Agronomic and Soil Quality Trends Over Five Years of Different Tillage and Cropping Systems across Iowa

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Acknowledgment

This report is one component of the Iowa Learning Farm project that was established in 2005. This agronomic report is an effort of many individuals over the past 5 years including farmers who offered sites where research was conducted across the state, Extension Field specialists who participated and helped in conducting field trials and collecting data, research associates who helped in managing this research and demonstration projects, many undergraduate students who helped in data collection and sample processing, and many other agriculture professionals and colleagues associated with the Iowa Learning Farm.

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Executive Summary

The Iowa Learning Farm was established with the goal of promoting conservation practices through field demonstrations and outreach activities that improve soil and water quality in Iowa. This project included field demonstrations on cooperators’ fields that included conservation management practices, where agronomic and soil quality monitoring also took place. Cooperator sites were established across four major soil regions of Iowa in order to achieve the goals of this project. This included 32 sites across the state; selected sites were chosen from each region for yearly monitoring of soil and agronomic properties. Agronomic and soil parameters monitored included: grain yield, surface residue, fall corn stalk nitrate, soil organic matter, bulk density, compaction, pH, microbial biomass carbon, aggregate stability, and water infiltration. Representative sites from different soil and climate conditions were used to make interpretations about each region’s response to different management practices.

The main objectives of the agronomic component of this project focused on: 1) Monitor changes in soil quality and productivity under different tillage and cropping systems over a 5 year period, 2) Document regional and statewide changes and trends in soil quality using a set of agronomic and soil quality parameters, and 3) Develop regional and state wide recommendations for tillage and cropping systems that are effective in sustaining soil quality and productivity.

Statewide and regional results indicate clear differences between tillage practices for corn yields, while differences in soybean yields are less pronounced. A loss of corn yield is associated with no-tillage for all regions, although the extent of yield loss varies by region and depends on specific site conditions. Reduced tillage practices offer a clear advantage over conventional tillage in the amount of residue left on the field, water infiltration rates, and amount of stable macroaggregates. The results demonstrated the slow change in soil organic matter (increase or decrease) under no-till or conventional tillage over the 5 year period. Soil compaction of no-tillage sites decreased slightly over time for individual sites, but the statewide average reveals no differences between tillage systems. Regional results show no clear difference between tillage systems for soil pH, bulk density, organic matter, or microbial biomass carbon for any of the four soil regions. Observation of these soil properties for longer than 5 years would be necessary to observe significant changes as documented by past studies.

The adoption of no-tillage offers clear advantages to soil and environmental quality over conventional tillage, regardless of region. No-tillage and reduced tillage offer benefits in the form of erosion control and improved soil quality, including: reduced soil compaction, higher water retention and flood control, increased surface residue, and stability of soil organic matter. However, decreased yields associated with no-tillage may not make it practical for some sites. Corn yield decreases in no-till are especially pronounced in poorly drained soils. The Adoption of conservation tillage practices such as strip-tillage, are a valid alternative to no-tillage in poorly drained areas where yield loss is a concern. Conservation tillage produces corn and soybean yields equivalent to conventional tillage, but still provides some of the environmental and soil quality benefits of no-tillage.
Introduction

The Iowa Learning Farm (ILF) was established in 2005 as a way of promoting education and communication about agricultural practices in Iowa. This is a statewide initiative involving producers, government agencies, conservationists, and ILF collaborators. The overall goal of the ILF project is to demonstrate and promote conservation management systems with emphasis on conservation tillage, cropping systems, and nutrient management across Iowa. Demonstration and evaluation of different management practices at cooperator sites is essential to making recommendations on practices and educating the public about management options. These findings will help to relate individual farm-level decisions to their impact on soil and water quality, and provide recommendations on management practices.

The adoption of no-tillage and conservation tillage practices has been increasing over the past few decades, especially in response to state and federal programs encouraging reduced tillage. Environmental concerns such as erosion control and water quality, as well as concerns over long-term soil quality drive the argument for adoption of reduced tillage practices. However, there are also concerns that reduced tillage will result in a loss of yield and economic returns, especially in corn. No-tillage produces a higher amount of surface residue, resulting in greater soil water retention and lower soil temperature. These conditions may cause a delay in corn emergence and slow down early season growth of corn. Slow corn growth due to no-tillage is most pronounced in poorly drained soils where conditions are already cool and wet, while yield loss due to no-tillage is generally minimal in well-drained soils (Kapusta et al., 1996; Kwaw-Mensah and Al-Kaisi, 2006). Yield losses associated with no-till are not only caused by drainage conditions, but can also be amplified by a mono-cropping system or cooler climate. Although a loss of corn yield is often reported due to no-tillage, some studies have indicated that no-tillage will produce the same economic returns even with a loss of yield (Al-Kaisi and Yin, 2004).

There are valid arguments both for and against the adoption of reduced tillage practices, but evidence from past studies is often conflicting and does not consider regional and site specific conditions such as the effect of climate and soil properties on yield performance. A key component of making sound recommendations on management practices involves collection of field data and assessment of the impact of tillage systems and crop rotations on soil and agronomic properties. Cooperator sites were established in locations across Iowa to achieve this goal; this includes 32 sites in four major soil regions in Iowa. Representative sites from different soil and climate conditions allow for interpretations about each region’s response to different management practices. This report will focus on presenting soil and agronomic trends over the past five years and will highlight differences due to tillage practices (no-till, conservation, or conventional), crop rotations (corn-soybean, corn-corn, or corn-corn-soybean), climate, and variation in soil properties.
The main objectives of the agronomic component of this project focused on:

1. Monitor changes in soil quality and productivity under different tillage and cropping systems over a 5 year period.

2. Document regional and statewide changes and trends in soil quality using a set of agronomic and soil quality parameters.

3. Develop regional and state wide recommendations for tillage and cropping systems that are effective in sustaining soil quality and productivity.

Results from the five year study will be presented separately for each soil and agronomic parameter. Soil quality and agronomic data will be presented both at a statewide level and also for each individual region. An average value of three replications is presented for each parameter; this value is used to compare trends between tillage practices. A statistical approach is also used to compare the significance of differences between management practices over the five year period.
Site Selection and Methods

Site Selection

Field sites were initially established in five regions across Iowa to evaluate changes in soil quality due to differing tillage practices, crop rotations, and conservation practices. The regions were chosen based on major differences in soil type across the state. The even distribution of field sites across the state is intended to capture any differences in soil quality due to soil and climatic conditions. The number of regions used in this report was reduced to four, including: (1) Northwest Iowa Plains, (2) Des Moines Lobe, (3) Northeast Iowan Surface, and (4) the Southern Iowa Drift Plain (Figure 1). The Loess Hills and Southern Iowa Drift Plain regions were combined due to the minimal amount of data for the Loess Hills region and the similar soil types found within the loess derived regions. The specific location of Iowa Learning Farm cooperator sites are shown in Figure 2.
Figure 1. Major soil regions of Iowa in which field sites were established. The four regions include (1) Northwest Iowa Plains, (2) Des Moines Lobe, (3) Northeast Iowan Surface, and (4) the Southern Iowa Drift Plain.
Figure 2. Specific location of Iowa Learning Farm cooperator sites. The color of each location indicates the amount of detailed field measurements that were collected.
**Experimental Design**

A replicated block design was used to monitor changes in soil properties and other parameters due to different management practices for each field site. An example of a plot layout showing typical replicated tillage treatments is shown in Figure 3. The plot arrangement, number and type of treatments, and size of each replication vary greatly between sites in different regions. This variation in plot layout is partially due to differences in equipment and the willingness of cooperators to adopt multiple management practices, but is also due to the large number of tillage and cropping systems that were evaluated. A summary of management practices and crop rotations that were evaluated as part of this study are shown in Table 1.

<table>
<thead>
<tr>
<th>No-till replication 1</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-till replication 2</td>
<td>X</td>
</tr>
<tr>
<td>No-till replication 3</td>
<td>X</td>
</tr>
<tr>
<td>Conventional till replication 1</td>
<td>X</td>
</tr>
<tr>
<td>Conventional till replication 2</td>
<td>X</td>
</tr>
<tr>
<td>Conventional till replication 3</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 3. Example of a plot map with three replications of each tillage treatment. The X represents a typical location for yearly soil sampling and infiltration measurements.
Table 1. Targeted conservation tillage practices and crop rotations for evaluation.

<table>
<thead>
<tr>
<th>Tillage Systems</th>
<th>Cropping Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>• No-tillage</td>
<td>• Corn-soybean</td>
</tr>
<tr>
<td>• Conservation Tillage (Strip-tillage, 1-pass field cultivation, minimal tillage)</td>
<td>• Corn-corn-soybean</td>
</tr>
<tr>
<td>• Conventional Tillage (Disc or chisel plow, V-rip, field cultivated, deep or subsoil tillage)</td>
<td>• Continuous corn</td>
</tr>
</tbody>
</table>

Materials and Methods

Field measurements were taken yearly on many of the 32 Iowa Learning Farm cooperator sites across the state. Measurements collected from the sites were used to compare the effects of management practices on soil quality and agronomic productivity. Fifteen of these sites were consistently sampled during the five year period, but many of these sites have partial data due to changes in cooperators or management practices. Six sites were sampled in detail for the full five years of the study. Soil samples and infiltration measurements were collected from a central location within each plot to avoid any confounding factors from neighboring plots or the edge of the field. Changes in soil quality due to management practices were monitored over the five year duration of the project using a standard set of agronomic and soil quality parameters. Agronomic parameters include yield, residue count, and stalk nitrate. Soil quality parameters include: organic matter content, soil bulk density, soil compaction, pH, microbial biomass carbon, infiltration rate, and aggregate stability. The methods used to analyze agronomic and soil parameters will be discussed for each parameter.

Residue Cover

The amount of surface residue for each plot was measured using a line transect method where beads were spaced every six inches for a total length of 50 feet. The percentage of residue on the plot was determined by counting the number of beads under which there was at least 1/8 inch of corn or soybean residue. The number of beads with residue is easily converted to percentage since there are 100 total beads on the line.

Corn Stalk Nitrate

Corn stalk nitrate was measured in the fall by determining NO$_3$-N concentration from dried and ground corn stalks. Fifteen 8 inch segments of corn stalk were collected between 6 to 14 inches above ground level; the collected stalks were then placed in a paper bag for drying.
Corn stalks were oven-dried at 60°C for 8 hours and were then ground with a carbon steel pulverizer (Blackmer and Mallarino, 1996). Stalk NO$_3$-N concentrations were determined using the 2M potassium chloride extraction method (Mulvaney, 1996) using a Lachat Quickchem FAI+8000 analyzer.

**Organic Matter Content**

Soil samples for organic matter determination were collected for the top six inches of each replication and treatment. Soil samples were air dried, ground, and stored at room temperature. Total carbon and nitrogen concentrations were determined by dry combustion using a Leco Truspec CN analyzer. One quarter gram of air dried soil was used to determine both total carbon and nitrogen percentage. The soil carbon percentage was converted to organic matter percent using the following equation that was developed through regression analysis:

$$\text{Organic Matter \%} = -0.0002*\text{Total Carbon \%} (\text{TC})^3-0.0002^\text{TC}^2+1.8276*\text{TC}+0.1012.$$  

**Bulk Density**

Bulk density was determined by collecting soil cores to a standard depth using a soil probe with a known diameter. Cores with a diameter of 0.7 inches were collected for depths of 0-6 and 6-12 inches; the volume of the core was then determined using these dimensions. The soil was dried overnight at 105°C to determine soil moisture content for calculating bulk density on an oven dry weight. The oven dry weight of the soil was then divided by the volume of the soil cores to obtain the bulk density value.

**Soil Compaction**

Soil compaction was measured using a Rimik CP20 cone penetrometer (see picture below). The penetrometer automatically logs measurements of soil resistance in increments of one inch as the cone is pushed to a depth of 24 inches. All plots were measured at soil moisture field capacity to eliminate soil moisture effect on penetration resistance values due to differing moisture content. The penetrometer records a resistance value in kilopascals; this value was converted to an index for ease of presentation. The compaction index ranges from 0 to 1, with the highest compaction value at 1. Index values were calculated by dividing each resistance value by the highest observed value for each site and for each year.
Soil pH

Soil pH was determined using a 1:1 mixture of water and soil. Ten grams of air dried soil was measured and an equal amount of water was added. The soil pH of the samples was measured after one half hour using an Accumet AR15 pH meter. The mixture was stirred immediately after adding water, left sitting for 30 minutes, and stirred again immediately before reading the pH.

Microbial Biomass Carbon

Soil samples for microbial biomass carbon analysis were collected early in the spring from selected sites by using a golf course hole cutter to collect soil from the top 6 inches. The collected soil samples were processed immediately to minimize any changes in microbial biomass carbon or were stored in a cooler until the next available time for processing. Samples were extracted within one week to observe microbial activity that closely matches field conditions. Soil samples were first sieved through a four mm sieve. Twenty grams of soil was measured out for a live microbial extraction, twenty grams for a dead microbial extraction, and ten grams to determine the soil moisture content. Dead microbial biomass samples were treated overnight with chloroform in a vacuum chamber. An extraction solution of 100 mL of 0.5 M potassium sulfate was used to extract both the live and dead microbial biomass from soil samples. The extractants were then filtered through Whatman 42 filter paper. The amount of dissolved carbon in each sample was determined using an Elementar TOC analyzer. The carbon
concentration was adjusted according to the moisture content of the soil and calculated on a dry basis. The amount of carbon measured in the live sample was subtracted from the carbon in the dead sample to determine the microbial biomass carbon.

**Infiltration Rate**

The infiltration rate of each plot was determined with a Cornell sprinkle infiltrometer (see picture below). A metal ring was pushed into the ground until the runoff hose on the ring was even with the soil surface. The infiltrometer was then placed on top of the metal ring. The sprinkler system dispenses water at a known inflow rate (IN) on the soil surface within the ring; this rate is calculated by subtracting the final water height (H2) from the initial height (H1) and dividing by time (T). The applied water simulates the effect of a heavy rainstorm. Water was added to the soil until runoff (R) was observed coming out of the ring. Once runoff began, the amount of water running off was collected and measured every three minutes. The runoff amount was recorded for a minimum of 30 minutes or until the runoff rate levels off for at least three readings. The infiltration (IR) rate can be calculated by subtracting the amount of runoff from the total amount of water being dispensed for each three minute interval. The average rate of water dispensed during the infiltration reading was determined with the following equation:

\[
IN \text{ (inch/min)} = \frac{(H_1 - H_2)}{T} \quad [1]
\]

The infiltration rate for each three minute interval was determined using the following equation:

\[
IR \text{ (inch/min)} = IN - R \quad [2]
\]
Aggregate Stability

Wet aggregate stability was measured for the top 6 inches of soil from selected plots using a method modified from Kemper et al. (1985). A golf course hole cutter was used to collect aggregate samples. Soil samples were broken down by applying light pressure to breaks between large aggregates; severely compacted portions were discarded. Once the sample was broken down as far as possible by hand, the soil was passed through an 8 mm sieve. The portion of the sample that passed through the sieve was air dried for 2 days and a subsample of 100 g was weighed out after spreading the sample and collecting the subsample randomly. The 100 g soil sample was sprayed with water until moist, making sure to cover all surfaces. The soil was then transferred to the top of a nest of sieves, including the following sizes from top to bottom: 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, and 0.053 mm. The amount of soil that passed through the 0.053 mm sieve (<0.053 mm fraction) was also calculated by subtraction from the amount retained on the other sieves. The sample was submerged in a column of water for 5 minutes at 90 rpm to break the samples; the stable aggregates for each size remain on the surface of the sieves. The remaining aggregates on each sieve were washed into plastic containers to weigh the amount of soil remaining. The weight of aggregates for each size fraction was calculated as a percentage of the initial 100 g soil sample.

Aggregate Stability Shaker
Results and Discussion

Data Presentation and Analysis:

Agronomic and soil quality parameters were monitored over a five year period to determine if there were any changes due to differences in management practices. Statewide trends in soil quality and agronomic productivity will first be discussed. Six parameters will be discussed at the statewide level, including: 1) corn and soybean yields, 2) residue cover, 3) organic matter content, 4) soil compaction, 5) infiltration, and 6) aggregate stability. These properties were chosen for discussion of the overall statewide trends or changes in soil quality because they are the most responsive indicators to short term effects of tillage and cropping systems on soil quality. The relevance of each parameter and the trends associated with each of the six statewide parameters will be discussed in detail.

Trends associated with each of the four major soil regions of Iowa will also be discussed after the statewide trends. Each region will be discussed separately using the data from detailed research sites within each region. Soil and agronomic parameters will be discussed for each soil region, including: 1) corn and soybean yields, 2) residue cover, 3) fall corn stalk nitrate, 4) soil organic matter content, 5) bulk density, 6) soil compaction, 7) soil pH, 8) microbial biomass carbon, and 9) infiltration rate.

Analysis of variance using the general linear procedure and a least significant difference of 0.05 was used to compare significance of difference between treatments. Separation of means in figures are presented with a letter, indicating a significant statistical difference in results if the letters are different.
Statewide Trends or Changes in Agronomic and Soil Quality Indicators Over Five Years

Grain Yield

Agronomic yields are one of the most obvious indicators in response to changes in soil management, and are also a major concern when producers are deciding whether to switch to different tillage practices. Adoption of no-tillage and conservation tillage systems has been promoted in recent years because of their benefits to soil health and environmental quality. However, yield losses associated with reduced tillage continue to be a concern, especially in no-till corn (Al-Kaisi and Yin, 2004).

Statewide corn yields for cooperator sites are shown in Table 2; soybean yields are presented in Table 3. Yield differences between tillage practices are summarized for each region in the right column of Table 2 and 3. Yield performance is presented as a percentage of no-till over conventional or conservation tillage and conservation over conventional tillage for each region. If yield percentage is below 100% that means no-till or conservation tillage was lower than conventional tillage. For example, the average corn yield of no-till in Region 1 is 84% of the conventionally tilled treatment, while no-till yields are 101% of conservation tillage plots (Table 2).
Table 2. Multi-year corn yields listed by cooperator and tillage treatment. Listed yields are an average of the three measured replicates from each treatment.

<table>
<thead>
<tr>
<th>Cooperator</th>
<th>Treatment</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>Percentage*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay Co. Growers</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
<td>143.1</td>
<td>-</td>
<td>184.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>-</td>
<td>176.0</td>
<td>-</td>
<td>213.9</td>
<td></td>
</tr>
<tr>
<td>Crew</td>
<td>No-tillage</td>
<td>202.9</td>
<td>170.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>205.1</td>
<td>167.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Manthe</td>
<td>No-tillage</td>
<td>203.6</td>
<td>-</td>
<td>187.0</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>196.9</td>
<td>-</td>
<td>189.1</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ronsiek</td>
<td>No-tillage</td>
<td>-</td>
<td>141.3</td>
<td>-</td>
<td>200.6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>140.4</td>
<td>-</td>
<td>200.6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Eklund</td>
<td>No-tillage</td>
<td>160.4</td>
<td>-</td>
<td>142.0</td>
<td>178.2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>170.3</td>
<td>-</td>
<td>155.6</td>
<td>171.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>-</td>
<td>152.1</td>
<td>169.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hoffman</td>
<td>No-tillage</td>
<td>188.7</td>
<td>-</td>
<td>150.9</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>193.5</td>
<td>-</td>
<td>155.8</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Mason</td>
<td>No-tillage</td>
<td>-</td>
<td>184.7</td>
<td>-</td>
<td>219.9</td>
<td>-</td>
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<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>185.0</td>
<td>-</td>
<td>224.9</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Pierce</td>
<td>No-tillage</td>
<td>-</td>
<td>186.8</td>
<td>-</td>
<td>203.3</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>191.8</td>
<td>-</td>
<td>209.8</td>
<td>-</td>
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<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>194.4</td>
<td>-</td>
<td>193.7</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Smeltzer (East)</td>
<td>No-tillage</td>
<td>-</td>
<td>126.2</td>
<td>-</td>
<td>161.6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>120.3</td>
<td>-</td>
<td>173.2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Smeltzer (West)</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
<td>163.8</td>
<td>-</td>
<td>78.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>-</td>
<td>176.3</td>
<td>-</td>
<td>84.9</td>
<td></td>
</tr>
<tr>
<td>Hunter</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
<td>192.6</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
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<td>Conventional</td>
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<td>-</td>
<td>193.0</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Jensen</td>
<td>No-tillage</td>
<td>-</td>
<td>206.1</td>
<td>-</td>
<td>200.6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>202.7</td>
<td>-</td>
<td>222.1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Moore 1</td>
<td>No-tillage</td>
<td>170.2</td>
<td>-</td>
<td>162.0</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>169.6</td>
<td>-</td>
<td>157.3</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Moore 2</td>
<td>No-tillage</td>
<td>-</td>
<td>193.2</td>
<td>-</td>
<td>167.1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>196.2</td>
<td>-</td>
<td>169.0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Vaske</td>
<td>Conservation</td>
<td>220.7</td>
<td>179.8</td>
<td>-</td>
<td>224.4</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>211.8</td>
<td>161.1</td>
<td>-</td>
<td>226.6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional + Manure</td>
<td>213.9</td>
<td>184.1</td>
<td>-</td>
<td>226.6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Caviness</td>
<td>No-tillage</td>
<td>196.1</td>
<td>-</td>
<td>211.5</td>
<td>-</td>
<td>205.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>200.1</td>
<td>-</td>
<td>199.4</td>
<td>-</td>
<td>203.1</td>
<td></td>
</tr>
<tr>
<td>Kielkopf</td>
<td>No-tillage</td>
<td>129.0</td>
<td>-</td>
<td>177.9</td>
<td>-</td>
<td>149.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>135.6</td>
<td>-</td>
<td>179.1</td>
<td>-</td>
<td>159.8</td>
<td></td>
</tr>
<tr>
<td>Nolte</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
<td>171.6</td>
<td>-</td>
<td>209.0</td>
<td>195.9</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>-</td>
<td>187.0</td>
<td>228.7</td>
<td>213.6</td>
<td></td>
</tr>
</tbody>
</table>

*No-till or conservation tillage yield was calculated as a percentage of conservation or conventional tillage based on the average yield over all years for each region.
Table 3. Multi-year soybean yields listed by cooperator and tillage treatment. Listed yields are an average of the three measured replicates from each treatment.

<table>
<thead>
<tr>
<th>Cooperator</th>
<th>Treatment</th>
<th>Average Soybean Yield (bu/ac)</th>
<th>Average Yield Percentage*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2005</td>
<td>2006</td>
</tr>
<tr>
<td>Clay Co. Growers</td>
<td>No-tillage</td>
<td>-</td>
<td>57.0</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>62.9</td>
</tr>
<tr>
<td>Manthe</td>
<td>No-tillage</td>
<td>-</td>
<td>58.2</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>59.1</td>
</tr>
<tr>
<td>Ronsiek</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Eklund</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hoffman</td>
<td>No-tillage</td>
<td>-</td>
<td>51.5</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>53.8</td>
</tr>
<tr>
<td>Mason</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Smeltzer (East)</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Smeltzer (West)</td>
<td>No-tillage</td>
<td>-</td>
<td>43.3</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hunter</td>
<td>No-tillage</td>
<td>-</td>
<td>62.0</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>61.3</td>
</tr>
<tr>
<td>Jensen</td>
<td>No-tillage</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Moore 1</td>
<td>No-tillage</td>
<td>-</td>
<td>41.4</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>41.9</td>
</tr>
<tr>
<td>Moore 2</td>
<td>No-tillage</td>
<td>60.7</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>61.7</td>
<td>-</td>
</tr>
<tr>
<td>Vaske</td>
<td>Conservation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Conservation + Manure</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Caviness</td>
<td>No-tillage</td>
<td>-</td>
<td>55.9</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>57.7</td>
</tr>
<tr>
<td>Kielkopf</td>
<td>No-tillage</td>
<td>-</td>
<td>33.7</td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>-</td>
<td>36.5</td>
</tr>
<tr>
<td>Nolte</td>
<td>No-tillage</td>
<td>-</td>
<td>54.5</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>-</td>
<td>56.1</td>
</tr>
</tbody>
</table>

*No-till or conservation tillage yield was calculated as a percentage of conservation or conventional tillage based on the average yield over all years for each region.
Over 5 years, average corn yields for all four regions were lower in no-tillage plots compared to conventionally tilled plots, with yield averages ranging from 84-97% of conventionally tilled treatments. On the other hand, average corn yields for no-tillage plots were similar to conservation tillage yields, where the percentage of yield performance ranges from 98-101%. Corn yields were higher for conservation tillage plots than conventionally tilled plots for Regions 2 and 3, where yields were 103% and 105%, respectively.

Soybean yield comparisons between no-tillage and conventionally tilled plots vary greatly, with a range of 92-105% between the four regions. Average soybean yields were similar between no-tillage and conservation tillage plots, with a percentage range of 96-100% for the four regions. Soybean yields in conservation tillage plots were higher than conventionally tilled plots. A percentage difference of 103% and 102% were observed for Regions 2 and 3, respectively.

Statewide corn and soybean yield trends are summarized below, in Table 4. A comparison of yields based on tillage practice is presented both as a percentage difference and as the average difference between yield values. The average statewide corn yield of no-tillage plots is 95% of conventionally tilled plots, no-tillage is 99% of conservation tillage, and conservation tillage is 104% of conventionally tilled plots. The average statewide soybean yield of no-tillage plots is 98% of conventionally tilled plots, no-tillage is 99% of conservation tillage, and conservation tillage is 102% of conventionally tilled plots. The differences in statewide yield are also shown as a difference of yield in bushels per acre. Corn yields in no-tillage plots are an average of 10.1 bushels less than conventionally tilled plots, no-tillage plots are an average of 1.6 bushels less than conservation tillage plots, and conservation tillage plots are an average of 6.3 bushels higher than conventionally tilled plots. Statewide soybean yields vary less than corn yields, with no-tillage average yields 1.6 bushels less than conventionally tilled plots, no-tillage plots are an average of 1.3 bushels less than conservation tillage plots, and conservation tillage plots are an average of 1.4 bushels higher than conventionally tilled plots.

There appears to be a loss of yield associated with no-till corn regardless of region, although variations in the conditions of each site determine the extent of yield loss. A loss of soybean yield in no-till plots is also observed in 3 out of 4 regions, but this loss is less pronounced than in corn. The statewide yield results showing some loss of yield due to no-tillage is consistent with past studies and demonstrates that yield response is affected by tillage, but also depends on moisture conditions and soil properties (Al-Kaisi and Yin, 2004).
Table 4. Statewide corn and soybean yield trends by tillage practice. Variability in yields between tillage practices are displayed as a percentage and as the average difference in bushels/acre.

<table>
<thead>
<tr>
<th>Relative Yield</th>
<th>Corn Yield (%)</th>
<th>Soybeans Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-tillage/Conventional Tillage x 100</td>
<td>95%</td>
<td>98%</td>
</tr>
<tr>
<td>No-tillage/Conservation Tillage x 100</td>
<td>99%</td>
<td>99%</td>
</tr>
<tr>
<td>Conservation Tillage/Conventional Tillage x 100</td>
<td>104%</td>
<td>102%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Difference in Yield</th>
<th>--------------</th>
<th>------------------</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-tillage - Conventional Tillage</td>
<td>-10.1</td>
<td>-1.6</td>
</tr>
<tr>
<td>No-tillage - Conservation Tillage</td>
<td>-1.6</td>
<td>-1.3</td>
</tr>
<tr>
<td>Conservation Tillage - Conventional Tillage</td>
<td>6.3</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Residue Cover

It is known that an increased amount of plant residue on the soil surface can minimize the amount of soil erosion and reduce water runoff. Soil physical, chemical, and biological properties can also improve due to reduced tillage and retention of residue on the soil surface (Gilley et al., 1986; Karlen et al., 1994). Average statewide corn surface residue percents for each tillage practice are presented in Figure 4. Average statewide soybean residue percents are presented in Figure 5. These measurements were taken after planting, which is the appropriate time to determine residue cover.

Corn residue cover is significantly higher in no-tillage plots compared to other tillage practices (Figure 4). There is no significant difference in corn residue cover between conservation and conventional tillage plots. The no-tillage average corn residue is the highest at 79%, followed by conservation tillage at 55%, and conventionally tilled plots have the lowest average at 50%. The lack of significant differences between residue cover percentages between conservation tillage and conventional tillage can be attributed to the accuracy of the transect method of determining residue cover and potential human error in using this method. Soybean residue cover is significantly different between all tillage practices (Figure 5). The average soybean residue cover is highest in no-till plots at 64%, followed by conservation tillage at 41%, and conventionally tilled plots have the lowest average at 32%. It is obvious, regardless of the location in the state, that residue cover is highly affected by the type of tillage system that was used.
Figure 4. Statewide average corn residue percent by tillage practice. Values reflect the amount of corn residue observed the following spring after corn was grown. Treatments with the same letter are not significantly different.

Figure 5. Statewide average soybean residue percent by tillage practice. Values reflect the amount of soybean residue observed the following spring after soybeans were grown. Treatments with the same letter are not significantly different.
Organic Matter

Soil organic matter plays several important roles in maintaining soil quality, including: promoting plant root growth, aeration, increasing crop production, and water retention. Also, proper management of soils can result in sequestration of CO\textsubscript{2} and reduction of greenhouse gases. It is known that conservation tillage practices will increase the amount of carbon and organic matter content in soil over the long-term, but short-term impacts of tillage on organic matter are not as well understood (Al-Kaisi et al., 2005). The short-term changes in organic matter due to tillage practice will be discussed for each of the four regions of Iowa, including trends for five years or less.

Average organic matter trends for sites within each of the four regions of Iowa are shown in Figure 6. There is no significant difference in organic matter percent between tillage practices, except for 2008 in north-central Iowa, where conservation tillage is significantly higher than no-tillage or conventional tillage. The higher conservation tillage value in 2008 may indicate a slight trend upward in conservation tillage organic matter, but is likely due to the variability of soil properties in the north-central region of Iowa and the inconsistency of soil sampling on large scale fields. The range in soil organic matter varies greatly by region. The northwest region ranges from about 6.5-7.0%, north central from about 5.0-6.2%, northeast from about 4.0-4.5, and southern Iowa ranges from about 3.0-3.3%. These differences between regions reflect the diverse conditions that affect the accumulation of organic matter, including: soil parent material, climate, topography, drainage conditions, and soil texture.

The results presented in Figure 6 demonstrate commonly expected slow changes in organic matter due to short-term monitoring. Generally, change in organic matter is a very slow process where increases with conservation tillage and no-till can be very small, but stability of such systems can protect soil organic matter for the long-term. Also, the percentage of carbon loss with conventional tillage may appear to not be significant, but this trend is expected in organic rich Iowa soils. The loss of organic matter can appear to be very slow since the beginning organic matter content is very high (Al-Kaisi et al., 2005). These trends reflect high field and seasonal variability, which is confounded by sampling errors and short-term monitoring.
Figure 6. Trends in soil organic matter percent by tillage treatment of four major soil regions across Iowa. Treatments with the same letter are not significantly different.

**Soil Compaction**

Compaction levels are an important indicator of soil quality. High soil compaction contributes to a loss of soil pore space, reduced water infiltration, and inhibited root growth. Most compaction in fields is the result of farm machinery traffic, especially on soils near field capacity. Deep tillage can be used as a temporary solution to break up a compacted layer, but a long-term plan to reduce traffic or change tillage practices is more likely to provide a permanent decrease in compaction. Reduced tillage practices are expected to result in lower compaction levels over time as traffic on the field is reduced and soil pores and structure are allowed to form (Varsa et al., 1997, Hanna and Al-Kaisi, 2009). Average compaction values to a depth of 12 inches for four sites across Iowa are shown in Figure 7.

Compaction values are similar between tillage systems for all four regions and across multiple years. In 2008, compaction in no-tillage is significantly higher than conventional tillage in the north-central region. In 2009, compaction of conventional tillage plots is significantly higher than no-tillage in southern Iowa. There are no significant differences for any of the other years. The greatest difference in compaction between tillage treatments is observed in north central Iowa. However, these differences are explained by the distant locations of the no-till and conventional tillage plots from one another, and the resulting soil variability. The results indicate
very little change in soil compaction due to tillage system over a five year period. We expect lower compaction levels in no-tillage as field traffic is reduced, but five years is too short of a time to observe significant changes. The assumption of using conventional tillage to reduce soil compaction is also not supported by these findings as shown in Fig. 7, where soil compaction of tilled plots in the top 12 inches was not significantly different from that for no-till. The use of conventional tillage can in the long-term create a less productive soil environment, destroying soil structure and leading to deeper soil compaction below the tillage zone. The results show two important factors affecting soil compaction: yearly variability and the effect of soil moisture on compaction. Proper soil moisture while measuring soil compaction is critical when comparing compaction results; soil compaction should be measured at field capacity. Variations in soil moisture between plots may explain the lack of differences between tillage systems.

Figure 7. Average soil compaction by tillage for four sites across Iowa. Values are an average of compaction indexes to a depth of 12 inches. Treatments with the same letter are not significantly different.
Infiltration

Raindrop impact on bare soil can cause compaction and formation of a surface seal that reduces water infiltration rates. An increased amount of residue on the soil surface has been shown to reduce the effects of raindrop impact, maintaining soil structure and a higher infiltration rate (Gilley et al., 1986). Direct compaction caused by field traffic also leads to a loss of soil structure resulting in decreased infiltration rates. It is expected that reduced tillage practices will result in higher infiltration rates both by decreasing compaction from field traffic and increasing the amount of residue left on the soil surface (Hanna and Al-Kaisi, 2009). Statewide infiltration rates by tillage treatment are shown in Figure 8.

No-tillage plots have a significantly higher infiltration rate than conventionally tilled and conservation tillage plots. The no-tillage average infiltration rate is the highest at 0.067 inches/min, followed by conservation tillage at 0.045 inches/min, and conventionally tilled plots have the lowest average at 0.044 inches/min. The results show the highest infiltration rates are in no-tillage plots, as expected.

![Infiltration Rate - Statewide Average](image)

Figure 8. Statewide average infiltration rate by tillage practice. Treatments with the same letter are not significantly different.
Aggregate Stability

The amount of soil organic matter and availability of nutrients for plant growth are both closely related to soil aggregate formation and stability. Soil disturbances, such as conventional tillage practices, cause macroaggregates to break down and ultimately may result in a loss of soil organic matter. Past studies have shown a preferential accumulation of C and N in macroaggregates and later formation of microaggregates. Thus, destruction of macroaggregates due to tillage leads to slower microaggregate formation and overall loss of organic matter (Hussain et al., 1999; Six et al., 1999). Aggregate stability data for four sites across Iowa are shown in Figure 9.

The percent of stable aggregates for each site are displayed by tillage and are split into 4 mm and 2 mm sizes, highlighting the changes in macroaggregates due to tillage. The amount of 4 mm aggregates is greatest in no-till plots for all four sites; conventional tillage ranges from 32-72% lower than no-tillage. Strip tillage is 13% lower than no-tillage at the 4 mm size for north central site 1. Aggregates at the 2 mm size are generally higher in no-till compared to conventional tillage; conventional tillage ranges from 19-33% lower than no-tillage for three of the sites shown. The first north central site has about 60% more 2 mm aggregates in conventional tillage than in no-tillage, while conservation tillage is about 52% higher than no-tillage. This lower amount of 2 mm aggregates in no-till at this site may be due to the large proportion of aggregates at the 4 mm size, resulting in fewer aggregates of smaller sizes. This data shows a clear relationship between tillage treatment and the presence of stable macroaggregates. No-tillage maintains the highest percent of aggregates, especially at the 4 mm size, while any disturbance due to conservation or conventional tillage reduces the amount of macroaggregates.
Figure 9. Soil aggregate stability of 4 mm and 2 mm sizes for four sites across Iowa; aggregates sizes are compared between tillage practices for 2007. Percentage differences in aggregates by tillage treatment were calculated using the aggregate content from no-tillage as a baseline.

Summary of Statewide Agronomic and Soil Quality Indicators Trends

Corn Yield

- No-till corn yield for all 4 regions ranged from 84-97% of conventional yields.
- Loss of yield in no-till is more pronounced in certain regions (Region 1), but also depends on specific site conditions.
- The five year trend shows little difference in corn yield between conservation and no-till for any region, while conservation tillage is slightly higher than conventional tillage for Region 2 and Region 3.
Soybean Yield

- Soybean yields show less differences compared to corn between no-tillage and conventional tillage, with no-tillage yields of 92-105% of conventional tillage.

- There is little difference in soybean yield between conservation and no-tillage for any region, while conservation tillage is slightly higher than conventional tillage for Region 2 and Region 3.

Yield and Crop Rotation

- The results show that a comparison between rotations within the same site and same year are necessary to draw any conclusions about yield results due to rotation. A clear trend for understanding the effect of crop rotation on agronomic performance is not available because of a lack of consistent crop rotations at each site for a long-term comparison within each region.

- The results show that yield differences between years cannot be clearly linked to rotation, but are likely due to a combination of factors, including: precipitation, soil water holding capacity, temperature, planting date, seed hybrid, and yearly variability.

Residue Cover

- No-tillage results in at least 20% more surface residue than conservation or conventional tillage whether corn or soybean residue is present.

- The presence of soybean residue amplifies this difference, with no-till having about 30% more residue than conventional tillage.

Organic Matter and Aggregate Stability

- There is no clear difference in soil organic matter due to tillage practice for any of the 4 regions, as is expected for a study of five years or less.

- The findings of this study show that changes in soil organic matter are very insignificant in the short-term. Also, the results show that there is high spatial and temporal variability due to a large scale grid used in measuring soil organic carbon.
• Aggregate stability of macroaggregates is higher in no-tillage or reduced tillage for the 4 sites observed. Higher aggregate content indicates a more stable environment for organic matter accumulation and could result in a long-term increase in soil organic matter.

**Soil Compaction**

• There is no clear difference in soil compaction due to tillage treatment for any of the four regions. The assumption that conventional tillage is more effective at reducing surface compaction than no-tillage is not supported by these results.

**Water Infiltration**

• No-till plots have a higher infiltration rate than conventionally tilled plots due to a higher amount of residue and lower compaction levels. Infiltration rates for conservation tillage and conventional tillage are not significantly different.

• Results indicate that soil surface disturbance with conventional or conservation tillage can contribute to reduction of infiltration rate due to destruction of soil surface aggregates and potential surface sealing.

**Potential Implication of Agronomic and Soil Quality Changes**

• No-tillage and reduced tillage offer benefits in the form of erosion control and improved soil quality, including: reduced soil compaction, higher water retention and flood control, increased surface residue, and stability of soil organic matter.

• Adoption of no-tillage in soybeans is recommended for all regions of Iowa; no-tillage in corn is recommended for well-drained soils.

• Conservation tillage yields are competitive with no-tillage and conventional tillage for both corn and soybeans. Adoption of reduced tillage practices is recommended when no-tillage is not practical.
Regional Trends or Changes in Agronomic and Soil Quality Indicators

Region 1 – Northwest Iowa Plains

Region 1 consists of the northwestern portion of the state, or the landscape region known as the Northwest Iowa Plains. This is a gently rolling landform with well developed stream systems, resulting in generally well drained soils. The entire region is underlain by a deposit of pre-Illinoian glacial till, which is exposed at the surface in some areas of the western part of the region. The eastern part of the region was later covered by Wisconsinan age glacial till; this was part of a glacial advance occurring prior to advances that resulted in formation of the Des Moines Lobe. Loess was later deposited across the entire region, covering the older pre-Illinoian and Wisconsinan glacial tills and smoothing the surface as loess filled in valleys. Loess deposits are nearly continuous across the region, with the thickest deposits in the southwest and thinning to the northeast. Precipitation across the state decreases from southeast to northwest, resulting in the driest conditions being found in the Northwest Iowa Plains. Mean annual precipitation amounts for this region are less than 25 inches (Prior, 1991).

Trend of Agronomic Indicators

Yield

Yields were recorded yearly for a corn-soybean rotation in Region 1 (Figure 10). There is little difference in soybean yields, but corn yields vary over time and between tillage treatments. The average soybean yield for conventionally tilled plots is significantly higher than no-tillage yield in 2006, but there is no significant difference in 2008. Average corn yield is
significantly higher in conventional plots compared to no-tillage plots for both 2007 and 2009, amounting to a yield advantage of about 30 bu/acre in conventionally tilled corn.

Soybean yields are expected to be about the same between tillage practices, although poorly drained soils under no-till are more likely to see a yield loss than well-drained soils (Yin and Al-Kaisi, 2004). The poorly drained soils of this site explain why soybean yields of no-till plots are lower than conventional in 2006 and 2008, although this is more pronounced in 2006. The lower no-till corn yield in 2007 and 2009 is consistent with past studies conducted in northwest Iowa. Al-Kaisi and Yin (2004) also found significantly lower corn yields in no-tillage compared to conventionally tilled plots in a similar corn-soybean rotation. Reduced corn yield for no-tillage is most pronounced in poorly drained soils, areas with a cooler growing season, and a continuous corn rotation (Al-Kaisi and Yin, 2004). The increase in corn yield between 2007 and 2009 can be explained by changes in weather conditions between years, but also by planting date and corn stalk nitrate values. Planting was earlier in 2009 (April 23) compared to 2007 (May 2); an earlier planting date could increase corn yields. Also, fall corn stalk nitrate values indicate that nitrogen availability in 2007 could have limited yield. Stalk nitrate values were in the marginal range for 2007 at an average of about 600 ppm, while 2009 values were in the excessive range with an average of 2200 ppm.

Figure 10. Corn and soybean yields by tillage practice for site 1 located in Region 1. Treatments with the same letter are not significantly different.
Residue Cover

The amount of residue cover for no-till and conventional till plots for Region 1 are presented in Figure 11. Residue values for no-tillage plots are significantly higher for all four years of observation, ranging from 71-85% in no-till plots, while conventional till plots range from 25-50%. The amount of residue for no-till plots is at least 30% higher than conventional plots for all years. There appears to be little difference in residue cover in no-till plots due to alternating residue of corn and soybeans. However, residue cover in conventionally tilled plots is clearly lower in years when soybean residue is present, with values at least 10% less than years when corn residue is present.

![Surface Residue - Region 1](image)

Figure 11. Percentage of surface residue by tillage practice observed at site 1 in Region 1. The type of residue left on the field from the previous crop is listed for each year. Treatments with the same letter are not significantly different.

Fall Stalk Nitrate

The fall corn stalk nitrate level is a useful indicator of the nitrogen availability to corn plants. An inadequate amount of N will result in a low fall stalk nitrate value, as the plant removes N from the stalk and other parts of the plants for grain filling near the end of the season. However, a high concentration of nitrate in the stalk may translate to an excess amount of N in the soil, indicating luxury N use by the plant. In this case, a lower amount of fertilizer can be...
used to attain optimal yields in the future. The concentration of fall corn stalk nitrate (NO$_3$-N) was measured for all plots in Region 1 for years in which corn was grown. The reported corn yield is shown as a function of the fall stalk nitrate concentration in Figure 12. Stalk nitrate concentration category is indicated in Figure 12 by dashed lines. Low or marginal stalk nitrate values are generally associated with lower corn yields, indicating a limitation in corn growth due to low nitrogen availability. High corn yields are generally associated with high stalk nitrate values, but yields level off as the nitrate level reaches the excessive range. The stalk nitrate test is a valuable tool for adjusting fertilization rates according to nitrate and yield levels. Producers may be able to save money on fertilizer application by reducing rates on fields in the excessive range (>2000 ppm), while still maintaining high yields. Also, nitrate values in the low or optimal range indicate that an increased application of fertilizer could result in higher yields (Blackmer and Mallarino, 1996).

![Figure 12. Corn yields as a function of fall stalk nitrate values for all measured sites in Region 1. Dashed lines indicate stalk nitrate category: L= Low (<250), M = Marginal (250-700), O = Optimal (700-2000), and E = Excess (>2000).](image-url)

The equation for the fitted line is $y = 142.33x^{0.0362}$ with $R^2 = 0.1744$.
Soil Quality Parameters

Organic Matter

Soil organic matter percentages for different tillage systems for Region 1 are presented in Figure 13. Organic matter percentage for no-tillage plots range from 6.54-7.09%, while conventionally tilled plots range from 6.51-7.15%. There is no significant difference in soil organic matter due to tillage for any of the four years. The organic matter percentage for both tillage practices changes slightly between years, but the values remain relatively constant at about 6.5-7.0%. Long-term implementation of conservation tillage practices is expected to increase soil organic carbon, resulting in a higher organic matter content. Past studies report a small increase or no change in the first 2-5 years of conservation tillage, while a greater increase occurs between 5-10 years (Franzluebbers and Arshad, 1996; Al-Kaisi et al., 2005). The data for Region 1 supports the idea that a change in tillage practice results in little or no change in organic matter for the first 5 years. A significant difference between tillage treatments would most likely be observed if this study was continued for several more years, allowing organic matter to accumulate in no-till plots, especially in rich organic matter soils.

Figure 13. Soil organic matter percent by tillage practice observed at site 1 in Region 1. Treatments with the same letter are not significantly different.
**Bulk Density**

Soil bulk density values for Region 1 are shown in Figure 14. No-till bulk density values range from 1.12-1.42 g/cm³, while conventionally tilled plots range from 1.08-1.41 g/cm³. There is some difference in bulk density between years, but there is no significant difference observed in bulk density between tillage treatments within each year. The lack of significant differences in bulk density between tillage practices is consistent with past studies. Hussain et al. (1998) also found no significant difference between no-till and conventional tillage after 8 years at a site in southern Illinois. The differences in bulk density values between years can be attributed to spatial variability, soil moisture content, time of year, and repeatability of sampling location.

![Bulk Density - Region 1](image)

Figure 14. Soil bulk density by tillage practice observed at site 1 in Region 1. Treatments with the same letter are not significantly different.

**Soil Compaction**

Compaction index values by tillage practice in Region 1 are presented for 2007 and 2009 (Figure 15). Compaction values for 2007 are higher in conventionally tilled plots for almost all depths, except for the 9-12 inch depth where no-till and conventionally tilled values are almost the same. The compaction values for 2009 are similar to 2007, but the no-till and conventionally tilled values are closer to one another near the soil surface. Conventionally tilled plots have a
lower compaction value than no-till from 3 to 9 inches, but consistently have a higher compaction value below a depth of 9 inches. Compaction index values for the no-tillage plots appear to decrease slightly in the top few inches over the two year period observed. A slight decrease in the top 9 inches of conventionally tilled plots may indicate a temporary reduction in compaction due to tillage, but the compacted layer is pushed deeper in the soil profile over the two year period. Reduced tillage practices are expected to result in lower compaction levels over time, as traffic on the field is reduced and soil pores and structure are allowed to form (Varsa et al., 1997, Hanna and Al-Kaisi, 2009).

Figure 15. Compaction index by tillage practice to a depth of 24 inches. Observations from 2007 and 2009, including site 1 in Region 1.
Soil pH

Soil pH values for Region 1 are shown in Figure 16. The pH values between tillage practices are not significantly different for any of the years shown. No-tillage pH values range from 5.5-6.5, while conventionally tilled values range from 5.6-6.4. These results are consistent with the study by Hussain et al. (1999) in which pH was still not significantly different between no-tillage and conventional tillage after eight years. The results also show that pH variability across years was not significant. This reflects the nature of pH as a chemical indicator, indicating that any change in pH is a long-term process. Chemical changes are especially slow in high organic matter soils due to the high buffer capacity of such soils.

![Soil pH - Region 1](image)

Figure 16. Soil pH by tillage practice for site 1 in Region 1. Treatments with the same letter are not significantly different.
Microbial Biomass Carbon

Microbial biomass carbon values by year for Region 1 are shown in Figure 17. Microbial biomass carbon is a biological indicator that measures the health of soil and the effect of tillage and cropping systems on the soil environment. No-tillage average microbial biomass carbon values range from 239-300 µg C/g soil, while conventionally tilled values range from 236-258 µg C/g soil. There is no significant difference in microbial biomass carbon between tillage treatments for any of the three years shown. No-tillage soils are expected to have a significantly higher microbial biomass carbon than conventionally tilled soils over time, but only in the top three inches (Doran, 1987). The results shown in Figure 17 are to a depth of six inches; a clear increase in no-till microbial biomass may be more apparent if a three inch sample had been tested. Also, microbial biomass carbon is a long-term indicator and the change can be very slow with changing tillage or cropping systems.

Figure 17. Microbial biomass carbon by tillage practice for site 1 in Region 1. Treatments with the same letter are not significantly different.
Infiltration Rate

Infiltration rates for Region 1 are shown in Figure 18. The average infiltration rate for no-tillage plots is at least 0.02 inches/hour higher than conventionally tilled plots for all three years; conventional tillage infiltration rates range from 26-46% lower than no-tillage rates. Infiltration rates are sensitive to changes in tillage and cropping systems as it depends on stability of soil structure. It is known that conventionally tilled fields are susceptible to compaction and reduction of infiltration due to loss of macropores (Ankeny et al., 1990; Ankeny et al. 1995). The results of this study support the idea that infiltration rates will decrease in conventionally tilled plots.

Figure 18. Average infiltration rate by tillage practice for site 1 in Region 1. Percentage differences in infiltration rate by tillage treatment were calculated using the infiltration rate from no-tillage as a baseline.
Summary of Agronomic and Soil Quality Trends for Region 1:

- No-till results in a 14-19% decrease in corn yield compared to conventional tillage.

- Almost a 10% decrease is observed in soybean yield in no-tillage compared to conventional tillage; this is only a loss of 4-6 bu/acre. However, this is higher than what was reported by other studies.

- Surface residue for no-till is at least 30% higher than conventional tillage whether corn or soybean residue is present.

- Soil organic matter content, bulk density, pH, and microbial biomass carbon are not significantly affected by tillage over a period of five years or less.

- Compaction levels generally decrease in no-till plots over time; tilled soils remain constant at the surface but increase at depth as the compacted layer is pushed deeper.

- Infiltration rates are 26-46% lower in conventionally tilled plots when compared with no-tillage.
Region 2 – Des Moines Lobe

Region 2 encompasses the north-central area of the state, or the landscape region known as the Des Moines Lobe. The most recent episode of glaciation occurred in this area, leaving deposits of Wisconsinan age glacial till that have remained relatively undisturbed by erosion over time. Glacial till remains at the surface in this area of the state; older glacial till and loess deposits were buried by the Wisconsinan glacial advance. This region is generally flat and poorly drained due to the uniform deposition of glacial till. However, local variability in glacial deposits resulted in microtopography, allowing for the formation of wetlands and lakes in lower elevations. Poor drainage conditions and slow decay of organic matter has resulted in dark, organic rich soils in this region (Prior, 1991).

Agronomic Parameters

Yield

Yields were recorded yearly for corn-soybean and corn-corn-soybean rotations in Region 2 (Figure 19). There is no significant difference in corn yield between no-till and conservation tillage plots for 2005. In 2006, a significant difference in soybean yields is observed between all tillage practices. In 2007, average corn yields for conservation and conventional tillage are both significantly higher than no-till, although there is no significant difference between the two tilled treatments. In 2008, no significant difference in corn yields is observed. In 2009, conservation and conventional tillage soybean yields are both significantly higher than that of no-tillage; there is no difference between the tilled treatments.

Soybean yields are expected to be about the same between tillage practices, although poorly drained soils under no-till are more likely to see a yield loss than well drained soils (Yin and Al-Kaisi, 2004). The poorly drained soils of this site explain why soybean yields of no-till
plots are lower than conventional or conservation tillage in 2006 and 2009. The lower no-till corn yield in 2005 and 2007 is consistent with past studies conducted on a similar site in north-central Iowa (Licht and Al-Kaisi, 2005). However, Licht and Al-Kaisi found no significant advantage in corn yield of conservation tillage over no-tillage, as is shown for 2007.

Reduced corn yield for no-tillage is most pronounced in poorly drained soils, areas with a cooler growing season, and a continuous corn rotation (Al-Kaisi and Yin, 2004). Generally, a decrease in corn yield is observed for all tillage practices for second year corn in a corn-corn-soybean rotation (Al-Kaisi and Yin, 2004; Al-Kaisi and Oneal, 2010). The increase of all corn yields in 2008, and no-till having the highest yield are not consistent with past studies. However, changes in yield between years are not only due to rotation, but can be explained by a variety of environmental factors. Statewide corn yields in 2008 were one of the highest in Iowa’s history, explaining why an increase in yield for continuous corn is observed. Although a cool and wet spring resulted in slow planting and growth, late silking in corn and ideal late season weather conditions resulted in high corn yields for 2008 (Elmore and Abendroth, 2008).

Figure 19. Corn and soybean yields by tillage practice for site 1 located in Region 2. Treatments with the same letter are not significantly different.
Residue Cover

Residue cover observed for Region 2 is presented in Figure 20. Residue values for no-tillage plots range from 65-89%, conservation tillage values range from 17-70%, and conventional tillage ranges from 15-65%, respectively for both corn and soybean residues and across all years. There is no significant difference in residue between no-tillage and conservation tillage for 2005. However, no-tillage is significantly higher than both conservation and conventional tillage for 2006-2009. The no-tillage residue value is at least 20% higher than that of conventionally tilled plots for all years where corn residue is present and as much as 55% higher when soybean residue is present. No-tillage values are at least 15% higher than conservation tillage between 2006 and 2009 when corn residue is present, and as much as 50% higher when soybean residue is present. These results indicate that no-tillage maintains a high level of surface residue regardless of which crop was grown the year before, while conservation and conventional tillage plots are consistently lower and more variable due to mixing of residue into the soil. These differences in residue cover will have an implication on controlling soil erosion and type of tillage that should be used, especially with fragile residue such as soybean.

Figure 20. Percentage of surface residue by tillage practice observed at site 1 in Region 2. The type of residue left on the field from the previous crop is listed for each year. Treatments with the same letter are not significantly different.
**Fall Stalk Nitrate**

The fall corn stalk nitrate level is a useful indicator of the nitrogen availability to corn plants. An inadequate amount of N will result in a low fall stalk nitrate value, as the plant removes N from the stalk and other parts of the plants for grain filling near the end of the season. However, a high concentration of nitrate in the stalk may translate to an excess amount of N in the soil, indicating luxury N use by the plant. The concentration of fall corn stalk nitrate (NO$_3$-N) was measured for all plots in Region 2 for years in which corn was grown. The reported corn yield is shown as a function of the fall stalk nitrate concentration in Figure 21. Stalk nitrate concentration category is indicated in Figure 21 by dashed lines. Low or marginal stalk nitrate values are generally associated with lower corn yields, indicating a limitation in corn growth due to low nitrogen availability. High corn yields are generally associated with high stalk nitrate values, but yields level off as the nitrate level reaches the excessive range (>2000 ppm). The stalk nitrate test is a valuable tool for adjusting fertilization rates according to nitrate and yield levels. Producers may be able to save money on fertilizer application by reducing rates on fields in the excessive range (>2000 ppm), while still maintaining high yields. Also, nitrate values in the low or optimal range indicate that an increased application of fertilizer could result in higher yields (Blackmer and Mallarino, 1996).

![Corn Yield as a Function of Fall Stalk Nitrate - Region 2](image)

Figure 21. Corn yields as a function of fall stalk nitrate values for all measured sites in Region 2. Dashed lines indicate stalk nitrate category: L = Low (<250), M = Marginal (250-700), O = Optimal (700-2000), and E = Excess (>2000).
Soil Quality Parameters

Organic Matter

Soil organic matter percentages for different tillage systems for Region 2 are presented in Figure 22. Organic matter for no-tillage plots ranges from 5.19-5.52%, conservation tillage ranges from 5.41-6.23%, and conventional ranges from 5.66-6.37%. There is no significant difference in organic matter values between any of the tillage practices, except in 2008 where conservation tillage is significantly higher than no-tillage and conventional tillage, which can be attributed to sampling variability. There is some variation in organic matter both between tillage practices and between years. These differences may be explained by the highly variable soil conditions and microtopography of the Des Moines Lobe region. Poorly drained conditions in depressions and presence of carbonates leads to irregular breakdown of humus into organic matter, and could explain the variability within each plot (Cambardella et al., 1994; Schaetzl and Anderson, 2005). Long-term implementation of conservation tillage practices is expected to increase soil organic carbon, resulting in a higher organic matter content. Past studies report a small increase or no change in the first 2-5 years of conservation tillage, while a greater increase occurs between 5-10 years (Franzluebbers and Arshad, 1996; Al-Kaisi et al., 2005). The data for Region 2 supports the idea that a change in tillage practice results in little or no change in organic matter for the first 5 years. A significant difference between tillage treatments would most likely be observed if this study was continued for several more years, allowing organic matter to accumulate in no-till plots.
Figure 22. Soil organic matter percent by tillage practice observed at site 1 in Region 2. Treatments with the same letter are not significantly different.

**Bulk Density**

Soil bulk density values are shown for Region 2 in Figure 23. There is no significant difference in bulk density between tillage practices for any of the five years. Bulk density values remain constant at about 1.2 g/cm$^3$ for all years, except for 2006 where all tillage practices have a value of around 0.9 g/cm$^3$. This lower value in 2006 is most likely due to a difference in sampling technique for that year as opposed to an actual decrease in bulk density. The lack of significant differences in bulk density between tillage practices is consistent with past studies. Hussain et al. (1998) also found no significant difference between no-till and conventional tillage after 8 years at a site in southern Illinois.
Figure 23. Soil bulk density by tillage practice observed at site 1 in Region 2. Treatments with the same letter are not significantly different.

**Soil Compaction**

Compaction index values by tillage practice in Region 2 are presented for 2007 and 2009 (Figure 24). Conventionally tilled plots have a lower compaction value at all depths compared to no-tillage for 2007. Compaction values near the surface are similar between no-tillage and conventional tillage for 2009, but no-tillage values are slightly higher than conventional tillage to a depth of 10 inches. No-tillage plots consistently have a lower compaction value at lower depths than conventional tillage in 2009. These results indicate a decrease in compaction levels near the surface for no-tillage, while conventional plots remain the same. The compaction index for conventional plots greatly increases below a depth of 6 inches over the two year period, while no-tillage values decrease. The low compaction values in the top 6 inches of conventionally tilled plots is most likely due to increased porosity from tillage, but the index values at depth increase because the compacted layer is pushed deeper in the soil profile over the two year period. Reduced tillage practices are expected to result in lower compaction levels over time as traffic on the field is reduced and soil pores and structure are allowed to form (Varsa et al., 1997; Hanna and Al-Kaisi, 2009).
Figure 24. Compaction index by tillage practice to a depth of 24 inches. Observations from 2007 and 2009, including site 1 in Region 2.
Soil pH

Soil pH values for Region 2 are shown in Figure 25. No-tillage pH values range from 5.3-6.9, conservation values range from 5.5-6.3, and conventionally tilled plots range from 4.8-5.9. No-tillage and conservation tillage pH is significantly higher than conventional till between 2006 and 2008, but all treatments are significantly different from one another in 2009. There is no significant difference between no-till and conservation till for 2005. The variation in pH values for conservation tillage and conventional tillage could be explained by the spatial variability within the plots, and the uniformity of N fertilizer application and other amendments (Cambardella et al., 1994, Hussain et al., 1999). The pH of no-till plots appears to decrease steadily over the 5 year period. This decrease is most likely a result of nitrification of N fertilizers, accumulation of fertilizer on the soil surface, and mineralization of plant residue (Blevins et al., 1983; Dick 1983)

Figure 25. Soil pH by tillage practice for site 1 in Region 2. Treatments with the same letter are not significantly different.
Microbial Biomass Carbon

Microbial biomass carbon values by year for Region 2 are shown in Figure 26. Microbial biomass carbon is a biological indicator that measures the health of soil and the effect of tillage and cropping systems on the soil environment. No-tillage average microbial biomass carbon values range from 178-229 µg C/g soil, conservation tillage ranges from 286-311 µg C/g soil, while conventionally tilled values range from 205-262 µg C/g soil. Conservation tillage is significantly higher than both other treatments for 2007 and 2008 while there is no difference between no-till and conventional tillage plots. No-tillage soils are expected to have a significantly higher microbial biomass carbon content than conventionally tilled soils over time, but only in the top three inches. The results shown in Figure 26 are to a depth of six inches; a clear increase in no-till microbial biomass carbon may be more apparent if a three inch sample was tested. It is unclear why microbial biomass of conservation tillage plots are higher than no-tillage, although this could be due to a combination of favorable conditions for microbial activity including soil C and N, water content at depth, and distribution of residue on the soil surface (Doran 1987).

Figure 26. Microbial biomass by tillage practice for site 1 in Region 2. Treatments with the same letter are not significantly different.
Infiltration rates for Region 2 are shown in Figure 27. A high amount of variability in infiltration measurements is observed due to spatial variability and variations in sampling techniques. However, no-tillage infiltration rates are consistently higher than conventional tillage and conservation tillage. No-tillage values are at least 0.02 inches/hour higher than other treatments for all four years. Conventional tillage infiltration ranges from 57-84% lower than no-tillage while conservation tillage infiltration ranges from 25-60% lower. Infiltration rates are sensitive to changes in tillage and cropping systems as it depends on stability of soil structure. It is well known that conventionally tilled fields are susceptible to compaction and reduction of infiltration due to loss of macropores (Ankeny et al., 1990; Ankeny et al. 1995). The results of this study support the idea that infiltration rates will decrease in conventionally tilled plots.

Figure 27. Average infiltration rate by tillage practice for site 1 in Region 2. Percentage differences in infiltration rate by tillage treatment were calculated using the infiltration rate from no-tillage as a baseline.
Summary of Agronomic and Soil Quality Trends for Region 2:

- No-till corn yield is 6-10% lower than conventional and conservation tillage, except in 2007 where no-till is 4% higher than either. Conservation tillage corn yield is 1-2% higher than conventional.

- No-till soybean yield is 8-15% lower than conventional till and 10-19% lower than conservation tillage. Conservation tillage is 1-4% higher than conventional tillage.

- Surface residue for no-till is at least 20% higher than conventional tillage for all years, and as much as 55% higher when soybean residue is present. Residue for conservation tillage is generally higher than conventional tillage and lower than no-tillage, but varies by year.

- Surface compaction decreases with 2 years of no-till. Conventionally tilled soils remain constant at the surface but increase at depth as the compacted layer is pushed deeper.

- Soil pH steadily decreases in no-till plots due to mineralization and nitrification of fertilizers at the surface. Conservation and conventional pH values are unpredictable because of the spatial variability of carbonates and N application.

- Soil organic matter and bulk density are not significantly affected by tillage over a period of five years or less.

- Microbial biomass carbon for conservation tillage is significantly higher than conventional and no-till in 2008, and higher than no-till in 2007. The amount of C and N, mixing of residue, and the moisture content in the soil are all responsible for the higher microbial biomass carbon value.

- Differences in infiltration rate are highly variable for all tillage practices, but no-tillage is consistently higher than conservation and conventional tillage for all years. Infiltration rates are 57-84% lower in conventionally tilled plots when compared with no-tillage; infiltration is 25-60% lower in conservation tillage plots when compared to no-tillage.
Region 3 consists of the northeastern part of the state, or the landscape region known as the Northeast Iowan Region. This landscape is characterized by slight inclines and rolling hills. Well developed stream systems allow for well drained soils throughout much of the region, although scattered areas of wetlands and poorly drained soils do occur. This region was last covered by glaciers over half a million years ago during the pre-Illinoian advance. The pre-Illinoian glacial till remained exposed to weathering for hundreds of thousands of years resulting in widespread erosion and formation of stream systems. Loess was deposited in this region prior to the formation of the Des Moines Lobe, although current layers of loess are thin and inconsistent due to accelerated erosion during the Wisconsinan glaciations. The eastern portion of this region, known as the Paleozoic Plateau, was never completely covered by glaciers although patches of pre-Illinoian till are found in some areas. Thin soils of glacial till and highly weathered loess and shallow contact with bedrock characterize this landscape (Prior, 1991). The results for Region 3 will focus on the western portion of the Northeast Region, considering that no ILF cooperator sites were located on the Paleozoic Plateau.

Agronomic Parameters

Yield

Yields were recorded yearly for a corn-corn-soybean rotation in Region 3 (Figure 28). There is no significant difference in corn or soybean yields between conservation tillage, conventional tillage, or conventional tillage with manure for any of the four years shown. A statistical comparison is unavailable for 2006 due to the lack of multiple data points.

A significant decrease in soybean yield due to reduced tillage is not expected in this area due to the well drained soils of northeast Iowa (Yin and Al-Kaisi, 2004). The lack of significant differences in corn yields between conservation and conventional tillage for 2005, 2006, and 2008 are consistent with the results of a past study conducted in northeast Iowa (Licht and Al-
Kaisi, 2005). Generally, a decrease in corn yield is observed for all tillage practices for second year corn in a corn-corn-soybean rotation (Al-Kaisi and Yin, 2004; Al-Kaisi and Oneal, 2010). This decrease in yield is observed for all treatments in the second year of corn in 2006. However, the decreased corn yield in 2006 may also be a result of different weather conditions between years.

Figure 28. Corn and soybean yields by tillage practice for site 1 located in Region 3. An asterisk (*) indicates too few data points to make a statistical comparison. Treatments with the same letter are not significantly different.

Residue Cover

Residue cover observed for Region 3 is presented in Figure 29. Residue values for conservation tillage plots range from 38-73%, conventional tillage values range from 26-63%, and conventional tillage with manure ranges from 27-63% for corn and soybean across all years. Surface residue on conservation tillage plots is significantly higher than conventional tillage in 2005, but conventional tillage with manure is not significantly different from other treatments. The amount of conservation tillage residue is significantly higher than conventional and conventional tillage with manure in 2006, while conventional tillage with manure is significantly higher than conventional tillage. There is no significant difference in residue cover between any of the treatments for 2007. Conservation tillage residue is significantly higher than conventional
tillage or conventional tillage with manure in 2008 and 2009, while there is no difference between the conventional tillage treatments.

Corn residue for conservation tillage is at least 15% higher than conventionally tilled plots for all years except 2007, when conservation is about 10% lower than conventional treatments. Conservation residue values for corn are highest in all years except for 2007, indicating that tillage may not have as much of an influence on residue cover when corn is present for multiple years. Soybean residue levels for conservation tillage are consistently higher than conventionally tilled plots, but are much more variable than the results for corn residue.

![Surface Residue - Region 3](image)

Figure 29. Percentage of surface residue by tillage practice observed at site 1 in Region 3. The type of residue left on the field from the previous crop is listed for each year. Treatments with the same letter are not significantly different.

**Fall Stalk Nitrate**

The fall corn stalk nitrate level is a useful indicator of the nitrogen availability to corn plants. An inadequate amount of N will result in a low fall stalk nitrate value, as the plant removes N from the stalk and other parts of the plants for grain filling near the end of the season. However, a high concentration of nitrate in the stalk may translate to an excess amount of N in the soil, indicating luxury N use by the plant. The concentration of fall corn stalk nitrate (NO₃-
N) was measured for all plots in Region 3 for years in which corn was grown. The reported corn yield is shown as a function of the fall stalk nitrate concentration in Figure 30. Stalk nitrate concentration category is indicated in Figure 30 by dashed lines. Low or marginal stalk nitrate values are generally associated with lower corn yields, indicating a limitation in corn growth due to low nitrogen availability. High corn yields are generally associated with high stalk nitrate values, but yields level off as the nitrate level reaches the excessive range (>2000 ppm). The stalk nitrate test is a valuable tool for adjusting fertilization rates according to nitrate and yield levels. Producers may be able to save money on fertilizer application by reducing rates on fields in the excessive range (>2000 ppm), while still maintaining high yields. Also, nitrate values in the low or optimal range indicate that an increased application of fertilizer could result in higher yields (Blackmer and Mallarino, 1996).

Figure 30. Corn yields as a function of fall stalk nitrate values for all measured sites in Region 3. Dashed lines indicate stalk nitrate category: L = Low (<250), M = Marginal (250-700), O = Optimal (700-2000), and E = Excess (>2000).
Soil Parameters

Organic Matter

Soil organic matter percentages for different tillage systems for Region 3 are presented in Figure 31. Organic matter for no-tillage plots ranges from 4.01-4.52%, while conventional tillage ranges from 4.04-4.26%. There is no significant difference in organic matter values between tillage practices for any of the four years. There is a slight variation in organic matter both between tillage practices and between years, but the results remain between about 4.0-4.5%. Long-term implementation of conservation tillage practices is expected to increase soil organic carbon, resulting in a higher organic matter content. Past studies report a small increase or no change in the first 2-5 years of conservation tillage, while a greater increase occurs between 5-10 years (Franzluebbers and Arshad, 1996; Al-Kaisi et al., 2005). The data for Region 3 supports the idea that a change in tillage practice results in little or no change in organic matter for the first 5 years. A significant difference between tillage treatments would most likely be observed if this study was continued for several more years, allowing organic matter to accumulate in no-till plots.

Figure 31. Average soil organic matter percent by tillage practice for sites 2 and 3 in Region 3. Treatments with the same letter are not significantly different.
**Bulk Density**

Soil bulk density values for Region 3 are shown in Figure 32. Conservation tillage values range from 1.25-1.59 g/cm³, conventional tillage ranges from 1.05-1.46 g/cm³, and conventionally tilled plots with manure applied range from 1.31-1.42 g/cm³. Bulk density for conventional tillage is significantly lower than conservation tillage for 2006 and conventional with manure is significantly lower than conservation tillage in 2008, otherwise there are no other significant differences for any other years. The values for all tillage practices are fairly consistent around 1.4 g/cm³ except for a few outlier values, indicating that there is no trend in bulk density due to tillage system. The lack of a clear difference in bulk density between tillage practices is consistent with past studies. Hussain et al. (1998) also found no significant difference between tillage practices after 8 years at a site in southern Illinois.

![Bulk Density - Region 3](image)

Figure 32. Soil bulk density by tillage practice observed at site 1 in Region 3. Treatments with the same letter are not significantly different.

**Soil Compaction**

Compaction index values by tillage practice in Region 3 are presented for 2006 and 2009 (Figure 33). Compaction values for no-tillage plots in 2006 are higher than conventional tillage for the top 7 inches, but no-tillage is lower than conventional tillage at all other depths. The compaction curves for 2009 are more similar between tillage practices, although no-tillage
remains at a higher compaction value for the top 15 inches. No-tillage compaction index values are only lower than conventional tillage between depths of 20-24 inches. These results indicate a decrease in compaction levels near the surface for no-tillage while conventional plots remain the same in the top few inches and decreases from about 3 to 15 inches. The low compaction values in the top 15 inches of conventionally tilled plots is most likely due to increased porosity from fresh tillage, but the index values at lower depth remain high because the compacted layer is pushed deeper in the soil profile over the three year period. Reduced tillage practices are expected to result in lower compaction levels over time as traffic on the field is reduced and soil pores and structure are allowed to form (Varsa et al., 1997, Hanna and Al-Kaisi, 2009).

Figure 33. Compaction index by tillage practice to a depth of 24 inches. Observations from 2006 and 2009, including site 3 in Region 3.
 Soil pH

Soil pH values for Region 3 are shown in Figure 34. There is no significant difference in pH between treatments for any of the five years. The pH of conservation tillage plots ranges from 6.1-6.4, conventionally tilled plots range from 6.0-6.8, and conventional tillage with manure application ranges from 6.0-6.8. There is some variation in soil pH between years, but these changes are observed for all tillage practices. These results are consistent with the study by Hussain et al. (1999) in which pH was still not significantly different between no-tillage and conventional tillage after eight years. This reflects the nature of pH as a chemical indicator, indicating that any change in pH is a long-term process. Chemical changes are especially slow in high organic matter soils due to the high buffer capacity of such soils.

Figure 34. Soil pH by tillage practice for site 1 in Region 3. Treatments with the same letter are not significantly different.
Microbial Biomass Carbon

Microbial biomass carbon values by year for Region 3 are shown in Figure 35. Microbial biomass carbon is a biological indicator that measures the health of soil and the effect of tillage and cropping systems on the soil environment. No-tillage average microbial biomass carbon values range from 263-514 µg C/g soil while conventionally tilled values range from 290-394 µg C/g soil. No-tillage is significantly higher than conventional tillage for 2009, but there is no significant difference between treatments in 2007. No-tillage soils are expected to have a significantly higher microbial biomass carbon than conventionally tilled soils over time, but only in the top three inches. The increase in no-tillage microbial biomass carbon over two years is great enough to appear even to a depth of six inches; this increase might be more pronounced at a depth of three inches (Doran 1987).

![Figure 35. Microbial biomass by tillage practice for site 3 in Region 3. Treatments with the same letter are not significantly different.](image)
Infiltration Rate

Infiltration rates for Region 3 are shown in Figure 36. A high amount of variability in infiltration measurements is observed due to spatial variability and variations in sampling techniques. However, no-tillage infiltration rates are consistently higher than conventional tillage rates. No-tillage infiltration values are at least 0.01 inches/hour higher than conventional tillage for all four years, and as much as 0.12 inches/hour higher in 2008. Conventional tillage infiltration rates range from 32-74% lower than no-tillage infiltration rates. Infiltration rates are sensitive to changes in tillage and cropping systems as it depends on stability of soil structure. It is well known that conventionally tilled fields are susceptible to compaction and reduction of infiltration due to loss of macropores (Ankeny et al., 1990; Ankeny et al. 1995). The results of this study support the idea that infiltration rates will decrease in tilled plots.

Figure 36. Average infiltration rate by tillage practice for site 3 in Region 3. Percentage differences in infiltration rate by tillage treatment were calculated using the infiltration rate from no-tillage as a baseline.
Summary of Agronomic and Soil Quality Trends for Region 3:

- No significant difference in corn yield is observed between conservation tillage, conventional tillage, or conventional tillage with manure treatments. All yields drop about 25% in the second year of corn in the corn-corn-soybean rotation.

- Conservation tillage soybean yield is 2% higher than conventional and about 8% higher than conventional with manure. This is a difference of 1-5 bu/acre.

- Surface residue for conservation tillage is at least 15% higher than conventional tillage for all years, except 2007, indicating that tillage may not have as much effect on amount of residue after multiple years of corn.

- Soil organic matter and pH are not significantly affected by tillage over a period of five years or less.

- Changes in bulk density are observed between years and significant differences are present between treatments for 2 out of 5 years. These differences are due to sampling error and soil variability and do not appear to reflect a change due to tillage or manure treatment.

- Surface compaction for no-till decreases slightly over 3 years, but remains relatively constant at lower depths. Compaction of conventional tillage plots remains constant throughout most of the profile, but remains high at lower depths where the compaction layer is pushed deeper.

- Microbial biomass carbon in no-till plots is significantly higher than that of conventional tillage after 2 years. This indicates a possible trend upward, but a longer time period is necessary to determine if this is due to tillage treatment.

- Infiltration rates in no-tillage plots are consistently higher than conventional tillage plots. Conventional tillage infiltration is 32-74% lower than no-till infiltration rates.
Region 4 – Southern Iowa Drift Plain

Region 4 covers approximately the bottom half of the state, or the landscape region known as the Southern Iowa Drift Plain. This region was last glaciated during the pre-Illinoian period and was not disturbed by more recent glacial advances. The landscape of this area is greatly dissected due to uninterrupted erosion and formation of drainage systems after deposition of pre-Illinoian glacial till. The result is a rolling landscape with well drained soils and a greater variation in topography than any other region in the state. Loess was deposited across this region during the Wisconsinan period, although the current loess derived surface reflects the topography of the eroded glacial till buried beneath. Loess depths vary greatly across this region, but the greatest depths are observed near sources of windblown loess such as the Missouri River. The deepest loess deposits are found on the western edge of the state, in the Loess Hills, and depths generally decrease as you move southeast away from the Missouri River. This region offers a wide variety of soils due to the varying depths of loess, exposures of pre-Illinoian glacial till in some areas, and varying levels of erosion due to steep hill slopes. Precipitation also varies greatly in this region because of its large size. The highest amount of annual precipitation at 34 inches per year is observed in the southeast corner of this region. The precipitation rate gradually increases as you move northwest across the state (Prior, 1991).

Agronomic Parameters

Yield

Yields were recorded yearly for a corn-soybean rotation in Region 4 (Figure 37). Corn yield was not significantly different between no-tillage and conservation tillage in 2005 and 2009. However, no-tillage corn yields were significantly higher than conservation tillage in 2007. There is no significant difference in soybean yields between no-tillage and conservation tillage for 2006 or 2008.
Soybean yields are expected to be about the same for all tillage practices under well drained conditions, as reflected by the similar results in yield for 2006 and 2008 (Yin and Al-Kaisi, 2004). Corn yield is significantly higher for no-till in 2007, but there is no difference between conservation and no-till for 2005 or 2009. These corn yield results are consistent with a study conducted by Al-Kaisi and Yin (2004) on a corn-soybean rotation in southeast Iowa.

Figure 37. Corn and soybean yields by tillage practice for site 1 located in Region 4. Treatments with the same letter are not significantly different.

Residue Cover

Residue cover observed for Region 4 is presented in Figure 38. Residue values for no-tillage plots range from 61-82% and conservation tillage values range from 15-70% for both corn and soybean residue across all years. The amount of residue on no-tillage plots is significantly higher than conservation tillage for all years except 2008, where there is no statistical comparison. No-tillage residue is at least 15% higher than conservation tillage for all years, but is as much as 45% higher in years where soybean residue is present. These results indicate that no-tillage plots maintain a high amount of residue cover regardless of which crop was grown the prior year, while conservation tillage plots are consistently lower than no-tillage, especially in years with soybean residue.
Figure 38. Percentage of surface residue by tillage practice observed at site 1 in Region 4. The type of residue left on the field from the previous crop is listed for each year. An asterisk (*) indicates too few data points to make a statistical comparison. Treatments with the same letter are not significantly different.

*Fall Stalk Nitrate*

The fall corn stalk nitrate level is a useful indicator of the nitrogen availability to corn plants. An inadequate amount of N will result in a low fall stalk nitrate value, as the plant removes N from the stalk and other parts of the plants for grain filling near the end of the season. However, a high concentration of nitrate in the stalk may translate to an excess amount of N in the soil, indicating luxury N use by the plant. The concentration of fall corn stalk nitrate (NO₃-N) was measured for all plots in Region 4 for years in which corn was grown. The reported corn yield is shown as a function of the fall stalk nitrate concentration in Figure 39. Stalk nitrate concentration category is indicated in Figure 39 by dashed lines. Low or marginal stalk nitrate values are generally associated with lower corn yields, indicating a limitation in corn growth due to low nitrogen availability. High corn yields are generally associated with high stalk nitrate values, but yields level off as the nitrate level reaches the excessive range (>2000 ppm). The stalk nitrate test is a valuable tool for adjusting fertilization rates according to nitrate and yield levels. Producers may be able to save money on fertilizer application by reducing rates on fields in the excessive range (>2000 ppm), while still maintaining high yields. Also, nitrate values in
the low or optimal range indicate that an increased application of fertilizer could result in higher yields (Blackmer and Mallarino, 1996).

![Corn Yield as a Function of Fall Stalk Nitrate - Region 4](image)

Figure 39. Corn yields as a function of fall stalk nitrate values for all measured sites in Region 4. Dashed lines indicate stalk nitrate category: L= Low (<250), M = Marginal (250-700), O = Optimal (700-2000), and E = Excess (>2000).

**Soil Quality Parameters**

**Organic Matter**

Soil organic matter percentages for different tillage systems for Region 4 are presented in Figure 40. Organic matter for no-tillage plots ranges from 3.08-3.30%, while conservation tillage ranges from 3.01-3.31%. There is no significant difference in organic matter values between tillage practices for any of the four years. There is a slight variation in organic matter between tillage practices in 2006, but organic matter content remains constant between years. Long-term implementation of conservation tillage practices is expected to increase soil organic
carbon, resulting in a higher organic matter content. Past studies report a small increase or no change in the first 2-5 years of conservation tillage, while a greater increase occurs between 5-10 years (Franzluebbers and Arshad, 1996; Al-Kaisi et al., 2005). The data for Region 4 supports the idea that a change in tillage practice results in little or no change in organic matter for the first 5 years. A significant difference between tillage treatments would most likely be observed if this study was continued for several more years, allowing organic matter to accumulate in no-till plots.

Figure 40. Average soil organic matter percent by tillage practice observed at sites 1 and 2 in Region 4. Treatments with the same letter are not significantly different.

**Bulk Density**

Soil bulk density for Region 4 is shown in Figure 41. No-till bulk density values range from 1.12-1.56 g/cm³ and conservation tillage ranges from 1.13-1.52 g/cm³. There is no significant difference between tillage practices for any of the five years. The lack of a clear difference in bulk density between tillage practices is consistent with past studies. Hussain et al. (1998) also found no significant difference between tillage practices after 8 years at a site in southern Illinois. There is a clear change in bulk density values between years, ranging from as low as about 1.1 g/cm³ to almost 1.6 g/cm³. These changes can be explained by errors in measuring the bulk density, which can account for the range in values while still offering consistent values within each year. If any trend can be picked from these data it is that there is
high yearly variability affected by moisture conditions and the timing of taking bulk density measurements.

Figure 41. Soil bulk density by tillage practice observed at site 1 in Region 4. Treatments with the same letter are not significantly different.

**Soil Compaction**

Compaction index values by tillage practice in Region 4 are presented for 2006 and 2009 (Figure 42). Compaction values for no-tillage plots in 2006 are higher than conservation tillage for the top 2 inches, but no-tillage is lower than conservation tillage at a depth of 3 to 12 inches. No-till and conservation tillage compaction values are about the same below a depth of 12 inches. Surface compaction of no-tillage plots decreased in 2009, so that no-till is less compacted than conservation tillage from a depth of 0-9 inches. No-till compaction increases to be higher than conservation plots at a depth of 12-24 inches. It is unclear why no-till compaction levels increase dramatically at lower depths, although this is likely a result of soil variability within the plots rather than physical compaction. Glacial till and paleosols are found beneath the loess in this area of Iowa; the presence of these different parent materials could greatly increase the compaction levels (Prior, 1991). Compaction in conservation tillage plots remains about the same to a depth of 12 inches, but increases below this. Compaction values remain fairly low near the surface of conservation tilled plots due to increased porosity from tillage, but the index values increase slightly at depth because the compacted layer is pushed deeper in the soil profile over the three year period. Reduced tillage practices are expected to result in lower compaction...
levels over time as traffic on the field is reduced and soil pores and structure are allowed to form (Varsa et al., 1997, Hanna and Al-Kaisi, 2009).

Figure 42. Compaction index by tillage practice to a depth of 24 inches. Observations from 2006 and 2009, including site 1 in Region 4.
Soil pH

Soil pH values for Region 4 are shown in Figure 43. No-tillage pH ranges from 5.2-6.2 and conservation tillage ranges from 5.5-6.4. In 2005 and 2007, soil pH of conservation tillage plots was significantly higher than pH of no-tillage plots. There is no significant difference between no-till and conservation tillage for 2006, 2008, or 2009.

These results show no definite trend in pH due to differences in tillage, which is consistent with the findings of Hussain et al. (1999). It is likely that the observed difference between treatments is due to changes in sampling location and spatial variability, rather than any change in chemical soil properties in the short time of this study.

Figure 43. Soil pH by tillage practice for site 1 in Region 4. Treatments with the same letter are not significantly different.
**Microbial Biomass Carbon**

Microbial biomass carbon values by year for Region 4 are shown in Figure 44. Microbial biomass carbon is a biological indicator that measures the health of soil and the effect of tillage and cropping systems on the soil environment. No-tillage average microbial biomass carbon values range from 426-432 µg C/g soil, while conservation tillage values range from 351-454 µg C/g soil. Conservation tillage is significantly lower than no-tillage in 2007, but there is no difference in 2009. No-tillage soils are expected to have a significantly higher microbial biomass carbon than tilled soils over time (Doran, 1987). The results shown in Figure 44 show no significant change in biomass carbon, especially in such a short period since the establishment of a no-till system or conservation tillage system. A longer time under each tillage system would be necessary to produce significant changes in the microbial biomass carbon.

![Microbial Biomass Carbon - Region 4](image)

Figure 44. Microbial biomass by tillage practice for site 2 in Region 4. Treatments with the same letter are not significantly different.
Infiltration Rate

Infiltration rates for Region 4 are shown in Figure 45. A high amount of variability in infiltration measurements is observed due to spatial variability and variations in sampling techniques. However, no-tillage infiltration rates are consistently higher than conservation tillage rates. No-tillage infiltration values range from about 0.01-0.05 inches/hour higher than conservation tillage for 2007 through 2009; this amounts to conservation tillage infiltration rates 8-89% less than no-tillage across three years. Conservation tillage is about 0.01 inches/hour higher than no-tillage for 2006, or 24% higher than no-tillage infiltration. It is known that tilled fields are susceptible to compaction and reduction of infiltration due to loss of macropores (Ankeny et al., 1990; Ankeny et al. 1995). The results of this study support the idea that infiltration rates will decrease in tilled plots.

Figure 45. Average infiltration rate by tillage practice for site 1 in Region 4. Percentage differences in infiltration rate by tillage treatment were calculated using the infiltration rate from no-tillage as a baseline.
Summary of Agronomic and Soil Quality Trends for Region 4:

- No-till and conservation tillage corn yields are about the same, except in 2007 where conservation tillage yield is 6% lower than that of no-tillage.

- There is no significant difference in soybean yields between no-tillage and conservation tillage, as is expected for a well drained soil.

- Surface residue for no-till is at least 15% higher than conservation tillage for all years, and as much as 45% higher when soybean residue is present.

- Soil organic matter is not significantly affected by tillage over a period of five years or less.

- Bulk density is not significantly affected by tillage over a period of five years or less. Yearly differences in bulk density are due to spatial variability and soil conditions rather than a clear trend due to the treatment.

- Compaction levels remain very similar between no-tillage and conservation tillage plots over 3 years. Surface compaction in no-tillage decreases slightly over time until it is about equal to conservation tillage, while compaction in conservation tillage plots decreases slightly at depth.

- pH values are significantly different between treatments for 2 out of 5 years. Differences in pH between treatments is due to changes in sampling location and spatial variability rather than any change in chemical soil properties in the short time of this study.

- Microbial biomass carbon is significantly higher in no-tillage for 2007, but a difference is not observed in 2009. This difference in 2007 could indicate a change in microbial biomass carbon due to tillage, but more observations would be necessary to confirm a trend.

- Infiltration rates in no-tillage plots are consistently higher than conservation tillage plots. Conservation tillage infiltration rates are 8-89% lower than no-tillage from 2007-2009, but conservation tillage is 24% higher than no-tillage in 2006.


Prior, J.C. 1991. Landforms of Iowa. University of Iowa Press for the Iowa Department of Natural Resources, Iowa City, IA.

