Conservation Cropping Systems Initiative

Individual Site Report:

Jamie Scott
Kosciusko County

Authors:
Dr. Stacy Zuber
Dr. Eileen Kladivko

Report Structure

This report is prepared for an individual farmer cooperator, with data from commercial soil health tests taken in 2015 and 2016. The report is structured as follows:

- Goals of the soil health tests analysis
- Summary of results from this individual cooperator
- Results in detail—this section discusses in detail the individual site results that are summarized in the immediately previous section, for the cooperator and others who may want to study the results in more depth.

A short summary of the results from all cooperators is provided in a separate report. Further synthesis of all data from all sites is ongoing, and will be provided as available.

Soil Health

Soil health has been defined as "the capacity of soil to function as a vital living system to sustain biological productivity, promote environmental quality and maintain plant and animal health."[1] Developing sustainable agronomic practices is directly related to their ability to influence soil health. Any attempt to categorize an agricultural practice as sustainable must first consider the effect on the soil.

Goals of Soil Health Analyses

A key component of the project conducted by the Conservation Cropping Systems Initiative (CCSI) is the evaluation of four different commercial soil health tests—Phospholipid Fatty Acids (PLFA), Earthfort Biological Soil Analysis, Cornell Soil Health Assessment, and Haney-Soil Health Tool. The objectives of this facet of the project are to assess the usefulness and value of the different commercial tests on evaluating the health of Indiana soils as well as the ability of the soil health indicators to distinguish among different cropping practices. Each of the four commercial soil health tests contain upwards of 10 separate soil health measures and most also include a ranking or calculation of overall soil health. While each of these commercial tests includes a large number of different soil properties, they each are supposed to evaluate overall soil health. One of the main goals of this project is to assess the usefulness of these tests on Indiana soils when comparing different cropping systems.

1 Doran et al., 1996; Doran and Zeiss, 2000

Climate	
Mean Annual Temperature:	49.1°F
Mean Annual Precipitation:	39.9 in

Treatments
No-till + Single Species Cover Crop
No-till + Cover Crop Mix
No-till, No Cover
Neighbor (Tillage, No Cover)

Summary of Scott Site

The Scott farmer site was a no-till field with two different cover crop treatments and a no cover crop treatment in fall 2013. There were no cover crops in fall 2014 on any of the plots. Thus samples taken in summer 2015 would not be expected to detect the effects of the cover crops. Then a wheat cover crop was grown across all plots in fall 2015-spring 2016, again limiting the expected differences between the cover crop treatment plots. These factors are likely the reason for only a few significant differences being detected among these treatments. Of the significant differences that were detected, several of the soil health measures were higher for the no cover control than one or both of the cover crop treatments. This includes Earthfort amoeba, Cornell quality score, organic matter, and soil respiration while total fungi as measured by PLFA was lower for the no cover/no-till treatment.

In contrast, there were many more differences in 2016 between the neighbor and the conservation cropping system plots, especially from the Cornell health test, but also from PLFA and Haney tests. Of these, the three PLFA measures that were significant were greater at the neighbor than the cover and no cover no-till treatments at the Scott farmer site. A possible explanation for these results is related to the timing of the soil sampling in the cover and no cover no-till plots. The samples were collected in late July following wheat harvest so there were no living crops in those no-till fields, whereas soybeans were growing in the neighbor field. Since PLFA measures the currently living cells of different microbial groups, the absence of living plant roots may have reduced the amount of microbes in the cover and no cover no-till plots (at least in the short term). Among the Cornell soil health measures that significantly differed between the neighbor and the cover or no cover treatments, most of these favored the conservation cropping system plots at the Scott farmer site. These include higher quality score, organic matter, active carbon, and protein values and lower surface and subsurface hardness in the cover and/or no cover plots compared to the neighbor.

More work is needed to further evaluate the potential usefulness of these commercial tests for characterizing differences in soil health as found in Indiana cropland. The commercial tests as performed in this project, were often unable to distinguish between treatments that appear in the field to show differences. This may reflect a lack of sensitivity of the tests to important characteristics of key field soil functions. Please refer to the separate overall summary report for further discussion of overall questions, further analyses planned, and questions for future research on soil health assessment methods.

Results

Results are presented in the following tables with a subset of a soil health measures from each of the commercial soil health tests evaluated in 2015 and 2016 at the Scott farmer site. The selected variables were chosen based on preliminary analysis that indicated that these soil parameters had the greatest potential to be sensitive to conservation cropping practices and allow us to distinguish between treatments.

Average values are presented for each of the treatments at the location—cover crop mix/no-till, cover crop single species/no-till, no cover/no-till, and neighbor. We compared the three conservation cropping system treatments at the farmer site to evaluate them for statistically significant differences. For the neighbor, each treatment was separately compared to the neighbor (cover mix vs. neighbor, cover one vs. neighbor, and no cover vs. neighbor). The significant differences are found for each year in three columns to the right of the averages and degree of significance is indicated by the number of asterisks Three asterisks (***) indicates a very strong statistical significance while comparisons with fewer asterisks are less statistically significant. Lower significance or lack of significant differences between treatments could be because of a smaller (or no) difference between treatments, but could also be due to greater variability within the measure so we are less confident that the apparent differences between treatments are real. If two means have the same letter, they are not significantly different; for instance, soil respiration in 2016 from the cover crop mix and single species treatments are labeled with the letter 'b'. However, since the no cover average value for soil respiration is labeled as 'a', this indicates this measure from the no cover plot is significantly different from the cover crop treatments.

Brief Statistics Primer—Statistically Significant Differences

Here is an example from one of our farmer cooperators of the highly variable numbers we are analyzing. The average total fungi for four strips of no-till with cover crops was 195 ng/g compared to the neighboring field with an average of 51.5 ng/g of total fungi. These seem like those numbers are very different, but the difference between them is NOT statistically significant.

How in the world can these two numbers not be different? The no-till cover crop is 4x larger than the other, why do the

How in the world can these two numbers not be different? The no-till cover crop is 4x larger than the other, why do the ***statistics say they aren't different?*** Statistical analysis tries to determine how confident we can be that this difference is real and would occur again. It's not based just on how large the difference is. We compare how different the two fields are to the amount of variation within each field.

Example

Treatment	Rep #1	Rep #2	Rep #3	Rep #4	Average
No-Till + Cover Crops	98	38	390	254	**195**
Neighbor	32	85	33	56	**51.5**

To make sense of this, we need to look to the numbers that go into the averages. For the no-till, cover crop field, we have numbers that are kind of all over the place with some lower values—38 and 98, but also two very high numbers—254 and 390. For this field, the average is much higher than the average of the neighbor, but there is a high amount of variability in this measure as well. With so much variability in the measure, we can't be confident that this treatment is truly different from the neighbor.

As an example, if you have a field that has a lot of variability in it, you could randomly select a few different spots to check for yield. Depending on what spots you check, you may think you could have record yields or that it's going to turn out to be a disappointing harvest. In this case, eventually you will harvest the whole field and so you know what your true yield is. For the soil health indicators we are looking at, we can only estimate these measures based on the 3 or 4 replicated plots in each field. When there is high amounts of variability, we have no way of knowing what the true average is so we need to be cautious in declaring these differences to be real. If we were to repeat this experiment with four different plots in those fields, we might get a very different average and the difference between the no-till cover crop and the neighbor might end up being much smaller.

The soil health measurements tend to be much more variable than standard soil fertility tests, as the soil biology can be very patchy with microbes clustering near cover and cash crop roots and residues. Wheel tracks can reduce pore space in the soil, affecting water and oxygen availability for microbes. We try to reduce this problem by collecting 20-30 soil cores from each strip to get a more representative sample, but high variability still remains. Soil biology can also change dramatically throughout the summer as moisture and temperature change so these tests only provide a snapshot of these measures at the time of sampling. Ultimately, these issues complicate our ability to detect significant differences even when there are large numerical differences between the treatments.

Site Details—Soils, Treatments

Conservation Cropping System Experimental Plots						
% of Field	Soil Series Name	Soil Texture	Slope	Drainage Class	Native Vegetation	Parent Materials
100%	Wawasee	Fine sandy loam	2-6%	Well drained	Forest	Till

Neighbor						
% of Field	Soil Series Name	Soil Texture	Slope	Drainage Class	Native Vegetation	Parent Materials
50%	Wawasee	Fine sandy loam	2-6%	Well drained	Forest	Till
50%	Crosier	Loam	0-1%	Somewhat poorly drained	Forest	Till

Treatments	Fall 2012	Spring 2013	Summer 2013	Fall 2013	Spring 2014	Summer 2014	Fall 2014	Spring 2015	Summer 2015	Fall 2015	Spring 2016	Summer 2016	Fall 2016	Spring 2017	Summer 2017
NT (JS 1,4,7,10)	WH		–			CN	–		SB	WH		–			CN
NT+CC One (JS 2,5,8,11)	WH		SB	–		CN	–		SB	WH		CR			CN
NT+CC Mix (JS 3,6,8,12)	WH		13-way mix		–	CN	–		SB	WH		14-way mix		–	CN
NBR (JS 13,14,15,16)	–		?	–		?	–		?	–		SB	–		CN

NT—No Cover No-till; NT+CC One—Single Species Cover Crop No-till; NT+CC Mix—Cover Crop Mix No-till; NBR—Neighbor (No cover and conventional tillage)
Cash and Cover Crop Abbreviations: CN—Corn; SB—Soybean; WH—Wheat; CR—Cereal Rye
Cover crops are color-coded as light green.

Soil Health Sampling Dates	Soil Moisture (%)			
	NT	NT+CC One	NT+CC Mix	NBR
July 24, 2015	11.8	12.2	11.7	–
July 28, 2016	16.5	16.7	15.8	15.2

NOTE: Cover crop plots in Fall 2014 were accidentally sprayed so there was no cover crop growth on these plots.
Sampling dates in both 2015 and 2016 were later in the season than most of our other sites. This difference in timing may affect the soil health measures.

Phospholipid Fatty Acids (PLFA)

Phospholipid fatty acids are found in the cell membrane of all cells. Specific fatty acids are only found in the cell membrane of certain types of microbes—these are called biomarkers. The amount of biomarker fatty acids measured in the soil tell us how large each of these microbial groups are within the soil sample.

- In soils, we look at total microbial biomass as well as several microbial groups—bacteria, fungi, mycorrhizal fungi, and protozoa.
- The PLFA tests in 2015 and 2016 were analyzed by two different commercial laboratories so the units between years are different and make comparisons between 2015 and 2016 difficult.

Table 1. Average values for Phospholipid Fatty Acid (PLFA) from 2015 and 2016 for no cover/no-till (NT), single species cover crop/no-till (NT+CC One), cover crop mix/no-till (NT+CC Mix) and neighbor with no cover/conventional tillage (NBR). PLFA tests in 2015 were analyzed by Ward Laboratories and measured in ng/g while in 2016, PLFA tests were analyzed at the Missouri Soil Health Assessment Center and measured in nmol/g. Statistical differences within pairs of treatments are indicated as significant at <0.01 by ***, at <0.05 by ** and at <0.10 at *. NT+CC vs NT significant difference compares NT+CC Mix, NT+CC One, and NT no-till treatments simultaneously and for these, significantly different average values are indicated by different letters. NT+CC vs NBR compares the average of the two cover crop treatments to the neighbor. Measurements in italics are calculations within commercial tests purported to be indicators of overall soil health. **NOTE: Different units and labs between the two years, make direct comparisons between 2015 and 2016 impossible, except for Diversity Index and Fungi:Bacteria Ratio.**

	July 24, 2015			
	Average Values			Significant Differences
PLFA—Ward Laboratories	NT+CC Mix (SB)	NT+CC One (SB)	NT (SB)	
Total Microbial Biomass (ng/g)	2621	2620	4512	
Total Bacteria (ng/g)	1215	1230	1081	
Total Fungi (ng/g)	279	285	267	
Mycorrhizal Fungi (ng/g)	84	91	84	
Protozoa (ng/g)	28	27	26	
Fungi:Bacteria Ratio	0.23	0.23	0.24	
Diversity Index	1.52	1.52	1.55	

	July 28, 2016						
	Average Values				Significant Differences		
PLFA—Missouri	NT+CC Mix (WH stubble)	NT+CC One (WH stubble)	NT (WH stubble)	NBR (SB-Till)	NT+CC vs NT	NT+CC vs NBR	NT vs NBR
Total Microbial Biomass (nmol/g)	60.4	59.2	54.8	66.4			
Total Bacteria (nmol/g)	34.7	33.7	30.7	35.8			
Total Fungi (nmol/g)	0.71a	0.55ab	0.46b	0.87	*	**	***
Mycorrhizal Fungi (nmol/g)	2.62	2.53	2.32	2.53			
Protozoa (nmol/g)	0.30	0.32	0.27	0.55		***	***
Fungi:Bacteria Ratio	0.19	0.19	0.19	0.20			
Diversity Index	1.32	1.32	1.31	1.35		**	**

SB—Soybean; WH stubble—Wheat stubble

PLFA, cont

Total Microbial Biomass
Represents the overall size of the microbial community within the soil; larger microbial communities indicate a more favorable environment for microbial growth and a healthier soil.

- No significant difference in microbial biomass among treatments was detected in either 2015 or 2016.
- Ward Laboratories, which analyzed PLFA in 2015, has a rating system for total microbial biomass (see Appendix).
    - According to the rating system, the microbial biomass of the two cover crop treatments are rated slightly above average and no cover microbial biomass was rated excellent.

Total Bacteria
Bacteria are decomposers that help break down residues and cycle nutrients and are an important part of the microbial community. However, for optimal soil health, it is important that the microbial community not be dominated by bacteria. Therefore, a high bacteria number does not indicate by itself that the soil has high soil health.

- No significant difference between treatments was detected either year.

Total Fungi
Fungi, like bacteria, are decomposers, but some fungi have fairly specialized enzymes that break down residues that are more complex and difficult to break down. They are also important to soil organic matter formation and soil aggregation. This makes fungi a very valuable part of the microbial community, and high levels of fungi can be a strong indicator of soil health.

- No significant difference between treatments was detected in 2015.
- In 2016, total fungal biomass of the neighbor was significantly higher than the cover crop and no cover no-till treatments.
    - This may be related to differences in living plant biomass at the time of sampling between the neighbor with a living soybean crop and the no-tilled cover and no cover plots, which were sampled after wheat harvest in late July. The presence of living plants and roots can affect the microbial community as the roots release carbon and nutrients that support microbial growth.
- Within the plots at Scott, the cover crop mix had greater total fungi that the no cover treatment (even 2.5 years after the mix was grown) while the single species cover crop was not significantly different from either the mix or no cover treatment.

Mycorrhizal Fungi
Mycorrhizal fungi, also known as arbuscular mycorrhizae fungi (AMF), can be beneficial to many crops as they colonize plant roots and form mutually beneficial relationships. Mycorrhizae are able to scavenge for nutrients in the soil that the plant would not otherwise be able to reach—these can be especially important for P and N.

- No significant difference between treatments was detected in 2015 or 2016.

Protozoa
These microbes are important to nitrogen cycling within soils. Protozoa mainly feed on bacteria and as they eat, they release excess nitrogen that is then available for crop uptake.

- No significant differences found between treatments in 2015.
- In 2016, greater protozoa PLFA was measured at the neighbor compared to the cover crop treatments as well as the no cover control.
    - Again, this difference may be related to the lack of living plant roots in the cover and no cover no-till plots compared to the soybean in the neighbor field. Plant roots can release molecules into the soil that serve as microbial food and attract bacteria. Protozoa then feed on the bacteria. All of this can increase nutrient cycling, releasing more nutrients in plant available forms.

Fungi: Bacteria Ratio
As mentioned above, fungi can be a strong indicator of soil health so it is important to have a high ratio of fungi to bacteria.

- There were no significant differences among treatments in either year.
- Ward Laboratories has a rating system for this measurement as well (see Appendix).
    - Based on this, the values for the 2015 measurements for all treatments fall in the slightly above average category while in 2016 all treatments were in the average category.

Diversity Index
This measurement is calculated using the proportion of the microbial biomass that is in each of the microbial groups listed above and indicates how much diversity is found within the microbial community. High diversity is preferred as a microbial community is better able to deal with environmental stresses and able to decompose a more diverse array of residues.

- None of the calculated diversity indices were different in 2015, but in 2016, the neighbor had a higher diversity index than the cover or no cover treatments. This is likely again due to the living cash crop versus the harvested wheat, as discussed earlier.
- Ward Laboratories provided a rating system for this calculation as well (see Appendix).
    - For 2015, all of the treatments had a diversity index in the very good category while in 2016, all of the treatments are slightly above average.

Earthfort Biological Soil Analysis

Similar to PLFA, this commercial test measures the size of various microbial groups; however, these measurements were made using microscopy, directly counting the size of these microbe groups. This analysis was only completed in 2015.

Table 2. Average values for Earthfort Biological Analysis in 2015 for no cover/no-till (NT), single species cover crop/no-till (NT+CC One), and cover crop mix/no-till (NT+CC Mix). Statistical differences within pairs of treatments are indicated as significant at <0.01 by ***, at <0.05 by ** and at <0.10 at *. NT+CC vs NT significant difference compares NT+CC Mix, NT+CC One, and NT no-till treatments simultaneously and for these, significantly different average values are indicated by different letters.

	June 24, 2015			
	Average Values			Significant Differences
Earthfort	NT+CC Mix (SB)	NT+CC One (SB)	NT (SB)	
Active Bacteria (µg/g)	41	41	44	
Total Bacteria (µg/g)	990	923	1435	
Active Fungi (µg/g)	9	11	12	
Total Fungi (µg/g)	378	298	435	
Protozoa--Flagellates (µg/g)	3154	4947	3552	
Protozoa--Amoeba (µg/g)	76064 b	108005 b	328428 a	*
Protozoa--Ciliates (µg/g)	188	178	122	
Total Fungi: Total Bacteria Ratio	0.48	0.36	0.35	

SB—Soybean

Total and Active Bacteria

As mentioned above, bacteria are decomposers, but are not considered strong indicators of soil health. While some bacteria may be dormant or dead, active bacteria gives an indication of how many bacteria are able to actually cycle nutrients and contribute to decomposition of residues at the time of soil sampling.

- There were no differences between any of the treatments for either total or active bacteria.

Total and Active Fungi

Fungi are also decomposers, but because of their contributions to soil aggregation and soil organic matter, it is preferred to have high fungi levels and have a fungal dominated microbial community. Again, the active fungi gives a better indication of how many fungi are currently able to contribute to nutrient cycling.

- There were no significant differences between treatments for total or active fungi in 2015.

Protozoa

As mentioned above, protozoa eat bacteria and release excess nitrogen, which is now plant available. The Earthfort analysis measures the amounts of three different types of protozoa. Flagellates and amoebae are aerobic protozoa that require oxygen to survive. Ciliates are the largest and least common protozoa, and they are able to survive without oxygen in anaerobic conditions.

- There were no significant differences between any of the treatments for flagellate and ciliate types of protozoa.
- There was significantly more amoeba in the no cover plots than in either of the cover crop treatments.
    - This is particularly surprising as none of the no-till plots actually had growing cover crop in them from Fall 2014-Spring 2015 prior to the 2015 soil sampling. These measures are highly variable so this difference may be not actually be real.

Total Fungi: Total Bacteria Ratio

Fungal dominated microbial communities are a strong indicator of soil health so higher values of the fungi: bacteria ratio are preferred.

- No significant differences were found between any of the treatments.

Cornell Soil Health Assessment

This commercial soil test consists of twelve different measures of different aspects of the soil, which are all rated and then combined together to form an overall quality score (out of 100). The chemical tests of soil pH, P, K and minor elements are not shown in this report as they were not different between treatments, but they are included in the calculated quality score. In general, most of the chemical tests were in the optimal range, reflecting long-term good soil fertility practices.

Note on Rating System:
The ratings in the Cornell Soil Health Assessment are determined by scoring functions for each soil property. The scoring functions used in this report are specific to the Midwest region and some differ based on the soil texture (sandy soils would be rated differently than finer soils). These scoring functions were developed based on a large database of measurements collected from throughout the region. Certain soil measurements rate higher for higher values (Aggregate Stability, Available Water Capacity, Organic Matter, ACE Protein, Soil Respiration, and Active Carbon). Surface and Subsurface hardness are rated higher with lower measured values. Others, such as pH and phosphorus, are rated closer to 100 when within an optimum range; above and below that range are rated lower.

Table 3. Average values for Cornell Soil Health Assessment from 2015 and 2016 for no cover/no-till (NT), single species cover crop/no-till (NT+CC One), cover crop mix/no-till (NT+CC Mix) and neighbor with no cover/conventional tillage (NBR). Statistical differences within pairs of treatments are indicated as significant at <0.01 by ***, at <0.05 by ** and at <0.10 at *. NT+CC vs NT significant difference compares NT+CC Mix, NT+CC One, and NT no-till treatments simultaneously and for these, significantly different average values among NT+CC Mix, NT+CC One and NT are indicated by different letters. NT+CC vs NBR compares the average of the two cover crop treatments to the neighbor. Measurements in italics are calculations within commercial tests purported to be indicators of overall soil health.

Cornell Soil Health Assessment	July 24, 2015				July 28, 2016						
	Average Values				Average Values				Significant Differences		
	NT+CC Mix (SB)	NT+CC One (SB)	NT (SB)	Significant Differences	NT+CC Mix (WH stubble)	NT+CC One (WH stubble)	NT (WH stubble)	NBR (SB-Till)	NT+CC vs NT	NT+CC vs NBR	NT vs NBR
Quality Score	62b	61b	64a	*	60	62	61	52		***	***
Aggregate Stability (%)	41	36	35		19	20	17	23			**
Available Water Capacity	0.19	0.21	0.22		0.17	0.17	0.16	0.16			
Surface Hardness (psi)	209	216	213		156	158	179	298		***	***
Subsurface Hardness (psi)	272	291	306		254	245	245	300		***	***
Organic Matter (%)	1.80b	1.93ab	1.98a	*	1.85	2.02	2.00	1.59			***
Active Carbon (ppm)	456	482	507		399	425	447	306		**	***
ACE Soil Protein Index	4.58	4.63	4.78		4.10	4.44	4.54	3.13		***	***
Soil Respiration-96 hrs (ppm)	370b	380b	430a	***	340	360	360	420		**	

SB—Soybean; WH stubble—Wheat stubble

Cornell, cont.

Quality Score

This is calculated based on the rating for each of the 12 different soil measures within this commercial soil health test. It is supposed to indicate overall soil health and values above 60 are considered excellent. Quality scores between 40 and 60 are rated medium and indicate soil health could still be improved. If the values are less than 20, this is considered a constraint and needs to be addressed.

- For 2015, the quality score is higher for the no cover plots than either of the cover crop treatments.
- In 2016, the quality score of the neighbor is lower than either of the cover crop/no-till treatments or the no cover/no-till control.

Aggregate Stability

This measures how well the soil aggregates stay together and can be a strong indicator of how well the soil is able to resist erosion. High aggregate stability can prevent crusting and increase water infiltration

- No significant differences were found between treatments in 2015.
- In 2016, aggregate stability was higher at the neighbor than the no cover/no-till treatment.
    - The values for aggregate stability in 2016 for the no-till cover and no cover treatments were much lower than the measures in 2015. This change in aggregate stability may be related to the sample timing of late July after wheat harvest, which may also explain the lower aggregate stability in those conservation cropping system plots compared to the neighbor where soybeans were actively growing.

Available Water Capacity

This measures how much water the soil holds between field capacity and permanent wilting point, which is the amount of plant-available water the soil can store. Available water capacity is dependent on the soil texture as coarse texture soils are able to store much less water than finer soils. However, for a specific soil texture, more organic matter can increase available water capacity.

- There were no significant differences between any treatment for either year.

Surface and Subsurface Hardness

These are measures of strength of the soil and is an indication of the physical structure of the soil. High levels of surface and subsurface hardness can restrict root growth and influence water infiltration. Surface hardness is measured in the top 6 inches, while subsurface hardness measures 6-18 inches. These measures can also be affected by soil moisture at the time of sampling. These numbers were taken with a cone penetrometer at the time of the field sampling

- No significant differences in surface hardness or subsurface hardness in 2015.
- In 2016, the surface and subsurface hardness was significantly higher at the neighbor compared to any of the cover and no cover/no-till treatments.

Organic Matter

Soil organic matter is one of the most important indicators of soil health due to its relationship with many other aspects of the soil, including water infiltration and holding capacity, aggregate stability, and nutrient cycling. However, the limitation of this measure is that it can take several years to significantly alter organic matter.

- In 2015, the organic matter is significantly higher in the no cover treatment compared to the cover crop mix.
- In 2016, the neighbor has significantly lower organic matter than the no cover/no-till treatment.

Active Carbon

This measures the portion of organic matter that is most easily decomposed by soil microbes. High active carbon is an indicator of good soil health and is much more sensitive to management changes than organic matter as a whole.

- No significant differences in 2015 for active carbon.
- In 2016, the cover crop and no cover no-till treatments had greater active carbon than the neighbor.

ACE Soil Protein Index

This is similar to active carbon as it represents the most easily cycled part of organic matter, but measures nitrogen. Proteins are readily broken down by microbes, which mineralizes N into plant-available forms.

- No significant differences in 2015 among treatments.
- In 2016, the cover crop and no cover no-till treatments had greater soil protein than the neighbor.

Soil Respiration

Soil respiration measures the amount of carbon dioxide released by soil microbes over a certain period of time. For Cornell, it is measured over 96 hours so the measure is able to stabilize and is more consistent than measures over a short period of time. This measures how active the soil microbes are.

- No cover/no-till plots had higher soil respiration rates than either of the cover crop treatments in 2015.
- In 2016, soil respiration was significantly higher from the neighbor than the cover crop treatments, but not quite significantly higher than the no cover plots.
    - As a measure of microbial activity, soil respiration can be affected by the presence of living plant and root biomass. Since the no-till cover and no cover treatments were sampled after wheat harvest, the microbial activity was likely less than it would have been with growing crops at the time of sampling.

Haney-Soil Health Tool

Like the Cornell commercial soil health test, the Soil Health Tool consists of many different tests that evaluate different aspects of the soil. The tests focus on nutrient availability and microbe activity.

Table 4. Average values for the Haney Soil Health tool in 2015 and 2016 for no cover/no-till (NT), single species cover crop/no-till (NT+CC One), cover crop mix/no-till (NT+CC Mix) and neighbor with no cover/conventional tillage (NBR). Statistical differences within pairs of treatments are indicated as significant at <0.01 by ***, at <0.05 by ** and at <0.10 at *. NT+CC vs NT significant difference compares NT+CC Mix, NT+CC One, and NT no-till treatments simultaneously and for these, significantly different average values among NT+CC Mix, NT+CC One and NT are indicated by different letters. NT+CC vs NBR compares the average of the two cover crop treatments to the neighbor. Measurements in italics are calculations within commercial tests purported to be indicators of overall soil health.

	July 24, 2015				**July 28, 2016**						
	Average Values				Average Values				Significant Differences		
Haney-Soil Health Tool	NT+CC Mix (SB)	NT+CC One (SB)	NT (SB)	Significant Differences	NT+CC Mix (WH stubble)	NT+CC One (WH stubble)	NT (WH stubble)	NBR (SB-Till)	NT+CC vs NT	NT+CC vs NBR	NT vs NBR
Nitrogen (N lb/A)	33	35	34		48	43	51	51			
Phosphorus (P_2O_5 lb/A)	97	80	74		65	30	28	21			
Soil Respiration-24 hrs (ppm)	44	51	45		40	33	41	39			
Water Extr. Organic C (ppm)	213	222	202		153	165	173	151			*
Water Extr. Organic N (ppm)	14.9	15.1	14.2		13.0	13.7	14.5	13.1			
Carbon: Nitrogen Ratio	14.3	14.7	14.2		11.7	12.1	12.0	11.6			
Soil Health Calculation	8.0	8.8	7.9		6.8	6.3	7.2	6.7			

SB—Soybean; WH stubble—Wheat stubble

Nitrogen and Phosphorus Nutrient Content

These are measures of N and P currently in the soil.

- No significant differences were detected for either N or P.

Soil Respiration

As for the Cornell soil respiration, this measures the amount of microbial activity by measuring the amount of carbon dioxide released. For this test, it is measured over 24 hours. Since this is such a short time period, these measures can be highly variable.

- No differences between treatments.

Water Extractable Organic Carbon and Nitrogen

Like active carbon and protein in the Cornell commercial test, water extractable organic C and N are supposed to measure the amount of carbon and nitrogen in organic matter that is readily available to soil microbes.

- No significant differences for C in 2015, but the no cover/no-till treatment had higher water extractable organic C than the neighbor.
- No significant differences were found for water extractable organic N in 2015 or 2016.

Soil Health Calculation

This is calculated from the 24 hour soil respiration as well as the water extractable organic carbon and nitrogen. It is supposed to represent the overall soil health and can range from 0 to over 30. While the Soil Health Tool does not provide a rating system, they do suggest that good management practices that improve soil health will cause this calculation to increase over time.

- No differences were detected between treatments either year.

Appendix

The rating system provided by Ward Laboratories for Total Biomass, Fungi: Bacteria Ratio and Diversity Index.

Rating	Total Biomass (ng/g)	Fungi: Bacteria Ratio	Diversity Index
Very Poor	< 500	< 0.05	< 1.0
Poor	500+ - 1000	0.05+ - 0.1	1.0+ - 1.1
Slightly Below Average	1000+ - 1500	0.1+ - 0.15	1.1+ - 1.2
Average	1500+ - 2500	0.15+ - 0.2	1.2+ - 1.3
Slightly Above Average	2500+ - 3000	0.2+ - 0.25	1.3+ - 1.4
Good	3000+ - 3500	0.25+ - 0.3	1.4+ - 1.5
Very Good	3500+ - 4000	0.3+ - 0.35	1.5+ - 1.6
Excellent	> 4500	> 0.35	> 1.6