Comparison of Soil Quality Indicators Among Different Farming Systems—Final Report

Written by Kevin Dietzel

Abstract

Soil quality indicators were compared in different farming systems at eight "pods" of neighboring farms around Iowa. Samples were collected for three years and analyzed for organic matter, total carbon and nitrogen content, bulk density, stable aggregate content and pH. Organic matter was higher in organic crops than conventional crops and higher in continuously-grazed pastures than in rotationally-grazed pastures. The nitrogen content was higher in rotationally-grazed pastures than in continuously-grazed pastures, and the nitrogen in the top six inches was higher in the organic crops than in the conventional crops. Stable aggregate content was higher in organic than conventional and higher in pastures than in annual crops but was not significantly different between the pasture management treatments.

Cooperators

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Background

During Iowa's spring 2008 floods, PFI members who had grass-based livestock systems and long crop rotations reported their soils held the rainwater better and eroded less than surrounding fields. This experiment was designed to test those claims. The main objective of the experiment was to quantify the ecological resiliency of different farming systems by measuring water infiltration rates (reported separately) and soil quality indicators including organic matter, total soil carbon and nitrogen, bulk density, pH and stable aggregate content in various farming systems.

Initial data from research conducted at the Neal Smith Wildlife Refuge showed that agricultural landscapes need to be redesigned to include at least 10% to 20% continuous living cover. This amount of cover avoided a seven ton per acre loss of soil during the spring 2008 floods as compared to systems with no cover (Personal Communication, Matthew Helmers, 2009).

Quantitative measurement of soil loss from farm fields or pastures is difficult and expensive to conduct, so we chose to measure specific indicators of soil health. Stable aggregate content (SAC) is an indicator of a healthy soil structure that allows better water infiltration, is less likely to erode away, has more pore space (air) and allows plant roots to penetrate (Brady and Weil, 2002). Soils with stable aggregates are better able to withstand the destructive forces of rain and are less susceptible to runoff.

Total soil carbon (of which soil organic matter is a portion) can be an indicator of a soil's ability to hold water and to store and supply nutrients for plants. Carbon provides food for soil biological organisms and helps to maintain good soil structure. In addition, carbon stored in the soil is an ecosystem service that agricultural systems can provide to society, thereby reducing atmospheric carbon dioxide, a greenhouse gas.

Bulk density can be an indicator of soil compaction, infiltrability and a healthy soil structure.

Previous studies have shown that SAC and carbon levels tend to decrease under annual cropping systems but can be maintained or increased with the addition of perennials or even small grains to the crop rotation (Sparling et al., 1992, Haynes et al., 1991, Haynes and Swift, 1990, Studdert et al., 1997). Both SAC and soil carbon tend to be higher in pastures and other grasslands than in cropland.

Our hypotheses were that soil carbon, organic matter, stable aggregate content and total soil nitrogen would be higher with longer crop rotations, with the addition of perennials, and with rotational grazing; and that bulk density would be lower in those same systems. Finally, we hypothesized that management would have no effect on soil pH.

Table 1

Soil Organic Matter (%) in Surface 0-36 Inches*

Farm pod location	Organic crop rotation	Conventional crop rotation	Continuously grazed pasture	Rotationally grazed pasture	Pasture	Annual crops
Giard	-	-	-	-	2.27	2.39
Paullina	3.71	3.36	3.59	3.53	3.47	3.43
New Albin	-	-	2.43 a	1.72 b	2.11	2.04
Fairfield	-	-	1.59	1.59	1.59 a	1.23 b
Glidden	-	-	1.75	1.76	1.75 b	2.88 a
Harlan	2.37	1.83	-	-	2.66	2.31
McGregor	-	-	-	-	1.64 a	1.25 b
Sutherland	3.10	2.77	-	-	-	-
Average	3.07 a	2.66 b	2.40 a	2.04 b	2.17	2.19

Table 1. Different letters indicate differences between two adjacent rows. All differences calculated using the student's t-test, with an alpha-level of 0.05. *Each value is the least squares mean of all depth segments (0-6 inches, 6-12 inches, 12-24 inches, and 24-36 inches).

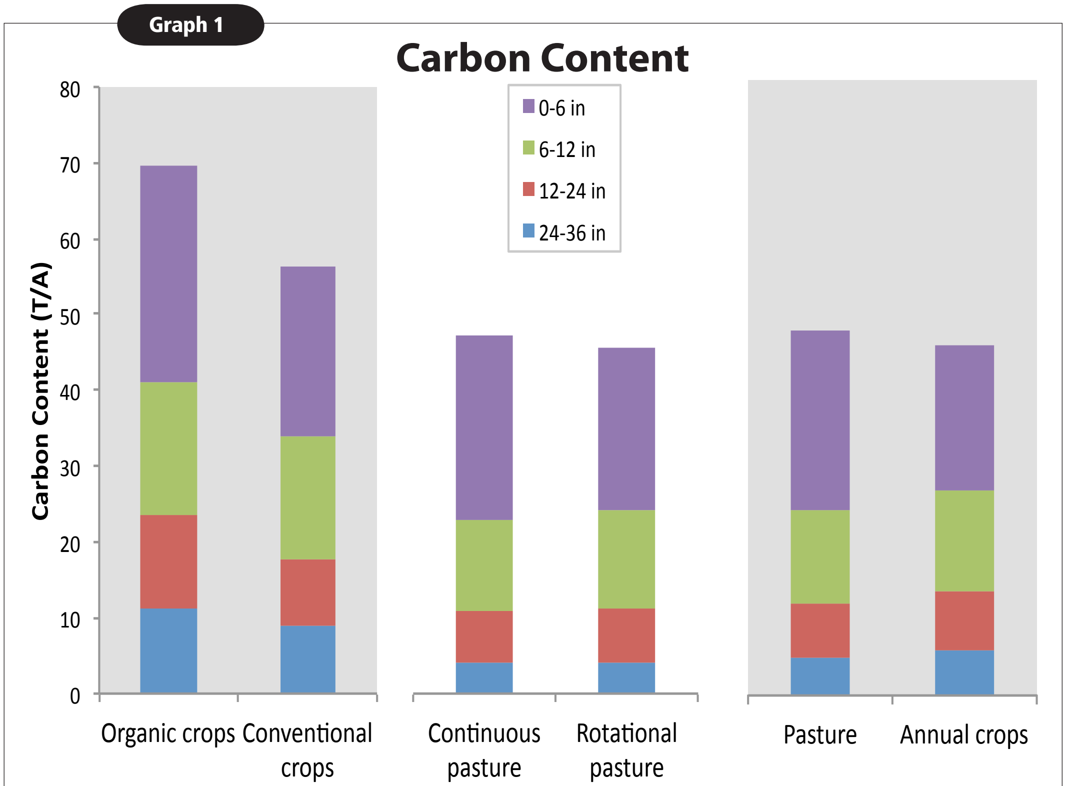
Method

Field sites

Data were collected on farms of PFI members and on farms of one or two of their neighbors who used differing farming practices. These groups of farms are considered "pods." Pods are located near Fairfield, Harlan, Glidden, Paullina, Sutherland, New Albin, Giard and McGregor, IA. The farmers in each pod selected sampling locations using their County Soil Series book. The sampling locations are the same soil series, slope, erosion class and position on the landscape but different farming practices for at least the past five years, with several locations having more than 10 years of the same farming practice. Each location was geolocated for multiple years of data collection in the same areas. The treatments are described as:

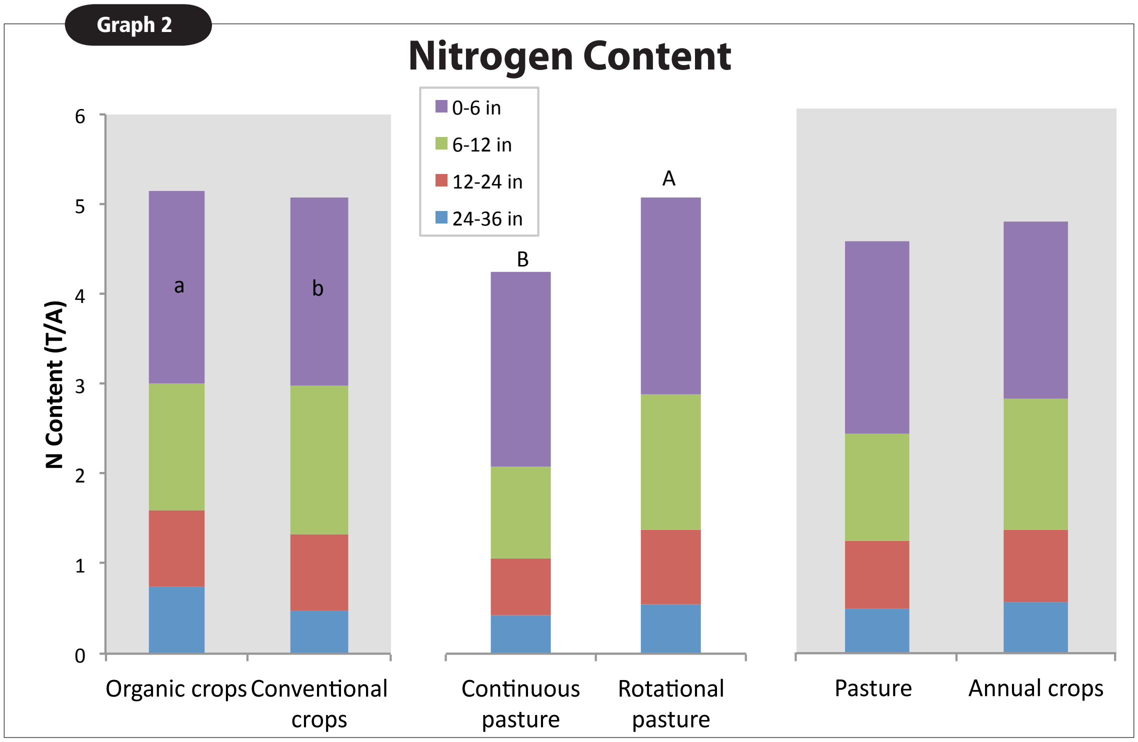
- Conventional Crop (CC): Annual crops in a two-year (or less) crop rotation (i.e. corn on corn or corn-soybean).
- Organic Crop (OC): Annual crops in a three-year (or more) crop rotation and using organic production practices.

Graph 1



Graph 1. Carbon Content by Depth – Least Squares Means of All Pods. *Comparisons are pair-wise between adjacent columns, including only the pods that were present in both treatments in each comparison.*

- *Rotational Graze (RG): Pasture grazed with livestock, with a rest period of 21 days or more and grazing periods of five days or less.*
- *Continuous Graze (CG): Pasture grazed with livestock, with a rest period of less than 21 days and grazing periods of more than five days.*
- *Pasture: Data from the RG and CG treatments combined.*
- *Annual Crops: Data from the CC and OC treatments combined (from pods where pasture was also present).*



Graph 2. Nitrogen Content by Depth—Least Squares Means of All Pods. *Different lower-case letters indicate differences between two adjacent columns for an individual depth. Different capital letters indicate differences between two adjacent columns (total of all depths). All differences calculated using the student's t-test, with an alpha-level of 0.05. Comparisons are pair-wise between adjacent columns, including only the pods that were present in both treatments in each comparison.*

Sample Collection

One to two 4–6 inch diameter soil cores at the 0-6 inch depth from the soil surface were taken at each location to measure stable aggregate content (SAC). In addition, six to eight 0.75-inch soil cores fractioned into four depths: 0–6, 6–12, 12–24 and 24–36 inches were collected near the geolocated site to measure total carbon, total nitrogen, pH, and soil texture. All cores from each depth at each location were bulked into one sample for processing and analysis. Three soil cores of the same depth fractions as above were taken and bulked together for bulk density analysis. To accurately compare the cumulative effects of the farming practice on soil characteristics, we sampled in the middle of the growing season (late July and August) to avoid potential influences from short-term field practices inherent to the annual cropping system conducted in the spring and fall.

Laboratory Analysis

Bulk density was determined by drying the soil at 105°C, weighing it, then dividing the dry weight by the volume of the sample. SAC was determined by the method described in Patton et al. (2001). Soil samples for total carbon and total nitrogen were air dried and ground to pass through a two-millimeter sieve. Total carbon and total nitrogen were determined by dry combustion using a Leco C/N Analyzer (Leco Corporation, St. Joseph, MI). Carbon content was calculated by multiplying the percent total carbon by the bulk density, then multiplying by 6.79 to convert to tons of carbon per acre. The percent total carbon (TC) was converted to percent organic matter (OM) using the formula $OM = 0.0002 \cdot TC^3 - 0.0002 \cdot TC^2 + 1.8276 \cdot TC + 0.1012$ *(Personal Communication, Kerry Culp, 2009). Soil pH was measured in a 1:1 soil:water mixture.*

Data Analysis

Data were analyzed using a mixed model and the student's t-test to compare means. All reported means are the least-squares means for accuracy. All data analyses were performed using the JMP9 software (SAS Institute Inc., Cary, NC). Treatment comparisons were done as pair-wise comparisons, only using pods that had both treatments in that comparison.

Results and Discussion

Organic matter

*Organic matter results are presented in **(Table 1, page 2)**. The organic crops had significantly higher organic matter than the conventional crops when all pods were combined (average) but not at any individual pods. This could be explained by the longer rotations and having perennials as part of the organic rotation. The continuously-grazed pasture had significantly higher organic matter than the rotationally-grazed pasture. It is unclear whether this difference is due to current* management practices or the history of the sites. There were varying results when comparing the pasture and crop treatments so no overarching conclusions can be drawn.

The biggest differences in organic matter were found between the pods (analysis not reported), indicating that the inherent soil properties play a much larger role in organic matter content than management.

Carbon content

The only significant difference in C content between treatments was seen at the McGregor pod, where the pasture had significantly more carbon in the soil than the annual crops.

Depth and pod location were the most significant factors affecting carbon content in the soil. Deeper in the soil there was less carbon, as there is less root growth and less biological activity. ***(See graph 1, page 2.)***

There was no interaction between treatment and depth affecting C content.

Nitrogen content

In the sum of all depths, there was a significant difference in total N content between rotationally grazed pasture (5.08 T/A) and continuously grazed pasture (4.24 T/A). This could be attributed to higher plant diversity that often occurs with rotational grazing, resulting in more legumes and therefore more nitrogen in the soil throughout the profile since they are all perennial, deep-rooted plants. At the six-inch depth, there was a significant difference in N content between the organic crops (2.07 T/A) and the conventional crops (1.93 T/A). This could be due to the timing of sampling. Since we sampled in late July and August, much of the synthetic nitrogen fertilizer in the conventional crops had already been utilized by the plants or leached out of the system, but the organic crops rely on organic sources of nitrogen that are more stable so more nitrogen remains in the soil later in the season.

Our analysis showed that the nitrogen content was highly correlated (r^2=0.86) with the organic matter percentage. As organic matter increased in the soil so did the nitrogen content. The correlation was strongest at the depth, 0-6 inches, (r^2=0.87) and weakest at the depth, 24-36 inches, (r^2=0.11). It is important to note that total nitrogen content does not tell us the amount of nitrogen available for plant uptake. ***(See Graph 2, page 3.)***

Bulk density

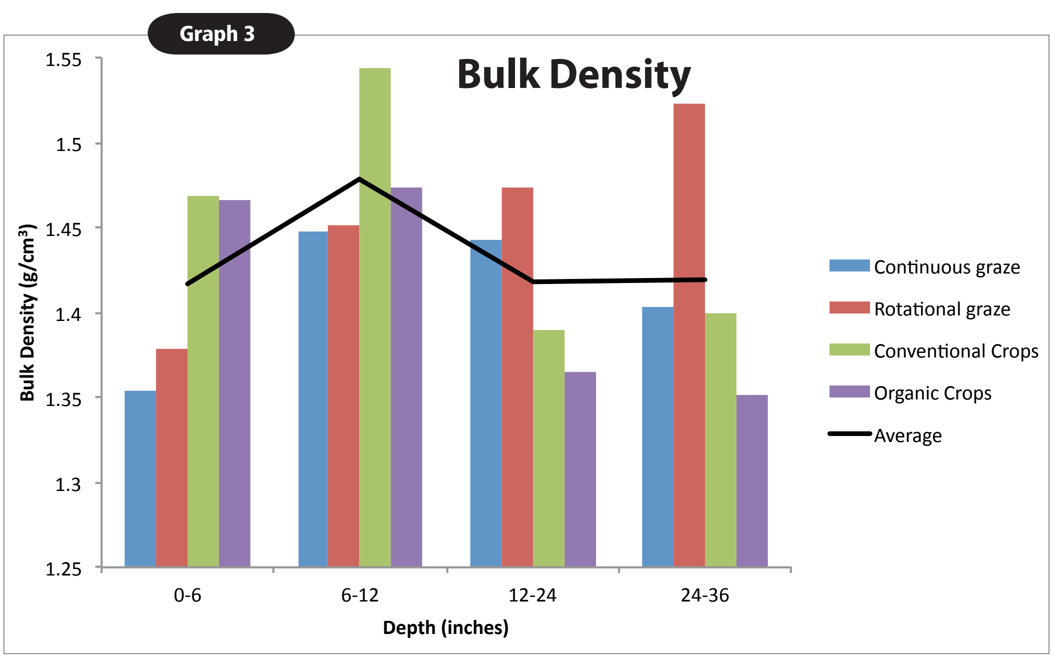
The only significant differences between treatments were at the Fairfield pod, where CG was significantly higher than RG, and annual crops were significantly higher than both pasture treatments. Higher bulk densities indicate more soil compaction.

Although there were no significant differences between the depth segments measured, there were some notable trends. ***(See Graph 3, below.)*** *On average, the 6- to 12-inch depth had the highest bulk density. This is most prominently seen in the CC treatment, probably reflecting the location of compaction from tillage equipment (the "plow pan"). The other interesting trend seen in* ***(Graph 3)*** *is that the bulk density increases with each depth in the RG treatment, whereas the CG treatment follows a trend more similar to the crop treatments.*

Stable aggregate content

SAC was significantly higher in the OC than in the CC. ***(See Table 2, page 5.)*** *It was also significantly higher in the pastures than in annual crops. Grazing management did not have any significant effect on SAC. These results indicate that perennial vegetation is the biggest driver of improved soil aggregation. Incorporating perennials into a crop rotation (as the organic rotations do) or as 100% of the land cover all the time as in a permanent pasture will result in an improved, more stable soil structure that is less likely to erode than annual crop fields.*

It is important to note that the correlation between bulk density and SAC is not strong (r^2=0.22), indicating that high bulk densities do not necessarily mean poor soil structure stability.



Graph 3. Bulk Density—Least Squares Means of All Pods.

Table 2

Stable Aggregate Content (%)						
Farm pod location	Organic crop rotation	Conventional crop rotation	Continuously grazed pasture	Rotationally grazed pasture	Pasture	Annual crops
Giard	-	-	-	-	38.9	33.7
Paullina	61.6 a	25.9 b	57.1	43.3	44.5	31.5
New Albin	-	-	65.9	60.5	49.4	34.4
Fairfield	-	-	44.8	43.3	35.8 a	26.9 b
Glidden	-	-	42.4	49.2	47.3 a	31.8 b
Harlan	27.5	17.3	-	-	48.1 a	22.2 b
McGregor	-	-	-	-	41.9	29.6
Sutherland	32.4	45.3	-	-	-	-
Average	40.7 a	28.3 b	57.4	52.6	45.6 a	31.3 b

Table 2. *Different letters indicate differences between two adjacent rows. All differences calculated using the student's t-test, with an alpha-level of 0.05. *Each value is the least squares means of depth 0-6 inches.*

pH

The only significant difference in soil pH across all pods was the annual crops versus the pasture. ***(See Table 3, page 5.)*** *This can most likely be explained by the fact that cropland is more likely to receive lime, and when that lime is applied it gets incorporated into the soil with tillage, so it affects more of the soil profile more quickly. The other differences at individual locations could be management differences between the farmers other than those described here (frequency of liming or other fertilizer application).*

Conclusions

Our hypotheses were partially substantiated, and partially disproven. It does appear that longer rotations positively affected the organic matter content of the soil, but rotational grazing did not increase the organic matter content at the locations we compared. When the percentage of carbon was corrected for bulk density to calculate the tons of carbon contained in the soil profile, there were no differences between the treatments we compared. Nitrogen content was affected by grazing management, with the rotationally-grazed pastures containing more nitrogen than the continuously-grazed pastures, and the organic crops had significantly higher nitrogen than the conventional crops in the top six inches. Bulk density was not significantly affected by the treatment effects. Incorporation of perennials resulted in higher stable aggregate content. Due to the time it takes to measure a change in carbon and soil organic matter levels, we will work to return to these sampling locations after at least five years. Potentially, after that time period we could see different results.

Table 3

Soil pH in Surface 0-36 Inches*						
Farm pod location	Organic crop rotation	Conventional crop rotation	Continuously grazed pasture	Rotationally grazed pasture	Pasture	Annual crops
Giard	-	-	-	-	6.31	6.65
Paullina	6.57	6.70	6.28 b	6.82 a	6.55	6.75
New Albin	-	-	5.97 b	6.31 a	6.19 b	6.81 a
Fairfield	-	-	6.45 a	5.78 b	6.08 b	6.68 a
Glidden	-	-	6.81	7.02	6.85	6.37
Harlan	7.28	7.21	-	-	7.35	7.18
McGregor	-	-	-	-	5.50 b	6.63 a
Sutherland	6.88	7.07	-	-	-	-
Average	7.01	7.05	6.36	6.54	6.41 b	6.68 a

Table 3. *Different letters indicate differences between two adjacent rows. All differences calculated using the student's t-test, with an alpha-level of 0.05. *Each value is the least squares mean of all depth segments (0-6 inches, 6-12 inches, 12-24 inches, and 24-36 inches).*

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