax253
TempMaxSquared56	1.00																				
TempMax005	-0.32	1.00																			
RainMax67	-0.35	0.14	1.00																		
TempAverageMaxSquared67	0.46	-0.28	-0.24	1.00																	
TempMaxSquared354	0.31	-0.34	-0.28	0.37	1.00																
TempMin89	0.43	-0.26	-0.19	0.53	0.17	1.00															
TempMaxSquared335	0.48	-0.28	-0.27	0.44	0.55	0.10	1.00														
TempMaxSquared67	0.51	-0.25	-0.29	0.79	0.45	0.57	0.49	1.00													
TempMaxSquared45	0.43	-0.59	-0.03	0.40	0.49	0.00	0.46	0.22	1.00												
TempAverageMaxSquared335	0.16	0.02	-0.15	0.24	0.40	0.04	0.72	0.41	0.11	1.00											
TempAverageMaxSquared45	0.33	-0.42	-0.11	0.43	0.57	0.10	0.29	0.30	0.72	0.10	1.00										
RainMax225	-0.04	0.20	0.47	0.07	-0.19	-0.06	-0.09	0.00	0.08	-0.16	-0.18	1.00									
TempMin56	0.43	-0.37	0.08	0.33	0.44	0.37	0.23	0.40	0.47	0.14	0.49	0.06	1.00								
RainSquared225	0.02	0.25	0.09	0.08	-0.04	-0.10	-0.01	0.03	0.10	-0.04	0.10	0.67	-0.01	1.00							
RainMax56	-0.32	-0.22	0.40	-0.06	-0.42	0.05	-0.33	-0.28	-0.02	-0.39	-0.26	0.28	-0.31	-0.04	1.00						
TempMin45	0.26	-0.21	-0.09	0.30	0.32	0.18	-0.05	0.18	0.35	-0.04	0.79	-0.14	0.26	0.07	-0.12	1.00					
Rain89	-0.19	-0.01	0.08	-0.32	-0.13	-0.63	-0.02	-0.36	0.17	-0.11	0.07	-0.01	-0.30	0.02	0.11	0.01	1.00				
RainMax45	-0.03	-0.20	-0.16	-0.21	-0.10	-0.27	-0.03	-0.21	0.12	-0.27	-0.11	-0.04	-0.24	0.09	0.15	-0.13	0.37	1.00			
TempMaxSquared115	0.48	-0.30	-0.09	0.03	0.13	0.24	0.27	0.15	0.37	0.05	0.19	-0.12	0.37	-0.09	-0.29	-0.03	0.00	0.11	1.00		
TempMin354	-0.01	-0.18	-0.31	0.12	0.65	0.21	0.24	0.25	0.09	0.23	0.33	-0.27	0.32	0.01	-0.33	0.20	-0.22	-0.08	0.02	1.00	
RainMax253	0.00	0.40	0.02	-0.01	-0.27	-0.22	-0.01	0.15	-0.26	0.11	-0.22	-0.14	-0.25	-0.01	-0.12	-0.22	0.14	0.05	-0.10	-0.29	1.00

Table 9: Weather Variables Categorized by Developmental Stage

Phase	Development Stage	Stage	Selected Weather Variables
Planted	Planted	0	-None
	Two leaves fully emerged	0.5	-None
Vegetative	Four eaves fully emerged	1	-Square of Max Temp
	Six leaves fully emerged (Growing point above soil)	1.5	-None
	Eight leaves fully emerged (Tassel beginning to develop)	2	-Maximum Rainfall -Square of Average Max Temp
	Tenth leaves fully emerged	2.5	-Maximum Rainfall -Square of Total Rainfall
	Twelve Leaves Fully Emerged (Ear formation)	3	-Square of Average Max Temp -Square of Max Temperature
	Fourteen leaves fully emerged (Silks developing on ear)	3.5	-Square of Max Temp -Minimum Temperature
Reproductive	Sixteen leaves fully emerged (Tip of tassel emerging)	4	-Maximum Rainfall -Square of Average Max Temp -Square of Max Temp -Minimum Temperature
	Silks emerging/pollen shedding (Plant at full height)	5	-Maximum Rainfall -Minimum Temperature
	Kernels in blister stage	6	-Maximum Rainfall -Square of Average Max Temp -Square of Max Temp
	Kernels in dough stage	7	-None
	Kernels denting	8	-Total Rainfall -Minimum Temperature
Maturation	Kernels dented	9	-None
	Physiological maturity	10	-None

A statistical summary of all variables for the Cropping System and Corn Yield analysis are presented in table 10.

Table 10: A Summary of the Data Used for the Corn Yield Analysis

	Obs.	Min.	Max.	Mean	Std. Dev.	Units
Dry_Yield	562	13.3	11670	6613	1966	kg/ha
Time	562	5	28			years
Time_sq	562	25	784			years^2
Year1999	562	0	1	20.2%		
Manure	562	0	1	40.4%		
Legume	562	0	1	45.4%		
Variety6	562	0	1	42.0%		
Variety10	562	0	1	49.6%		
Variety15	562	0	1	30.0%		
Variety19	562	0	1	38.9%		
Variety23	562	0	1	16.6%		
NoTill	562	0	1	1.4%		
Planting_j	562	116	159.0	128.7	8.8	Days
N_input	562	6.9	573.6	158.4	69.7	kg N/ha
N_input_sq	562	47.5	328975	29933	32623	(kg N/ha)^2
SeedRt	562	23200	36624	27405	3005.0	seeds/ha
Weed_Biomass	562	0	10426	858	1158.2	kg/ha
TempMaxSquared56	562	7303.4	9801	8330.9	699.7	(°F)^2
TempMax005	562	78	95	86.3	3.9	°F
RainMax67	562	0	96	25.7	23.5	mm
TempAverageMaxSquared67	562	5440.4	8431	6842	600.6	(°F)^2
TempMaxSquared354	562	6889	10000	8355	754.4	(°F)^2
TempMin89	562	43	80	66.1	6.1	°F
TempMaxSquared335	562	6760.1	9604	7870.5	646.5	(°F)^2
TempMaxSquared67	562	6561	9801	8074.8	694.0	(°F)^2
TempMaxSquared45	562	7225	10000	8372.0	723.3	(°F)^2
TempAverageMaxSquared335	562	6121.1	8564	6930.0	502.6	(°F)^2
TempAverageMaxSquared45	562	6192.5	7999	7114.0	497.9	(°F)^2
RainMax225	562	0	52.07	11.9	13.0	mm
TempMin56	562	65	87	76.1	5.6	°F
RainSquared225	562	0	22840	993.1	2940.3	(mm)^2
RainMax56	562	0	61.00	25.6	17.9	mm
TempMin45	562	65	83.66	75.0	5.6	°F
Rain89	562	6.4	251	59.8	49.4	mm
RainMax45	562	3.6	60.96	27.2	15.3	mm
TempMaxSquared115	562	6183.2	8836	7692.9	639.7	(°F)^2
TempMin354	562	70.3	93	80.5	6.0	°F
RainMax253	562	0	71.12	18.8	18.4	mm

Soil Chemistry (Carbon and Nitrogen) Data

A total of four carbon and soil nitrogen analyses were conducted. The data set I used for the carbon and soil nitrogen analyses was a subset of the full FST data set. Since the goal was to understand the impact of the system on corn yields through the production system impact on soil nitrogen and carbon, the data set was limited to the soil chemistry following the planting of corn. A statistical summary of this data set is presented in table 11. During the 28 year history of the FST, soil organic carbon and nitrogen data were collected for 10 years and most of those data were gathered in recent years. From 1981 to 1993, soil analysis data were only available for 1981. Then, from 1994 to 2008, there were 9 years with soil analysis data: 1994, 1995, 2000, 2002, 2003, 2004, 2006, 2007, and 2008.

Rodale Institute estimated and tabulated nitrogen inputs using different processes for each cropping system. For the conventional system, applied nitrogen inputs were measured. For the legume and manure systems, Rodale Institute personnel estimated added nitrogen by random sampling of composted manure or incorporated plant matter. Then, they used laboratory analysis results to estimate the total amount of nitrogen added on a per acre basis. The remaining variables included four interaction variables where the system binary variables were multiplied by the soil and carbon and soil nitrogen variables; and a time variable where 1981=1 and 2008=28.

Soil Chemistry (Carbon and Nitrogen) Methodology

Soil carbon and soil nitrogen clearly affect corn yields regardless of the system (Poudel et al., 2001; Lal, 2004). One question I investigated was whether the cropping system, i.e. organic manure, organic legume and conventional, had a perceptible impact on the quantity of soil organic carbon and soil nitrogen. Another question I examined was whether there was a difference in the amount of carbon sequestered by Rodale's three cropping systems. To answer these questions, I estimated the relationships between the production system and soil nitrogen (equation 3) and soil organic carbon (equation 4) are examined. Table 11 summarizes the data that were used for this.

Model:

$$Soil\_Nitrogen = \beta_0 + \beta_1 Time + \beta_2 Manure + \beta_3\ Legume\ + \epsilon \qquad \text{Eq. 3}$$

$$Soil\_Carbon\ = \beta_0 + \beta_1 Time + \beta_2 Manure + \beta_3\ Legume\ + \epsilon \qquad \text{Eq. 4}$$

Where:
Soil_Nitrogen ≡ Plot level soil nitrogen in grams of nitrogen per gram of soil.
Soil_Carbon ≡ Plot level soil organic carbon in grams of carbon per gram of soil.
Time ≡ An annual time count variable: 1, 2, 3… 28 and 1981=1.
Manure ≡ A binary variable where manure system =1 and all others = 0.
Legume ≡ A binary variable where legume system =1 and all others = 0.

Table 11: A Statistical Summary of the Data Used for the First Four Analyses

	Obs.	Min.	Max.	Mean	Standard Deviation	Units
Corn Yield	182	588.12	11670.33	6043.32	2533.67	kg/ha
Time	182	1	28			Years
Time_sq	182	1	784			Years^2
Manure	182	0	1	22.0%		
Legume	182	0	1	30.8%		
Soil_C	182	1.12	3.09	2.14	0.38	%C (g C/g soil)
Soil_N	182	0.14	0.38	0.30	0.04	%N (g N/g soil)
N_input	182	0	300.67	154.04	69.67	kg N/ha
Manure x Soil_C	182	0	3.07	0.52	0.99	%C (g C/g soil)
Manure x Soil_N	182	0	0.38	0.07	0.14	%N (g N/g soil)
Legume x Soil_C	182	0	3.09	0.70	1.06	%C (g C/g soil)
Legume x Soil_N	182	0	0.38	0.10	0.15	%N (g N/g soil)

Baseline Yields

To determine the overall average yield difference between the cropping systems in this data set, I estimated the model in Eq. 5 using the data summarized in table 12.

$$Dry\_Yield = \beta_0 + \beta_1 Manure + \beta_2\ Legume\ + \epsilon \qquad \text{Eq. 5}$$

Table 12: Baseline Yield Dataset

	Obs	Min	Max	Mean	Std. Dev.	Units
Dry_Yield	716	13.3	11670.3	6292.4	2143.7	kg/ha
Manure	716	0	1	20%		
Legume	716	0	1	31%		

Soil Fertility and Corn Yield Methodology

In order to gain a better understanding of how soil organic carbon and nitrogen interact with corn, I used the yield model represented by equation 6. This model estimated the impact of the unobserved elements of the cropping system on corn yields while holding constant the effects of technology, soil fertility, and contributions from nitrogen fertilizer. As with the previous models, table 11 summarizes data that were used to estimate the regression.

$$\begin{aligned} Dry\_Yield = {} & \beta_0 + \beta_1 Time + \beta_2 Time^2 + \beta_3 Manure + \beta_4\, Legume\, + \\ & \beta_5\, Soil\_Carbon + \beta_6\, Soil\_Nitrogen + \beta_7\, N\_Input + \epsilon \end{aligned} \qquad \text{Eq. 6}$$

Where:
Dry_Yield ≡ Plot level yield of corn calculated at 0% moisture (kg/ha).
Time ≡ An annual time count variable: 1, 2, 3… 28 where 1981=1.
Manure ≡ A binary variable where manure system =1 and all others = 0.
Legume ≡ A binary variable where legume system =1 and all others = 0.
Soil_Nitrogen ≡ Plot level soil nitrogen in grams of nitrogen per gram of soil.
Soil_Carbon ≡ Plot level soil organic carbon in grams of carbon per gram of soil.
N_input ≡ The amount of nitrogen added to the soil through chemicals, cover crops, or manure in kilograms of nitrogen per hectare.

Another question I investigated was whether an interaction could be observed between the cropping system and soil fertility. To answer this question, I added four additional interaction variables by multiplying the cropping system binary variables with the soil organic carbon or soil nitrogen variables.

$$\begin{aligned} Dry\_Yield = {} & \beta_0 + \beta_1 Time + \beta_2\, Time^2 + \beta_3 Manure + \beta_4\, Legume\, + \\ & \beta_5\, Soil\ Carbon + \beta_6\, Soil\ \ Nitrogen\, + \beta_7\, Manure\, \times \\ & Soil\ Carbon\, + \beta_8\, Manure\, \times Soil\ Nitrogen\, + \\ & \beta_9\, Legume\, \times Soil\ Carbon\, + \beta_{10}\, Legume\, \times \\ & Soil\ Nitrogen\, + \beta_{11}\, N\ Input + \epsilon \end{aligned} \qquad \text{Eq. 7}$$

Where:

Manure x Soil_Carbon ≡ An interaction variable which is the product of the manure binary variable and the soil organic carbon variable.

Manure x Soil_Nitrogen ≡ An interaction variable which is the product of the manure binary variable and the soil nitrogen variable.

Legume x Soil_Carbon ≡ An interaction variable which is the product of the legume binary variable and the soil organic carbon variable.

Legume x Soil_Nitrogen ≡ An interaction variable which is the product of the legume binary variable and the soil nitrogen variable.

Cropping System and Corn Yield Methodology

In order to evaluate the impact of the production system on corn yields, I estimated the model in equation 8 using the entire data set on corn yields. Due to the limited number of soil chemistry observations, soil organic carbon and nitrogen were omitted from this model. I designed this model to estimate the effect of the cropping system on corn yield while holding constant plant genetics, nitrogen inputs, planting density, and weather. In modeling the effect of weather on crop yields, I followed Kaufmann and Snell (1997). The Kaufmann and Snell approach was designed to match temperature and precipitation to the developmental stage of the crop, rather than using average temperature and rainfall matched to the calendar. Attempting to estimate a model that included temperature or precipitation data from April or May for corn planted in June would have been inaccurate. This was especially important for the FST data set where corn was planted as early as April 26th and as late as June 9th.

In addition, the Kaufmann and Snell approach modeled the effect of non-optimal weather on yield. For example, while a corn crop is expected to be productive with reasonable variations from optimal temperature and precipitation, more significant deviations from the optimum have a deleterious impact on physiological growth and yield (Kaufman and Snell 1997). Through the use of quadratic terms with all weather variables, the impacts of significant deviations from the physiological optimum are considered.

$$\begin{aligned} Dry\,Yield = {} & \beta_0 + \beta_1 Time + \beta_2 Time\ sq + \beta_3\ Year1999\ + \beta_4 Manure \\ & + \beta_5 Legume\ + \beta_6 Variety6 + \beta_7\ Variety10\ + \beta_8 Variety15 \\ & + \beta_9 Variety19\ + \beta_{10} Variety23\ + \beta_{11} NoTill\ + \beta_{12} Planting\ j \\ & + \beta_{13} N\ input + \beta_{14} N\ input\ sq\ \ + \beta_{15} SeedRt \\ & + \beta_{16} Weed\ Biomass\ + \beta_{17} TempMaxSquared56 \\ & + \beta_{18} TempMax005\ + \beta_{19} RainMax67 \\ & + \beta_{20} TempAverageMaxSquared67 \\ & + \beta_{21} TempMaxSquared354\ + \beta_{22} TempMin89 \\ & + \beta_{23} TempMaxSquared335\ \ + \beta_{24} TempMaxSquared67 \\ & + \beta_{25} TempMaxSquared45 \\ & + \beta_{26} TempAverageMaxSquared335 \\ & + \beta_{27} TempAverageMaxSquared45\ \ + \beta_{28}\ RainMax225 \\ & + \beta_{29} TempMin56\ + \beta_{30} RainSquared225\ + \beta_{31} RainMax56 \\ & + \beta_{32} TempMin45\ + \beta_{33} Rain89\ + \beta_{34} RainMax45 \\ & + \beta_{35} TempMaxSquared115\ + \beta_{36} TempMin354\ + \epsilon \end{aligned} \qquad \text{Eq. 8}$$

Where:

Dry_Yield ≡ Plot level yield of corn calculated at 0% moisture.

Time ≡ An annual time count variable: 1, 2, 3… 28 where 1981=1.

Time_sq ≡ The square of the time variable: 1, 4, 9,…

Year1999 ≡ A binary variable to account for the anomalous year 1999 where 1999=1 and all other years =0.

Manure ≡ A binary variable where manure system =1 and all others = 0.

Legume ≡ A binary variable where legume system =1 and all others = 0.

Variety3 ≡ A plant genetics binary variable where 1=corn variety E-3X717 and all others = 0

Variety6 ≡ A plant genetics binary variable where 1= corn variety A-RX788 and all others = 0

Variety10 ≡ A plant genetics binary variable where 1= corn variety Pioneer 3527and all others = 0

Variety15 ≡ A plant genetics binary variable where 1= corn variety Pioneer 3394 and all others = 0

Variety19 ≡ A plant genetics binary variable where 1= corn variety NC+68F32 and all others = 0

Variety23 ≡ A plant genetics binary variable where 1= corn variety Pioneer 33N58 and all others = 0

NoTill ≡ A binary variable for plots where “no-till” farming methods were used. When no till methods were used, NoTill =1 everywhere else= 0

Planting_j ≡ Day of year number for when the crop was planted. It is set to January 1 = 1, January 2 = 2, and December 31 = 365 (except for leap years)

N_input ≡ The amount of nitrogen added to the soil through chemicals, cover crops, or manure in kilograms of nitrogen per hectare

N_input_sq ≡ The square of N_input

SeedRt ≡ The planting density in number of seeds per acre

Weed_Biomass ≡ The dry biomass weight of the weeds on a plot. It is measured by sampling and then calculated in kilograms per hectare.

TempMaxSquared56 ≡ The square of the maximum daily temperature during stage 5

TempMax005 ≡ The maximum daily temperature during stage 0 (planting to emergence)

RainMax67 ≡ The maximum amount of daily rain in stage 6.

TempAverageMaxSquared67 ≡ The square of average of the maximum daily temperatures during stage 6

TempMaxSquared354≡ The square of the maximum daily temperature during stage 3.5

TempMin89 ≡ The minimum temperature during stage 8

TempMaxSquared335≡ The square of the maximum daily temperature during stage 3

TempMaxSquared67 ≡ The square of the maximum daily temperature during stage 6

TempMaxSquared45 ≡ The square of the maximum daily temperature during stage 4

TempAverageMaxSquared335 ≡ The square of the average maximum daily temperature during stage 3

TempAverageMaxSquared45 ≡ The square of the average maximum daily temperature during stage 4

RainMax225 ≡ The maximum amount of daily rain in stage 2.5

TempMin56 ≡ The minimum daily temperature during stage 5

RainSquared225 ≡ The square of the total amount of rain during stage 2.5

RainMax56 ≡ The maximum amount of daily rain in stage 5

TempMin45 ≡ The minimum daily temperature during stage 4

Rain89 ≡ The amount of rain in during stage 8
RainMax45 ≡ The maximum amount of daily rain in stage 4
TempMaxSquared115 ≡ The square of the maximum daily temperature during stage 1
TempMin354 ≡ The minimum daily temperature during stage 3.5

Economic Competitiveness of Organic Systems Data

The remainder of this analysis focuses on estimating the price premium that would be required in order for the organic systems to be economically competitive with conventional systems. I conducted the economic analysis using a discounted cash flow methodology. I calculated the net present value per acre for each agricultural system over a three year period (2006-2008). I chose this time frame to align with available observed data on the costs of production.

Costs

I obtained many of the direct input costs such as seed, fertilizer, and herbicide from Rodale's FST records. I obtained information on inputs such as fuel and some fertilizer and herbicide costs from academic and government sources: US Energy Administration, (2008); US Department of Agriculture's Economic Research Service, (2009); University of Minnesota). A summary of the costs used in this analysis is presented in .

table 13. In most cases, input prices were actual prices paid by the Rodale Institute. However, in some cases input costs were estimated. Seed and fertilizer costs,

with the exception of Urea Ammonium Nitrate (UAN), were actual prices paid by the Rodale Institute. I estimated UAN prices by using a national average price from the United States Department of Agriculture's Economic Research Service (2009). Rodale's actual seed and fertilizer prices were the same for 2006 and 2007. For 2008, I used actual herbicide costs from Rodale Institute. For 2006-2007, I used herbicide costs estimated by the University of Minnesota, College of Food, Agriculture, and Natural Resource Sciences provided by the Rodale Institute (University of Minnesota, 2007).

Rodale obtained its manure for free from a neighboring farmer, so I attempted to estimate an average manure cost for use in this analysis. Manure prices vary widely by nutrient content, conventional fertilizer prices, and the local market for manure (Allison et al., 1999; Araji et al., 2001; Ishler et al., 2002; Koehler et al., 2005; ScienceDaily, 2008). In addition, since manure has very low nutrient density compared to chemical fertilizers, significantly more equipment passes and farm labor are required to both transport it and distribute it over the field (Koehler et al., 2005; ScienceDaily, 2008). One additional complication is that Rodale's manure rotation is designed to mirror the operations of a dairy farm. As such, it is likely that an integrated dairy crop farm would not directly purchase manure. Further, unless there was a vibrant local market for manure, the economic value of the dairy manure is likely to be very low. These factors made estimating an accurate and appropriate manure price difficult. Nonetheless, several authors provided information that I used to estimate a price of $15/ton for the manure that was applied by Rodale. Because I have a very low degree of confidence in this number, I performed a sensitivity analysis to examine the impact of manure prices from $0 to $25 per ton on the organic premium. This price range was representative of the prices where the nitrogen content of manure can be applied for a lower cost than chemical fertilizers (Araji et al., 2001; Ishler et al., 2002; Koehler et al. 2005).

Table 13: Input Costs used in Profitability Analysis

Operation $/Acre	2006	2007	2008
Manure System			
Composted Manure	$225.00	$232.50	$219.00
Corn Seed	$45.00	$54.94	$70.50
Fertilizer (Potassium)			$366.75
Hairy Vetch Seed		$72.10	
Hay Seed	$73.20		
Lime	$91.05		
Oat Seed		$5.44	$23.48
Rye Seed	$24.75	$59.40	$98.25
Soybean Seed	$34.94	$49.78	
Wheat Seed	$42.50		
Oat, Alfalfa, & Orchard Grass mix			$104.64
Legume System			
Corn Seed	$45.00	$54.94	$70.50
Fertilizer		$123.45	
Fertilizer (Potassium)			$366.75
Hairy Vetch and Oat Seed Mix			$68.58
Hairy Vetch Seed	$65.80	$72.10	
Lime	$91.05		
Oat Seed		$5.44	$46.95
Rye Seed	$24.75	$59.40	$98.25
Soybean Seed	$34.94	$49.78	
Wheat Seed	$42.50		
Conventional System			
Corn Seed	$45.00	$54.99	$144.97
Fertilizer	$113.15	$103.84	$529.50
Herbicide	$91.69	$101.05	$116.53
Lime	$91.05		
Rye Seed		$89.10	
Soybean Seed	$33.60	$49.78	$53.28
Wheat Seed	$42.50		

Equipment costs per acre were based in part on University of Minnesota (UMN) estimates (Lazarus, 2008). The UMN estimates include purchase cost, depreciation, fuel and lubricants, maintenance, labor, interest, insurance, and housing for an implement and its associated power unit (a tractor) on a dollar per acre basis. Where the power unit was not precisely the same horsepower that Rodale used for the operation, I selected the power unit with the nearest horsepower. In cases where the exact operation was not listed in the UMN estimates, I used the equipment costs from other operations where Rodale used the same tractor and where the field times and implement values were most similar. I followed this procedure for operations such as applying compost with a manure spreader, cultipacking, tine weeding, and overseeding hay. In two cases, due to the size of their plots, Rodale used research scale equipment for harvesting and herbicides (the combine and the sprayer). For these equipment costs, I used the UMN estimates for both the dollars per acre and hour per acre. I then adjusted these costs by subtracting labor and fuel costs which are handled separately in this analysis. In addition to equipment cost per acre, I used the UMN Estimates to calculate diesel use on a per hour basis for each operation. I combined this with Rodale’s hour per acre data and fuel price data in order to calculate the total fuel cost per acre. The FST data set included hour per acre times for most operations. The Rodale Institute measured labor hours using a stopwatch as the operations were being conducted. For the field operations that did not have precise times, I used estimates provided by the Rodale farm foreman. In doing this, he considered both the tractor horsepower and the speed of the operations that were already clocked using a stopwatch. I then used these estimates to calculate a fuel cost per acre for each operation. To account for some of the uncertainty from this method, I performed a sensitivity analysis to determine the impact of errors resulting from using this method. One exception to the above equipment cost data was the combine. Since the FST uses a research-scale combine, I used only the field time and cost per acre estimates estimated by Lazarus (2008). Hourly equipment costs and operation times per acre is presented in table 14.

Table 14: Equipment Costs and Operation Times

Operation	Equipment $/hour	hr/acre	Type
Apply compost	$3.96	2.73	timed
Moldboard plow	$11.12	0.91	timed
Chisel plow	$6.53	0.61	timed
Disk	$5.77	0.45	timed
Field cultivator	$3.58	0.45	estimated
Cultipack	$5.77	0.45	timed
Planter (4-row)	$6.27	2.27	timed
Drill (small grains)	$6.89	0.45	timed
No-till drill (rye/grains)	$2.73	0.68	timed
Apply herbicide	$1.48	0.04	estimated
Rotary hoe (15 ft)	$1.35	0.25	timed
Tine weed	$1.35	0.30	timed
Cultivate (tine)	$6.94	0.75	estimated
Mow hay	$3.96	1.14	estimated
Ted hay	$2.25	0.55	estimated
Rake hay/straw	$2.25	0.91	timed
Bale hay/straw	$6.06	0.45	estimated
Combine (grain head)	$19.03	2.50	estimated
Combine (corn head)	$33.14	3.64	estimated
Mow corn residue	$7.93	0.91	timed
Apply N side dressing	$6.94	1.00	estimated
Overseed Hay	$1.35	0.17	estimated

Diesel fuel prices came from the United States Department of Energy's Energy Information Administration (DOE EIA). The prices used were the average annual diesel price for the Mid-Atlantic region of the United States for 2006-2008. I used the following annual average per gallon diesel prices: 2006 - $2.808, 2007 – $2.965 and 2008 - $3.995. Fuel costs per acre are presented in table 15.

Table 15: Per Acre Diesel Fuel Costs

	Fuel Cost ($/acre)		
	2006	2007	2008
Manure System	$64.90	$66.25	$100.18
Legume System	$65.04	$68.83	$105.29
Conventional System	$41.71	$45.13	$71.06

Revenues

I calculated revenues on a per acre basis using the system average yields for the FST and annual average crop prices for Pennsylvania which I obtained from the USDA's National Agricultural Statistics Service (NASS). The yields, prices and revenue per acre are presented in table 16.

Table 16: Per Acre Revenues

	$/Acre		
	2006	2007	2008
Manure System			
Corn	$448	$483	$503
Hay			$182
Oats			$208
Soybeans	$313	$535	
Wheat	$202	$429	
Legume System			
Corn	$384	$511	$446
Oats			$143
Soybeans	$300	$471	
Wheat	$291	$350	
Conventional system			
Corn	$379	$689	$1,308
Soybeans	$388	$567	$460
Wheat	$213	$462	

Discount Rate

I calculated the discount rate as the weighted average cost of capital by following the procedure in *Capital Investment Analysis and Project Assessment* (Boehlje and Ehmke, 2005). Equation 9 was used to calculate the discount rate.

$$d = K_e\, W_e + K_d W_d (1 - t) \qquad \text{Eq. 9}$$

Where:

d ≡ Discount rate

K_e ≡ Cost of equity funds (Return on Equity)

W_e ≡ Proportion of equity funds used (Equity to Asset ratio)

K_d ≡ Cost of debt funds (Average Interest Rate)

W_d ≡ Proportion of debt funds used (Debt to Asset ratio)

t ≡ Marginal tax rate

I obtained the financial data, K_e, K_d, W_e, & W_d, from the Farm Financial Database at the University of Minnesota (FINBIN). I chose financial data for 2004 to 2006 for all Ohio farm types except dairy and hog operations. I chose the years 2004 to 2006 because they precede the period I analyzed and contain the information that a farmer would likely have if he or she were making profitability decisions from a 2006 perspective. Ohio was chosen because it was the nearest state available in the data set to Pennsylvania. Finally, I included “all farms” (except dairy and hog) in the financial data set because the data set would have been too small to produce a statistically valid result with only “crop farms” included as the selected category. I obtained the 2006 marginal tax rate of 25% from the IRS website for a tax payer who was married and filing jointly with average income between \$61,300 and \$123,700. According to the FINBIN database, the average family income for the Ohio farm types used in this calculation was \$75,724. Table 17 is a summary of the discount rate calculations.

Table 17: Calculation of the Discount Rate

	Average	2006	2005	2004
Farm debt to asset ratio	25%	26%	23%	26%
Farm equity to asset ratio	75%	74%	77%	74%
Rate of return on farm equity	3.10%	0.30%	7.00%	- %
Interest Rate	4.91%	4.91%	5.81%	4.36%
Rate of return on equity	2.90%	1.70%	2.60%	4.20%

D/A Ratio (Wd)	25.0%	E/A Ratio (We)	75.0%
Average Interest Rate (Kd)	4.9%	RoE (Ke)	3.1%
Tax Rate	25.0%		

Discount Rate	3.2%

Returns and Organic Premium Methodology

I applied the cost and revenue data for the profitability analysis to Rodale's FST field operations logs for 2006-2008 in order to calculate the annual net returns on a per acre basis. These logs contain a record of operations performed at the system level. Then, I discounted the net returns to a present value for 2006 using the discount rate. Then, I summed the present values to determine the net present value (NPV) for each system.

To calculate the price premium that would be needed for the organic systems to be economically competitive with the conventional system (from the perspective of the farmer), I used Microsoft Excel's goal seek function to find the organic prices that equated the NPVs for the manure and conventional systems. All organic prices were simultaneously increased by the same percentage. For example, if corn prices were raised by a 10% price premium, then hay prices were also raised by a 10% premium. This process was repeated for the legume and conventional systems.

CHAPTER 4 –RESULTS

This chapter presents the results of the analyses outlined in Chapter 3, Data and Methods. First I present the impact of the organic and conventional rotations on soil chemistry: nitrogen and carbon using the first two econometric models. Second, using the remaining three econometric models, I present the impact of the organic and conventional rotations on corn yield. Finally, I examine the economic necessity of a price premium for certain organic grains and hay that was estimated using discounted cash flow and the solver function of Microsoft Excel.

Soil Chemistry (Carbon and Nitrogen) Results

The results of estimating the soil nitrogen and carbon models (equations 3 and 4) are presented in table 18. The results indicate a strong positive influence of time and rotation on soil organic carbon and soil nitrogen from both rotations and over time. However, when the soil organic carbon regression is estimated without the observations from 1981, the time variable loses its statistical significance (see table 19). This was not the case for soil nitrogen which maintained a strong significance on the time variable even without the 1981 observations (see table 19). Both the manure and legume binary variables are positive and highly significant for both soil organic carbon and nitrogen indicating that the manure crop system has a larger positive correlation with both variables than the conventional system. Both legume systems have a positive and significant variable with regard to soil organic carbon indicating both systems are maintaining higher levels of soil organic carbon than the conventional system.

Since the coefficient of the time variable for equation 4 loses significance if it is re-estimated without the 1981 soil organic carbon observations, the amount of carbon sequestered appears to have stabilized. The stable soil organic carbon levels are highest for the manure system, followed by the legume and conventional systems. For equation 3, the coefficient of the time variable is still significant and positive without the 1981 data, as such, it appears that average soil nitrogen levels are continuing to increase. These results indicate that, by maintaining organic manure and legume rotations such as those in Rodale Institute's Farming Systems Trial, a farmer could retain higher levels of soil nitrogen and sequester more carbon than a conventional system. As a result of the limited amount of soil chemistry data in the earlier years of the FST, this analysis could not predict the amount of time that would be required to achieve the previously discussed steady state of carbon sequestration.

Table 18: Rotational Impact on Soil Nitrogen and Carbon

Coefficient Std. Error (p-value)	Soil_N	Soil_C
Intercept	0.28	1.78
	0.0071	0.057
	(0.000)	(0.000)
Time	0.00052	0.011
	0.0003	0.0025
	(0.047)	(0.000)
Manure	0.042	0.36
	0.0070	0.0625
	(0.000)	(0.000)
Legume	0.028	0.29
	0.0061	0.0562
	(0.000)	(0.000)
Adjusted r2=	0.21	0.26
n=	182	182

Table 19: Rotational Impact on Soil Nitrogen and Carbon without 1981 observations

Coefficient Std. Error (p-value)	Soil_N	Soil_C
Intercept	0.23 0.012 (0.000)	2.02 0.109 (0.000)
Time	0.0022 0.0005 (0.000)	-0.00097 0.0048 (0.839)
Manure	0.047 0.0078 (0.000)	0.44 0.068 (0.000)
Legume	0.034 0.0068 (0.000)	0.33 0.060 (0.000)
Adjusted r^2=	0.32	0.26
n=	150	150

Baseline Yields

After estimating Eq. 5, I obtained the results presented in Table 20. These results indicate that overall average corn yields in the conventional system were 6,571.8 kg/ha and the average corn yields in the manure and legume systems were 92.7% and 91.0% of the conventional system, respectively. I obtained the yields following the conventional to organic transition period by estimating the model using data from 1985-2008. I found that the manure and legume system yields were 95.9% and 93.8% of conventional yields respectively. These are not statistically equivalent average yields, but are certainly closer than observed in other organic and conventional trial or farm data (Hepperly, 2003; Lotter, 2003).

Table 20: Baseline Yields

Coefficient Std. Error (p-value)	Dry_Yield
Intercept	6571.8
	113.8
	(0.000)
Manure	-481.3
	211.3
	(0.023)
Legume	-588.2
	182.4
	(0.001)
Adjusted r2=	0.014
n=	716

In order to gain a better understanding of how soil organic carbon and nitrogen interact with corn yields, I estimated the model represented by equation 6. The results of this regression are reported in the left-most column of table 21.

The coefficient of the time variable in this regression was positive and statistically significantly different from zero at a 95% confidence level. The coefficient of the time squared variable was significant and negative. Taken together, these coefficients indicate that yields were increasing with time but at a decreasing rate. The coefficients of the binary variables for the manure and legume systems were both negative and significantly different from zero indicating that, after controlling for variables such as time, soil fertility, and nitrogen inputs, the manure and legume crop systems had lower yields, on average, than the conventional crop systems. The soil organic carbon variable was positive and significantly different from zero, indicating that higher levels of soil organic carbon were associated with higher corn yields. The soil nitrogen variable was negative and significantly different from zero indicating that, on average, higher levels of soil nitrogen were correlated with lower corn yields. The nitrogen input variable was positive and significantly different from zero indicating that higher levels of nitrogen input are associated with higher corn yields.

These results present a number of confounding factors. With the exception of the 1981 samples, the soil nitrogen samples were taken after harvest. The results discussed above identify a large negative correlation of soil nitrogen levels with corn yields. It is possible that due to the timing of the soil sampling (after harvest), this model may not be observing the impact of systemic nitrogen levels on corn yields but rather that a higher level of nitrogen uptake occurs during years with conditions favorable to higher yields.

Table 21: Interaction of Soil Organic Carbon and Soil Nitrogen on Corn Yield

Coefficient Std. Error (p-value)	Corn Yield	Corn Yield
Intercept	2574.7 1058.7 (0.016)	-280.2 1079.1 (0.795)
Time	381.3 56.54 (0.000)	418.2 57.33 (0.000)
Time_sq	-7.5 1.91 (0.000)	-8.4 1.93 (0.000)
Manure	-727.7 297.9 (0.016)	3926.9 2374.0 (0.100)
Legume	-905.0 301.4 (0.003)	7225.8 2659.0 (0.007)
Soil_C	1215.8 469.6 (0.010)	1300.8 421.8 (0.002)
Soil_N	-11259.6 4450.1 (0.012)	-2622.6 4146.1 (0.528)
N_input	5.8 1.87 (0.002)	5.4 2.09 (0.011)
Manure x Soil_C		-444.5 1037.2 (0.669)
Manure x Soil_N		-12116.1 10500.3 (0.250)
Legume x Soil_C		-141.1 1339.4 (0.916)
Legume x Soil_N		-25672.6 9887.9 (0.010)
Adjusted r^2=	0.66	0.68
n=	182	182

To gain a better understanding of the interaction between the soil fertility variables and yield, I added four interaction variables to equation 6 to form equation 7. The results of this regression are reported in the right-most column of table 21. After including the interaction variables, both time variables remained significant and retained their original signs and interpretations. Of the remaining variables, those that are significant were: the legume system binary variable, soil organic carbon, input nitrogen, and the legume x soil nitrogen interaction variable. The legume system variable is positive indicating that, after controlling for the other variables, the legume system was associated with much higher yields on average than the conventional system. The soil organic carbon variable also remained positive and associated with higher corn yields. The input nitrogen variable has also remained positive and continues to indicate that higher levels of applied nitrogen were associated with higher yields. Finally, the legume x soil nitrogen system variable was negative, indicating that higher levels of soil nitrogen in the legume system were associated with lower corn yields. This may be evidence that supports the experience of the Rodale Institute, where nitrogen levels in the legume system were found to be higher than optimal. To address this situation, they reduced the seeding rates of nitrogenous cover crops (hairy vetch) in an effort to improve soil fertility (Hepperly, 2003).

In order to better understand the regression results in table 21, I used the model results to predict the impact of soil nitrogen and on each system over the range of observed values of soil organic carbon and soil nitrogen. Then, I graphed the results which are presented in figure 3 (for soil organic carbon) and figure 4 (for soil nitrogen). Figure 3 shows all three systems with similar positive slopes relating increased soil organic carbon to increased predicted yield. Conditional on the other variables evaluated, the manure system has the highest predicted yields overall followed by the legume system and then the conventional system. Figure 4 shows all three systems with negative slopes relating soil nitrogen to predicted yield. At a level of approximately 0.27 grams of nitrogen per gram of soil, all three lines intersect. To the left of this point the legume and manure systems experience the largest positive impacts on yield (relative to the conventional system) with increased nitrogen inputs. To the right of this point the manure and legume systems experience larger negative impacts on yield relative to the conventional system. These results are consistent with the discussion above where the legume system has historically received levels of nitrogen that depressed yields.

If there were more soil chemistry observations in the data set, additional useful information might be gained by adding squared interaction terms to the model to get a better sense of what the optimal soil nitrogen levels are for the organic systems.

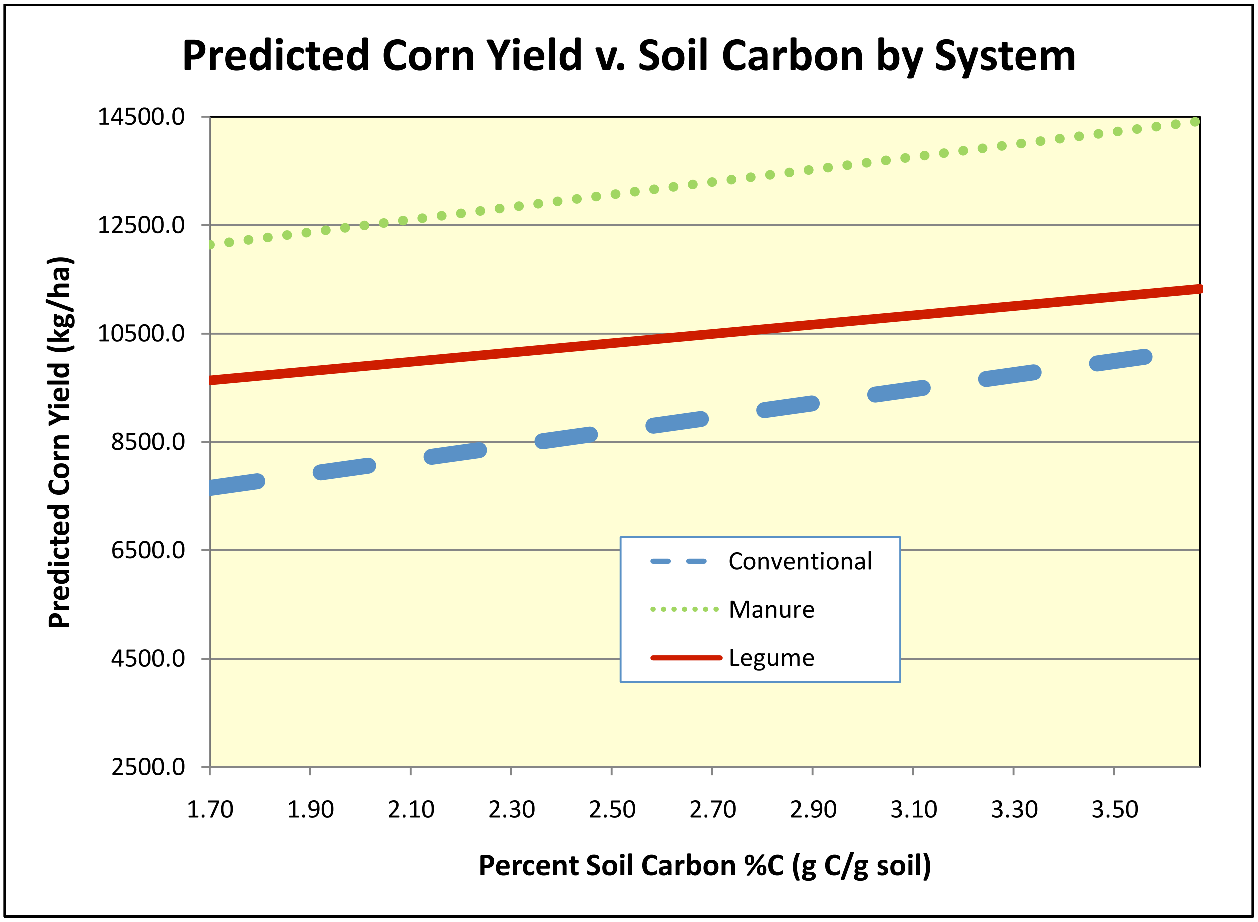


Figure 3: Predicted Corn Yield versus Soil Organic Carbon by Cropping System

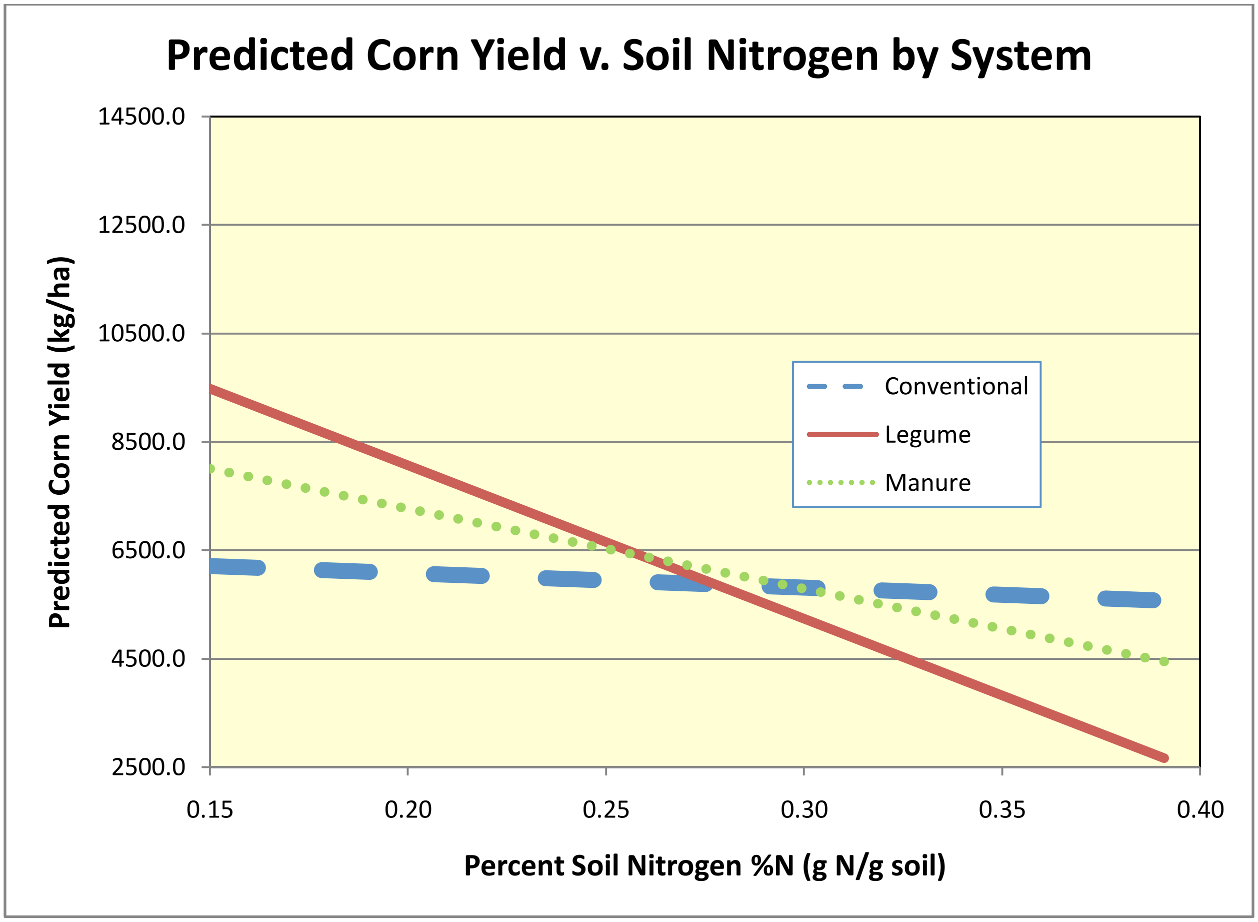


Figure 4: Predicted Corn Yield versus Soil Nitrogen by Cropping System

Cropping System and Corn Yield Results

To evaluate the impact of the cropping system on corn yields, I estimated the model in equation 8. The results from estimating this model are reported in table 22.

Unlike the previous yield models (equations 6 and 7), time and time squared are no longer significant both individually and jointly. The binary variable coefficient for the drought Year1999 is large, negative, and significant which indicates that the 1999 drought had a major impact on crop yields at the Rodale Institute. The manure and legume binary variables are both significant and positive indicating that once one controls for the other variables (time, plant genetics, nitrogen inputs, and weather), the corn yields in the organic systems are higher on average than corn yields in the conventional system. The variety variables are individually insignificant, but jointly significant at the 99% level indicating that the genetics of the planted varieties have a positive or negative impact on yield relative to variety1, which is the excluded variety. The NoTill variable is insignificant which was expected since Rodale added no till operations in 2008 and the effect of changing a tillage system may take several years and more observations to be observable. Planting_J is the day of the year variable indicating when the crop was planted. It is negative and significant which indicates that on average corn yield is negatively impacted by a later date of planting. Each additional day beyond the average plant date will likely result in a 44 kg/ha (0.7 bu/ac) yield loss. Since most farmers and the Rodale Institute attempt to choose the plant date that will have the best chance of producing higher yields, it was impractical to consider risk of frost or other adverse weather events. If these factors were considered, it is likely that a different conclusion regarding the optimal plant date would have been reached.

The nitrogen input variables were both significant with a positive linear term and a negative quadratic term which indicates that on average, additional nitrogen increases yields, but at a decreasing rate. The seeding rate variable, SeedRt, was statistically insignificant. Thus, no conclusion can be drawn with regard to the effect of corn density on yield in the FST. The weed biomass variable gives an indication of how much competition the corn crop had for soil nutrients and sunlight. This variable was significant and negative indicating that increased weed biomass had a negative effect on yield.

The remaining 20 variables are the constructed weather variables intended to allow an examination of the effect of extreme weather events (hot, cold, wet, and dry) on the optimal growth of corn. Of the 20, ten were significant at the 90% level. Of those, the top five in order of correlation with yield were: TempAverageMaxSquared45, TempMin45(-), TempMaxSquared45(-), TempMin354(-), and TempMaxSquared56. The (-) sign indicates a negative correlation with yield for higher temperatures or rainfall. There were several rain variables that were significant and these were, in priority order: RainMax225, RainMax45, RainMax67(-). The first two variables indicate that above average rainfall during stage 2 or 4 would improve yield. The last variable indicates that the maximum amount of rain received during stage 6, kernels in blister stage, was associated with reduced yields. Two other variables, TempAverageMaxSquared45 and TempMaxSquared56, indicate that higher than average maximum temperatures in stages 4 and 5 are correlated with reduced yields. For average maximum temperatures above 84°F in period 4 and maximum temperatures above 91°F in period 5, average yields could be expected to increase.

The most significant weather variables are clustered around the transition from the vegetative stage to the reproductive stage (stages 3, 4, and 5) where reproductive silks are developing, and where tasseling and pollination are occurring. This is a time where corn is particularly sensitive to stress (Kaufmann and Snell, 1997). In these stages, the optimum temperature range appears to be below both the average temperatures for the TempMin variables (75°F and 80°F respectively) and below the square root of the average value for TempMaxSquared45, which is 91.5°F. Due to the way these variables were constructed, higher minimum and higher maximum temperatures indicate that the weather was above the optimal range (it was hot) during entire silking or tasseling period.

Table 22: Comprehensive Corn Yield Model Estimation Results

Coefficient Std. Err. (p-value)	Corn Yield
Intercept	6560.73 10573.8 (0.535)
Time	27.48 407.8 (0.946)
Time_sq	3.00 12.3 (0.807)
Year1999	-5510.46 1224.7 (0.000)
Manure	472.77 198.1 (0.017)
Legume	1366.71 237.1 (0.000)
Variety6	-316.44 1472.4 (0.830)
Variety10	531.29 1723.5 (0.758)
Variety15	-2826.35 2402.4 (0.240)
Variety19	-1550.50 1737.7 (0.373)
Variety23	-224.73 1911.0 (0.906)
NoTill	-411.20 385.8 (0.287)
Planting_J	-44.70 16.2 (0.006)
N_input	17.32 2.54 (0.000)

Table 22: continued

Coefficient Std. Err. (p-value)	Corn Yield
N_input_sq	-0.02 0.006 (0.000)
SeedRt	-0.00064 0.077 (0.993)
Weed_Biomass	-0.31 0.077 (0.000)
TempMaxSquared56	0.62 0.28 (0.028)
TempMax005	65.53 47.5 (0.168)
RainMax67	-13.70 7.5 (0.068)
TempAverageMaxSquared67	-0.42 0.33 (0.199)
TempMaxSquared354	-0.24 0.16 (0.132)
TempMin89	60.89 26.2 (0.021)
TempMaxSquared335	-0.30 0.29 (0.299)
TempMaxSquared67	-0.25 0.29 (0.398)
TempMaxSquared45	-1.00 0.47 (0.033)
TempAverageMaxSquared335	0.42 0.33 (0.204)
TempAverageMaxSquared45	3.66 0.64 (0.000)

Table 22: continued

Coefficient Std. Err. (p-value)	Corn Yield
RainMax225	85.82
	16.1
	(0.000)
TempMin56	-8.09
	20.9
	(0.699)
RainSquared225	-0.12
	0.055
	(0.028)
RainMax56	27.21
	19.3
	(0.159)
TempMin45	-237.79
	47.5
	(0.000)
Rain89	3.76
	2.6
	(0.152)
RainMax45	21.95
	7.0
	(0.002)
TempMaxSquared115	-0.15
	0.22
	(0.489)
TempMin354	-72.84
	23.1
	(0.002)
RainMax253	8.15
	7.3
	(0.263)
Adjusted r^2=	0.67
n=	562

Heteroskedasticity

To ensure that the statistical significance of each variable's coefficient was accurate and based on statistically valid standard errors, I checked each of the preceding regressions for heteroskedasticity using both the White and Breuch-Pagan tests. For equations 3, 6, 7, and 8, I was able to reject the null hypothesis that there was homoskedasticity at the 99% percent level of confidence (see table 23). In response, to ensure that the statistical significance of each coefficient was valid, I re-estimated each of the regressions (equations 3, 6, 7, and 8) using robust standard errors. These standard errors were included in the results tables (table 18, table 21, and table 22).

Table 23: Heteroskedasticity Test Results

	White Test		Breusch-Pagan	
	Test Statistic	(p-value)	LM Statistic	(p-value)
Eq. 3	24.17	(0.000)	38.85	(0.000)
Eq. 4	7.58	(0.271)	8.51	(0.075)
Eq. 6	75.01	(0.000)	41.44	(0.000)
Eq. 7	82.82	(0.002)	51.21	(0.000)
Eq. 8	242.07	(0.000)	114.01	(0.000)

Economic Returns

After comparing yields between the conventional and organic systems, it is also important to examine the economic returns for each system. In the case of the Rodale Institute's FST, the last three years of actual and estimated expenses were examined and compared to projected revenues on a dollar per acre basis. As displayed in table 24, the conventional system had the highest NPV for the three year period. There were years where the organic net returns exceeded the conventional net returns, but on average and at conventional prices, organic agriculture is less economically desirable to a farmer than conventional agriculture. These returns have been calculated without including land, labor, or management costs and such should be considered the returns to land, labor and management.

Table 24: 3-Year Profitability Analysis

		2006	2007	2008	Average	NPV	
Manure System	Costs	$890	$769	$1,212	$957		$/ac
	Revenues	$963	$1,447	$892	$1,101		$/ac
	Net Returns	$73	$678	-$320	$144	$416	$/ac
Legume System	Costs	$625	$625	$935	$728		$/ac
	Revenues	$975	$1,331	$589	$965		$/ac
	Net Returns	$351	$706	-$346	$237	$687	$/ac
Conventional System	Costs	$663	$641	$1,139	$815		$/ac
	Revenues	$979	$1,718	$1,768	$1,488		$/ac
	Net Returns	$316	$1,076	$629	$674	$1,887	$/ac

Premiums

Farmers are assumed to be indifferent between options with equivalent NPVs if factors such as risk preferences, return on labor hours, and ecological preferences are not considered. To simulate this, the prices received by farmers for the organic crops were uniformly increased until the NPV of the organic system equaled the NPV of the conventional system. In the case of the manure system, a 47.4% price premium over conventional prices was found to be sufficient to equalize the NPVs. The legume system required a premium of 44.0% to equalize the NPVs. Although the previous analyses considered only corn, this price premium analysis considered all crops grown in each system. The nearly equivalent corn yields between the systems had less influence on the size of the premiums. This was also true since corn, an important cash crop, was grown less often in the organic cropping systems.

Two of the factors that had the potential to impact the estimation of the organic price premium were the discount rate and the purchase price of the manure for the manure system. To evaluate their impact, I ran a sensitivity analysis using reasonable ranges for these values. The results of this sensitivity analysis are presented in table 25. The first column contains the discount rates used (1.0%, 3.2%, and 20%) and the top row contains the range of manure prices that were tested ($0 to $25). The discount rate had the least impact when varied from low to high; the organic premium varies by about 6 percentage points at most. The manure price has a larger impact when it varies from low to high the organic premium can vary by as much as 34 percentage points. The organic premium's dependence on manure prices illustrates the very large role this particular input plays in determining economic returns and profitability.

Table 25: Discount Rate and Manure Price Sensitivity Analysis

	Legume	Manure				
Discount Rate	n/a	$0	$5	$10	$15	$25
1.0%	44.9%	27.4%	34.3%	41.1%	47.9%	61.6%
3.2%	44.0%	27.0%	33.8%	40.6%	47.4%	61.1%
20.0%	38.1%	23.8%	30.6%	37.4%	44.2%	57.9%

The year 2008 was unusual primarily because it resulted in losses at conventional prices for the organic systems. The primary reason for this was that oats were planted as a cash crop (versus a cover crop) in two of the three sub-rotational treatments. This was done as an attempt to improve weed control, but was later abandoned due to the detrimental impact on net returns. To test the sensitivity of including the 2008 data, I re-ran the Excel goal seek function on the NPVs for 2006 and 2007. The result was an organic premium of 30.4% for the manure system and 17.9% for the legume system. The large variance in premiums resulting from the exclusion of the 2008 data illustrates the importance of raising high value crops in organic systems to maintain economic competitiveness. However, all of the above organic premium results including those found in the sensitivity analyses fall well within the premiums observed in the marketplace of 20% to 140% (Hepperly et al., 2007)

Nonetheless, organic systems are required to have a minimum of a 3-year crop rotation in order to be certified as organic. This results in a non-trivial economic impact on organic returns since corn is usually the most important cash crop in the Corn Belt and conventional farmers are able to increase the frequency of corn and other high return crops to maximize their returns. Organic farmers, by the nature of the certification regime, do not have this flexibility to improve their net returns. Had another crop been planted in the organic systems in 2008, it is still quite likely that a premium would still have been needed to equalize the NPVs in both the organic and conventional systems.

These results are likely affected somewhat by the scale of the operation at Rodale Institute. Rodale's aim for the FST is to conduct operations in the same manner as a farmer on a 1,000 acre farm. However, some aspects of the FST cannot be scaled down. One of them is the size of the input purchases (seed, fertilizer, and chemicals).

Rodale's FST purchases inputs (seed, fertilizer, chemicals) in much smaller quantities than a full scale farm would and as such does not benefit from discounts offered to larger scale farms. The result is that this analysis is has the potential to be biased slightly in favor of the organic systems as they require the fewest off-farm inputs. In other words, the input prices used for the conventional system analysis are likely to be higher than what a full scale farmer would experience and as such the costs are likely overstated and the net returns understated.

Returns to Labor

Due to the design of the organic systems, more labor hours are required for operations such as planting cover crops and operating tractors for mechanical weed control. And since labor costs weren't explicitly included in the earlier calculations, it makes sense to also consider the returns to labor. Table 26 reports the returns to labor for each system on a dollar per hour basis. In each year and on average, the conventional system provided the highest return to labor. As such, even if an organic farmer using the Rodale rotations managed to achieve equivalent returns to land and management, a premium would still be needed to provide equivalent returns to labor.

Table 26: Returns to Labor ($/hour)

	2006	2007	2008	Average
Manure System	$2.18	$20.92	-$9.92	$4.39
Legume System	$12.62	$21.65	-$14.58	$6.56
Conventional System	$15.34	$53.16	$23.00	$30.50

CHAPTER 5 –CONCLUSIONS

This thesis examined several differences between organic and conventional cropping systems using data from a long term field trial conducted by the Rodale Institute in Kutztown, Pennsylvania. Rodale's FST was composed of three different cropping systems: manure, legume, and conventional. The first analysis examined the impact of the cropping system on soil chemistry, namely soil nitrogen and soil organic carbon levels. That analysis was followed by an examination of the impact of soil organic carbon and nitrogen levels on corn yield. The organic systems sequestered slightly more carbon than the conventional systems. With the soil chemistry models (equations 3 and 4), all three cropping systems had increased soil organic carbon levels that were associated with higher yields. However, I was not able to draw any cause and effect conclusions with regard to the positive correlation of higher levels soil organic carbon and corn yields.

With regard to the counterintuitive negative correlation between soil nitrogen and corn yields, again a cause and effect relationship could not be inferred. This was in part due to the time precedence of the observations (first yields were measured, then nitrogen levels) and in part to a lack of information about how the soil nitrogen levels are changing at other times of the year.

In the corn yield models (equations 5 - 8) several different stories were examined. When I considered only time and soil nutrients (Eq. 6), the conditional average corn yield in the organic systems was lower than the conventional systems. When I added the interaction between the cropping system and soil organic carbon and nitrogen (Eq. 7) the conditional average corn yield in the organic legume system was much higher than the conventional system and statistically insignificant in the manure system. When I considered a variety of other factors including corn genetics, nitrogen input, weeds, and weather, the conditional average corn yields for the organic systems were (Eq. 8) higher than the conventional system. The most comprehensive model (Eq. 8) was limited by scarce soil chemistry data and insufficient information on the growing degree day requirements of the individual corn varietal's used.

After examining cost and price data, I found that organic premiums of 44% and 27% for the manure and legume systems respectively would be necessary to make these systems economically competitive with the conventional system. These are larger premia than those found by Hanson et al. (1997) and Pimentel et al. (2005a), but less than actual organic premiums for corn and soybeans during the past decade (Lotter, 2003, Hepperly et al., 2007). The reason for the higher premiums found here is unclear because there wasn't sufficient detail in the other studies to be able to make a line by line comparison. The differences could have been related to market price differences or differences in methodology. I found the size of the premiums to be very sensitive to manure prices and crops chosen for the various rotations and somewhat sensitive to the discount rate chosen for the analysis.

Finally, I found the returns to labor on an hourly basis to be higher in the conventional system than in the organic systems. However, when attempting to approximate a farmer's choices, it is important to also consider the opportunity cost of a farmers time and potential income sources that are systemically symbiotic (ex. livestock) or seasonally compatible (ex. off-season off-farm employment). This analysis did not consider these elements and as such is limited in its applicability. Also, in order to apply these economic conclusions more broadly, caution should be taken since this analysis was conducted without regard to yield risk, price risk, and ecological preferences. However, these factors are important to farmers when deciding which cropping system to use (Walz 2004).

Despite these limitations, this analysis contains practical information for individuals considering or advising farmers about competing agriculture cropping systems. Additional research is needed to improve organic and conventional agriculture and ultimately the vitality of the food system for consumers and producers alike.

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