Conservation Cropping Systems Initiative

Report Structure

This report is prepared for three Purdue Agricultural Centers (PACs), 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 three PACs
- Results in detail—this section discusses in detail the individual site results that are summarized in the immediately previous section.

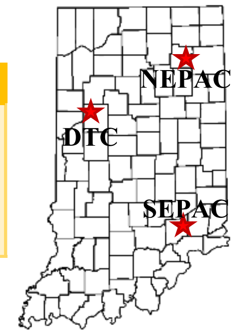
A short summary of the results from all cooperators is provided in a separate report. Further synthesis of all data from all sites is ongoing, and will be provided as available.

Treatments

No-till + Cover Crop—Large Mix

No-till + Cover Crop—Small Mix

No-till, No Cover



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.

Individual Site Report:

Purdue Ag Centers

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Goals of Soil Health Analyses

A key component of the research 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

Summary of Purdue Agricultural Centers

The commercial soil health tests were compared using no-till cover crop treatments at three different Purdue Agricultural Centers across the state of Indiana. Each of these sites compared two different cover crop mixes to a no cover comparison. In general, there were very few significant differences among these treatments at any of the sites for the two biological soil health tests—PLFA and Earthfort. For the small number of significant differences from the Earthfort test, there was no consistent pattern across sites for these measures. For instance, no cover at DTC had the highest number of flagellates, a type of protozoa. In contrast, at SEPAC, no cover had significantly lower numbers of flagellates than the small cover crop mix.

For the other commercial soil health tests that included chemical and/or physical properties in addition to biological, there were also relatively few statistically significant differences. Two sites, DTC and NEPAC, showed increased organic matter with cover crops relative to the no cover comparison. However, this is complicated because this difference was statistically significant at NEPAC only in 2015, but not in the following year. This may be evidence that there are fluctuations in the organic matter from year to year that may be related as much to the cash crop of corn in 2015 compared to soybean in 2016 as to the presence of cover crops.

There is some evidence that the small cover crop mix, which consisted of oat/radish in the fall of 2014 prior to corn and ce-

real rye in fall of 2013 and 2015 prior to soybean, may have improved some soil health indicators to a greater degree than the larger cover crop mix at NEPAC. Aggregate stability and organic matter at NEPAC were significantly higher in the small cover crop mix compared to both the larger cover crop mix and the no cover comparison in 2015. This is likely a residual effect of the cereal rye biomass from spring of 2014 in the small cover crop mix, which was almost double the amount of cover crop biomass from the large cover crop mix. There was also higher phosphorus levels at NEPAC in the small cover crop mix, which may be due to the uptake of P by radish and subsequent decomposition in 2015, releasing P near the soil surface.

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 three PACs—Diagnostic Training Center (DTC) in West Lafayette, Tippecanoe County; Northeast Purdue Agricultural Center (NEPAC) near Columbia City in Whitley County, and Southeast Purdue Agricultural Center (SEPAC) near North Vernon in Jennings County. 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 each location—no-till with a large cover crop mix and with a small cover crop mix, as well as no-till without cover crops. We compared these treatments to evaluate them for statistically significant differences. These are found for each year in the column 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, organic matter at DTC in 2016 from the large and small cover crop mixes are labeled with the letter 'a'. However, since the no cover average value for soil respiration is labeled as 'b', 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.

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

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:

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.

SEPAC Biomass, Fall 2015: Control (upper left), Cereal Rye (upper right), Oat-Radish-Cereal Rye (lower left), Oat-Radish-Clover-Cereal Rye (lower right). Images by Joe Rorick

Site Details - Climate, Soils, Treatments

DTC Treatments

	Summer 2013	Fall 2013 - Summer 2014		Fall 2014 - Summer 2015		Fall 2015 - Summer 2016	
Treatments	**Cash**	**Cover**	**Cash**	**Cover**	**Cash**	**Cover**	**Cash**
NT + CC Large Mix	SB	OA/RD/ CR	SB	OA/RD/ CR/CL	CN	OA/RD/ CR	SB
NT+CC Small Mix	SB	CR	SB	OA/RD	CN	CR	SB
NT	SB	-	SB	-	CN	-	SB

NEPAC AND SEPAC Treatments

	Fall 2012- Summer 2013		Fall 2013 - Summer 2014		Fall 2014 - Summer 2015		Fall 2015 - Summer 2016	
Treatments	**Cover**	**Cash**	**Cover**	**Cash**	**Cover**	**Cash**	**Cover**	**Cash**
NT + CC Large Mix	OA/RD/ CR/CL	CN	OA/RD/ CR	SB	OA/RD/ CR/CL	CN	OA/RD/ CR	SB
NT + CC Small Mix	OA/RD	CN	CR	SB	OA/RD	CN	CR†	SB
NT	-	CN	-	SB	-	CN	-	SB

Treatments at all PAC sites: NT+CC - Cover Crop No-till; NT - No Cover No-till;
Cash and Cover Crop Abbreviations: CN - Corn; SB - Soybean; CR - Cereal Rye; CL - Crimson clover; RD - Radish; OA - Oats
Cover crops are color-coded as light green.

†NOTE: An error in planting cover crops in Fall 2015 caused both cover crop treatments to be planted to the large cover crop mix of oats/radish/cereal rye at the SEPAC site.

Conservation Cropping Systems Initiative

DTC Details

Climate—Mean Annuals	
Temperature:	**50.8°F**
Precipitation:	**38.2 in**

Soil Health Sampling Dates	Soil Moisture (%)		
	NT+CC Large Mix	NT+CC Small Mix	NT
July 6, 2015	NA	NA	NA
July 7, 2016	18.7	18.7	18.5

Conservation Cropping System Experimental Plots						
% of Field	Soil Series Name	Soil Texture	Slope	Drainage Class	Native Vegetation	Parent Materials
55%	Starks	silt loam	0-2 %	Somewhat poorly drained	Forest	Loess over loamy outwash
35%	Fincastle	silt loam	0-2 %	Somewhat poorly drained	Forest	Loess over glacial till

NEPAC Details

Climate—Mean Annuals	
Temperature:	**49.1°F**
Precipitation:	**39.9 in**

Soil Health Sampling Dates	Soil Moisture (%)		
	NT+CC Large Mix	NT+CC Small Mix	NT
June 11, 2015	20.8	21.8	20.8
June 29, 2016	21.0	21.7	19.6

Conservation Cropping System Experimental Plots						
% of Field	Soil Series Name	Soil Texture	Slope	Drainage Class	Native Vegetation	Parent Materials
32%	Glynwood	Loam	2-6 %	Moderately well drained	Forest	Loess and till
30%	Blount	Silt loam	1-4 %	Somewhat poorly drained	Forest	Till
26%	Morley	Loam	3-6%	Moderately well drained	Forest	Loess and till
12%			5-12%			

SEPAC Details

Climate—Mean Annuals	
Temperature:	**53.0°F**
Precipitation:	**47.4 in**

Soil Health Sampling Dates	Soil Moisture (%)		
	NT+CC Large Mix	NT+CC Small Mix*	NT
May 28, 2015	20.7	21.7	23.2
June 20, 2016	21.6	22.5	21.2

Conservation Cropping System Experimental Plots						
% of Field	Soil Series Name	Soil Texture	Slope	Drainage Class	Native Vegetation	Parent Materials
86%	Ryker-Muscatatuck	silt loam	Rolling	Well drained	Forest	Loess over loamy till
14%	Oldenburg	silt loam	0-2 %	Moderately well drained	Forest	Loamy alluvium

Phospholipid Fatty Acids (PLFA)

Phospholipid fatty acids are found in the cell membrane of all cells. Each microbial group also has specific fatty acids only found in the cell membrane of that certain group 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 large cover crop mix/no-till (NT+CC Large Mix), small cover crop mix/no-till (NT+CC Small Mix) and no-till without cover crops (NT) from the three Purdue Agricultural Centers (DTC, NEPAC, and SEPAC) in 2015 and 2016. 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 for soil health indicator are indicated as significant at <0.01 by ***, at <0.05 by ** and at <0.10 at *, and treatments are indicated as statistically different with different letters by the average values. 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.**

DTC	**July 6, 2015**			
	Average Values			
PLFA—Ward Laboratories	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	Significant Differences
Total Microbial Biomass (ng/g)	2438	1501	2159	
Total Bacteria (ng/g)	737	744	830	
Total Fungi (ng/g)	180	163	241	
Mycorrhizal Fungi (ng/g)	35	36	41	
Protozoa (ng/g)	7.3	10.1	9.8	
Fungi:Bacteria Ratio	0.23	0.22	0.29	
Diversity Index	1.45	1.46	1.53	
	July 7, 2016			
	Average Values			
PLFA—Missouri	NT+CC Large Mix (SB)	NT+CC Small Mix (SB)	NT (SB)	Significant Differences
Total Microbial Biomass (nmol/g)	62.9	65.1	58.1	
Total Bacteria (nmol/g)	33.8	34.8	30.6	
Total Fungi (nmol/g)	0.73	1.14	0.99	
Mycorrhizal Fungi (nmol/g)	2.27	2.50	1.99	
Protozoa (nmol/g)	0.51	0.52	0.44	
Fungi:Bacteria Ratio	0.19	0.21	0.20	
Diversity Index	1.33	1.35	1.33	

NEPAC	June 11, 2015			
	Average Values			Significant Differences
PLFA—Ward Laboratories	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	
Total Microbial Biomass (ng/g)	1790	2705	1961	
Total Bacteria (ng/g)	1083	1300	1032	
Total Fungi (ng/g)	101	98	84	
Mycorrhizal Fungi (ng/g)	23	19	20	
Protozoa (ng/g)	8.4	2.2	2.4	
Fungi:Bacteria Ratio	0.09	0.08	0.08	
Diversity Index	1.30	1.26	1.26	
	June 29, 2016			
	Average Values			Significant Differences
PLFA—Missouri	NT+CC Large Mix (SB)	NT+CC Small Mix (SB)	NT (SB)	
Total Microbial Biomass (nmol/g)	94.7	92.6	80.6	
Total Bacteria (nmol/g)	50.8	48.8	41.4	
Total Fungi (nmol/g)	0.72	1.92	0.62	
Mycorrhizal Fungi (nmol/g)	3.45	2.92	2.66	
Protozoa (nmol/g)	0.65	0.58	0.45	
Fungi:Bacteria Ratio	0.17	0.20	0.17	
Diversity Index	1.29	1.31	1.27	

SEPAC Plots: Cereal Rye (background) and Control (foreground) illustrate the benefits of cover crops for erosion control.

SEPAC	May 28, 2015			
	Average Values			Significant Differences
PLFA—Ward Laboratories	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	
Total Microbial Biomass (ng/g)	2198	1811	2034	
Total Bacteria (ng/g)	941	938	1017	
Total Fungi (ng/g)	158	145	90	
Mycorrhizal Fungi (ng/g)	40	50	23	
Protozoa (ng/g)	38.5	44.3	4.7	
Fungi:Bacteria Ratio	0.15	0.15	0.09	
Diversity Index	1.47	1.45	1.3	
	June 20, 2016			
	Average Values			Significant Differences
PLFA—Missouri	NT+CC Large Mix (SB)	NT+CC Small Mix* (SB)	NT (SB)	
Total Microbial Biomass (nmol/g)	68.4	63.7	59.3	
Total Bacteria (nmol/g)	36.8	34.3	30.5	
Total Fungi (nmol/g)	0.83	0.80	0.60	
Mycorrhizal Fungi (nmol/g)	2.68	2.55	2.14	
Protozoa (nmol/g)	0.93	0.43	0.28	
Fungi:Bacteria Ratio	0.19	0.20	0.18	
Diversity Index	1.35	1.34	1.30	

CN—Corn; SB—Soybean
*At SEPAC, the small mix cover crop treatment was mistakenly planted with the large cover crop mix in fall 2015.

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 between treatments was detected in either 2015 or 2016 at any of the three PACs.
- While not statistically different, both DTC and SEPAC had the lowest microbial biomass after the small cover crop mix in 2015. This mix consisted of oats and radish and is the only cover crop mix that would not have overwintered.
    - In contrast, the same cover crop mix in 2015 at NEPAC had the highest microbial biomass.
- 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 all of the treatments at DTC and SEPAC fall in the average category. At NEPAC, the large cover crop mix and the no cover treatment had average microbial biomass, but the smaller cover crop mix was rated as slightly above average.

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 in either year for any of the PACs.

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 differences between any of the treatments for fungi in 2015 or 2016.

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 at any of the PACs.
- In 2016, the cover crop treatments at all three sites tended to have slightly higher values, however this was not statistically significant.

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 difference between treatments was detected in 2015 at any of the PACs.
- Similar to mycorrhizal fungi, protozoa PLFA values tended to be higher in the cover crop treatments than the no cover crop treatment at all three sites, but these differences were not statistically significant.

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.

- No significant difference between treatments was detected in either year for any of the PACs.
- Ward Laboratories has a rating system for this measurement as well (see Appendix).
    - DTC fungi:bacteria ratios were rated as average for both cover crop treatments and good for the no-till treatment without cover crops in 2015. The following year all DTC treatments fell in the average to slightly above average category.
    - The fungi:bacteria ratios at NEPAC were all rated as poor in 2015, but were rated as average in 2016.
    - At SEPAC, the fungi:bacteria ratios were average for both cover crop treatments while the no cover treatment was poor in 2015. All three treatments were average in 2016.

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 treatments at any of the three PACs were significantly different for the diversity index.
- Ward Laboratories provided a rating system for this calculation as well (see Appendix).
    - At DTC, the diversity index was rated as good for both cover crop mixes and very good for the no cover/no-till treatment.
    - The diversity indices of NEPAC were all rated as average, except the small cover crop mix in 2016 was slightly above average.
    - The diversity indices of the cover crop treatments at SEPAC were both rated as good in 2015 while the no cover/no-till treatment was only slightly above average. However, in the following year, all of the treatments were categorized as having slightly above average diversity indices.

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 large (NT+CC Large Mix), small (NT+CC Small Mix) cover crop/ no-till treatments as well as no-till without cover crop treatment (NT) at the three Purdue Agricultural Centers (DTC, NEPAC, SEPAC). Statistical differences for soil health indicator are indicated as significant at <0.01 by ***, at <0.05 by ** and at <0.10 at *, and treatments are indicated as statistically different with different letters by the average values.

DTC	**July 6, 2015**			
	Average Values			
Earthfort	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	Significant Differences
Active Bacteria (µg/g)	39a	34b	34b	**
Total Bacteria (µg/g)	1232	1160	859	
Active Fungi (µg/g)	20	23	17	
Total Fungi (µg/g)	487	462	467	
Protozoa--Flagellates (µg/g)	2439b	3170ab	4621a	*
Protozoa--Amoeba (µg/g)	33172	72404	100801	
Protozoa--Ciliates (µg/g)	71	34	27	
Total Fungi: Total Bacteria Ratio	0.43	0.50	0.58	

NEPAC	**June 11, 2015**			
	Average Values			
Earthfort	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	Significant Differences
Active Bacteria (µg/g)	40	39	41	
Total Bacteria (µg/g)	2127	2285	1703	
Active Fungi (µg/g)	20	30	27	
Total Fungi (µg/g)	171	124	167	
Protozoa--Flagellates (µg/g)	4098	3628	2353	
Protozoa--Amoeba (µg/g)	104107b	181761b	392899a	**
Protozoa--Ciliates (µg/g)	87	260	38	
Total Fungi: Total Bacteria Ratio	0.08ab	0.05b	0.10a	**

SEPAC	May 28, 2015			
	Average Values			Significant Differences
Earthfort	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	
Active Bacteria (µg/g)	85	75	77	
Total Bacteria (µg/g)	2016	2358	2051	
Active Fungi (µg/g)	42	33	28	
Total Fungi (µg/g)	378	388	454	
Protozoa--Flagellates (µg/g)	2657ab	3519a	1209b	*
Protozoa--Amoeba (µg/g)	38112	52739	62212	
Protozoa--Ciliates (µg/g)	86	45	39	
Total Fungi: Total Bacteria Ratio	0.22	0.17	0.25	

CN—Corn

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.

- At DTC, the large cover crop mix had higher active bacteria than the smaller cover crop mix or no-till without cover crop mix. The trend was similar for total bacteria, but these differences were not statistically significant.
- There were no differences between any of the treatments for either total or active bacteria at NEPAC and SEPAC.

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.

- None of the three PACs had significant differences among treatments for total or active fungi in 2015 as measured by the Earthfort analysis.

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.

- Two of the PACs, DTC and SEPAC, both had significant differences among treatments for flagellates; however, the trend for the treatments was very different for the two sites.
    - At DTC, the no-till without cover crops treatment had higher counts of flagellates than the large cover crop mix treatment.
    - The small cover crop mix treatment at SEPAC had more flagellates than the no cover treatment.
    - For NEPAC, there were no significant difference between treatments for flagellates, but the trend among the treatments was similar to SEPAC with higher values for the cover crop treatments than with no cover.
- Only NEPAC had significant differences for the amoeba type of protozoa with higher values in the no-till/no cover treatment than with either cover crop mix.
- None of the PACs had any statistically significant differences for the third type of protozoa, ciliates.

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 at DTC or SEPAC for fungi:bacteria ratio.
- NEPAC had total fungi:bacteria ratios that are lower than the other two PACs with highest values of 0.10 for the no-till/no cover treatment. The fungi:bacteria ratio of the smaller cover crop mix was significantly lower than the no-till treatment without cover crops, which is opposite of what might be expected.

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.

Table 3. Average values for Cornell Soil Health Assessment in 2015 and 2016 from large cover crop mix/no-till (NT+CC Large Mix), small cover crop mix/no-till (NT+CC Small Mix), and no-till without cover crops (NT) at the three Purdue Agricultural Centers (DTC, NEPAC, SEPAC). Statistical differences for soil health indicator are indicated as significant at <0.01 by ***, at <0.05 by ** and at <0.10 at *, and treatments are indicated as statistically different with different letters by the average values.

DTC	**July 6, 2015**				**July 7, 2016**			
	Average Values				Average Values			
Cornell	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	Significant Differences	NT+CC Large Mix (SB)	NT+CC Small Mix (SB)	NT (SB)	Significant Differences
Quality Score	44.5	48.1	45.4		41.1	42.3	39.5	
Aggregate Stability (%)	12.1	12.9	11.3		16.5	16.0	14.6	
Available Water Capacity	0.28	0.28	0.28		0.26	0.26	0.29	
Surface Hardness (psi)	–	–	–		335	341	375	
Subsurface Hardness (psi)	–	–	–		320	336	362	
Organic Matter (%)	1.85	1.90	1.85		1.87a	1.89a	1.82b	*
Active Carbon (ppm)	310	320	305		285	333	261	
ACE Soil Protein Index	3.35	3.55	3.38		3.52	3.54	3.47	
Soil Respiration-96 hrs (ppm)	270	290	280		250	280	240	

NEPAC	**June 11, 2015**				**June 29, 2016**			
	Average Values				Average Values			
Cornell	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	Significant Differences	NT+CC Large Mix (SB)	NT+CC Small Mix (SB)	NT (SB)	Significant Differences
Quality Score	57.1	61.6	55.6		57.2	61.1	59.1	
Aggregate Stability (%)	19.1b	25.1a	17.6b	**	18.3	21.9	16.3	
Available Water Capacity	0.22	0.24	0.24		0.22	0.23	0.23	
Surface Hardness (psi)	–	–	–		244	266	238	
Subsurface Hardness (psi)	–	–	–		265	275	274	
Organic Matter (%)	2.83ab	3.03a	2.58b	**	2.77	3.00	2.68	
Active Carbon (ppm)	444	458	402		486	505	471	
ACE Soil Protein Index	3.83	4.60	3.85		3.80	4.04	4.28	
Soil Respiration-96 hrs (ppm)	410	430	360		350	360	340	

SEPAC	May 28, 2015				June 20, 2016			
	Average Values				Average Values			
Cornell	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	Significant Differences	NT+CC Large Mix (SB)	NT+CC Small Mix (SB) *	NT (SB)	Significant Differences
Quality Score	48.7	49.1	47.5		49.9	47.0	46.4	
Aggregate Stability (%)	17.9	20.1	17.7		19.8	18.2	17.5	
Available Water Capacity	0.28	0.28	0.29		0.29	0.30	0.28	
Surface Hardness (psi)	–	–	–		293	281	337	
Subsurface Hardness (psi)	–	–	–		320	342	338	
Organic Matter (%)	2.17	2.20	2.17		2.29	2.22	2.25	
Active Carbon (ppm)	405	415	384		349	364	317	
ACE Soil Protein Index	3.63	3.67	4.00		4.35	3.95	3.88	
Soil Respiration-96 hrs (ppm)	270	290	300		326	317	265	

CN—Corn; SB—Soybean

*At SEPAC, the small mix cover crop treatment was mistakenly planted with the large cover crop mix in fall 2015.

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.

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.

- There were no significant differences among treatments in either year at any of the three PACs.
- The quality scores for all three treatments at DTC are rated as medium in 2015. In 2016, both cover crop treatments are again rated medium, but the no cover no-till treatment was rated as low as it was just below the threshold for medium.
- The NEPAC quality scores were rated as medium for the large cover crop mix and the no cover no-till treatment while the small cover crop mix is rated as excellent in both 2015 and 2016.
  - The higher rating of the small cover crop mix is probably due to the higher values of aggregate stability and organic matter.
- All three treatments at SEPAC are rated as medium in both 2015 and 2016.

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

- None of the treatments were statistically different at DTC in either year, but the aggregate stability measures were higher for all three treatments in 2016 than they were in the previous year.
- At NEPAC, the aggregate stability of the small cover crop mix was significantly higher than the larger cover crop mix or the no cover no-till treatment in 2015. In 2016, the pattern of aggregate stability among the treatments is similar, but the differences are not statistically significant.

- In spring 2015, cover crop biomass was fairly low for both treatments so it is unlikely to have been the cause of the difference between the treatments. However, the cover crop biomass from the previous year (spring 2014) was much higher for cereal rye in the small cover crop mix compared to the oat/radish/cereal rye mix in the large cover crop mix. Therefore, the greater aggregate stability in the small cover crop mix in 2015 is likely a residual effect from the cover crops grown the previous year.
- At SEPAC, there were no significantly differences among treatments in either 2015 or 2016.

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.

- None of the PACs have any statistically significant differences among the treatments for either 2015 or 2016.

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 2016 at any of the three PACs.

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.

- At DTC, there were no statistically significant differences in 2015, but the organic matter was significantly lower in the no cover/ no-till treatment than the two cover crop treatments in 2016.
- In 2015, the organic matter of the small cover crop mix was significantly higher than the no cover/no-till treatment at NEPAC. There was a similar pattern in 2016 between treatments, but the difference was no longer significant.
    - These results are consistent with the results for aggregate stability for both years as well. As described for aggregate stability, this is probably a result of higher cereal rye biomass from spring of 2014 causing an increase in organic matter during the following year of 2015.
- At SEPAC, none of the treatments were significantly different in either year.

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.

- None of the sites had statistically significant differences among treatments for active carbon in either 2015 or 2016.

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 were found in 2015 or 2016 at any of the three PACs.

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.

- All three PACs had no statistically significant differences between any of the treatments in either year.

SEPAC, Fall 2014

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 from large cover crop mix/no-till (NT+CC Large), small cover crop mix/no-till (NT+CC Small) from and no-till without cover crops (NT) from the three Purdue Agricultural Centers (DTC, NEPAC, and SEPAC) in 2015 and 2016. Statistical differences for soil health indicator are indicated as significant at <0.01 by ***, at <0.05 by ** and at <0.10 at *, and treatments are indicated as statistically different with different letters by the average values.

DTC	**July 6, 2015**				**July 7, 2016**			
	Average Values				Average Values			
Haney-Soil Health Tool	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	Significant Differences	NT+CC Large Mix (SB)	NT+CC Small Mix (SB)	NT (SB)	Significant Differences
Nitrogen (N lb/A)	59	70	72		32	32	31	
Phosphorus (P_2O_5 lb/A)	21	19	23		19	20	17	
Soil Respiration-24 hrs (ppm)	29	29	30		61b	75a	55b	**
Water Extr. Organic C (ppm)	183	185	176		108	106	111	
Water Extr. Organic N (ppm)	13.6	14.0	11.1		11.0	11.1	10.5	
Carbon: Nitrogen Ratio	13.7	13.2	16.0		9.8	9.7	10.5	
Soil Health Calculation	6.1	6.1	5.9		8.3b	9.7a	7.6b	**

NEPAC	**June 11, 2015**				**June 29, 2016**			
	Average Values				Average Values			
Haney-Soil Health Tool	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)	Significant Differences	NT+CC Large Mix (SB)	NT+CC Small Mix (SB)	NT (SB)	Significant Differences
Nitrogen (N lb/A)	55a	55a	52b	**	51	58	50	
Phosphorus (P_2O_5 lb/A)	34b	51a	35b	**	57b	80a	50b	**
Soil Respiration-24 hrs (ppm)	78	87	64		79b	104a	71b	**
Water Extr. Organic C (ppm)	140	129	117		238	285	236	
Water Extr. Organic N (ppm)	10.2	10.0	10.0		19.7	22.4	19.7	
Carbon: Nitrogen Ratio	13.7	12.9	11.7		12.0	12.8	12.0	
Soil Health Calculation	10.2	11.0	8.6		12.2b	15.5a	11.4b	**

SEPAC	May 28, 2015				June 20, 2016			
	Average Values			Significant Differences	Average Values			Significant Differences
Haney-Soil Health Tool	NT+CC Large Mix (CN)	NT+CC Small Mix (CN)	NT (CN)		NT+CC Large Mix (SB)	NT+CC Small Mix (SB) *	NT (SB)	
Nitrogen (N lb/A)	124	115	134		41	38	37	
Phosphorus (P_2O_5 lb/A)	39b	38b	48a	*	23	16	16	
Soil Respiration-24 hrs (ppm)	33	33	65		93	80	66	
Water Extr. Organic C (ppm)	222	201	207		174	163	150	
Water Extr. Organic N (ppm)	13.1	13.1	13.6		16.2	14.9	12.1	
Carbon: Nitrogen Ratio	17.2	15.8	15.6		10.6	11.0	12.6	
Soil Health Calculation	6.8	6.6	9.9		12.7	11.2	9.3	

CN—Corn; SB—Soybean
*At SEPAC, the small mix cover crop treatment was mistakenly planted with the large cover crop mix in fall 2015.

Nitrogen and Phosphorus Nutrient Content

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

- At DTC, no significant differences were detected in 2015 and 2016 for either N or P.
- For NEPAC, the nitrogen measured in the Haney Soil Health test was statistically higher for the two cover crop treatments compared to the no cover no-till treatment in 2015, but the actual difference between the different treatments is relatively small.
- The phosphorus of the NEPAC small cover crop mix was significantly higher than the large cover crop mix or the no cover treatment in both 2015 and 2016.
    - This may be due to the oats/radish cover crop growing in fall 2014. Radish has high uptake of P that then accumulates on the soil surface after it dies and decomposes.
- At SEPAC, the no cover no-till treatment had higher P levels than the two cover crop treatments in 2015, but there were no differences among the treatments in 2016.

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.

- At DTC and NEPAC, there were no significant differences in 2015, but both sites had higher soil respiration rates for the small cover crop mix compared to the large cover crop mix or the no cover treatment in 2016.
- No significant differences among treatments at SEPAC in either 2015 or 2016, but there was a trend towards higher soil respiration in the no cover treatment in 2015, which may be related to the higher P values in the same treatment.
- These results are not consistent with the 96 hour soil respiration as measured in the Cornell test, which we feel is a more reliable measure of soil respiration as it tends to be less variable.

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 were found for water extractable organic C or N at any of the three PACs.

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.

- At DTC and NEPAC, there were no significant differences in 2015, but both sites had higher soil health calculations for the small cover crop mix compared to the large cover crop mix or the no cover treatment in 2016.
    - One part of the soil health calculation is soil respiration so it makes sense that the differences among treatments for the soil health calculation is the same as for soil respiration.
- No differences among treatments at SEPAC in either 2015 or 2016 for the soil health calculation.

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