Final Technical Report for Indiana Corn Marketing Council / Indiana Soybean Alliance
Project start date: August 1, 2015
Project end date: February 28, 2017
Grant number: 208482

Project title: **Cover Crops for Soil Health and Resiliency**
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This final technical report summarizes research conducted during the "cover crop year" of fall 2015 through cash crop harvest 2016, with a grant from the Indiana Corn Marketing Council and Indiana Soybean Alliance. The 2015 ICMC/ISA grant received a no-cost extension through February 2017, due to very late receipt of soil health measurement results from commercial labs.

Research Procedures

This report covers the first of two years of direct ICMC/ISA funding to Kladivko, which built upon a 3-year project funded by a Conservation Innovation Grant (CIG) from the national NRCS (and partially matched by ICMC/ISA funds to the Indiana Association of Soil and Water Conservation Districts for that project). Since many of the benefits of cover crops are expected to take longer than three years to accrue, the ICMC/ISA funding is providing an opportunity to detect the changes that have just started to occur in some of these systems. The objectives of the project were to evaluate and measure the effects of various cover crops on 1) soil health, as indicated by a variety of measures, 2) cover crop biomass production, and 3) corn/soybean yield. The project is testing various cover crops across a range of soils and locations in Indiana, with the ICMC/ISA funding the analyses on a subset of the 17 test sites. Measurements included a range of soil health measures, including three new commercial soil health tests which have caught the attention of farmers. We are evaluating those tests for their usefulness in helping farmers assess the progress and improvement in their soils as the cover crops are grown over multiple years. This project is done in conjunction with the Indiana Conservation Cropping Systems Initiative (CCSI) and in collaboration with all the current partners in the Indiana Conservation Partnership (ICP), who participate in field sampling as well as outreach and Extension activities, workshops, trainings, etc.

The research design was put in place during the original CIG with the Conservation Cropping Systems Initiative, as stated earlier (see the Soil Health Hubs tab under the CCSI website, www.ccsin.org). There were 17 total sites, including 12 farmer cooperators, three Purdue Ag Centers (PACs), the Vincennes University-Jasper Campus, and the Wabash County Farm. This ICMC/ISA funding allowed for continuation of sampling of the three PACs and four of the farmer cooperators. The PACs all consist of six treatments: both corn and soybeans in rotation, each of which have a no cover treatment and two different cover crop treatments, replicated three or four times. The farmer cooperators each have two main treatments, which includes their former system on that field (usually no-till with no cover) and a new treatment where cover crop was added, replicated three or four times. A yearly calendar for the various soil health measures was established (http://ccsin.iaswcd.org/?page_id=813), and a team of designated conservation partnership staff, farmers and agricultural professionals did most of the sampling on the farmer fields, while the Purdue graduate student did all the sampling on the PACs. Measurements included three commercial soil health tests focusing on biology; cover crop biomass and N content; soil nitrate at two times per season; and crop yield.

Results

Commercial soil health measurements

As farmer interest in assessing soil health on their fields continues to increase in Indiana, there are a number of different commercial soil health tests to consider. Each of these tests include many soil parameters, which each focus on different aspects of the soil system. The first of the commercial soil health tests focuses on the soil biology as phospholipid fatty acids (PLFA) are used as indicators of the size of the microbial community overall as well as individual microbial groups. Microbes are the drivers of nutrient cycling and play important roles in the formation of soil organic matter and availability of nutrients. Soils with greater amounts of microbial biomass, bacteria, and fungi are better able to serve those functions. Mycorrhizal fungi form symbiotic relationships with crops and can help increase water and nutrient availability.

Both the Cornell Soil Health Assessment and the Haney Soil Health Tool incorporate soil chemical and biological properties. The Cornell test includes measures of carbon and nitrogen stored within the soil as organic matter. Readily cycled carbon and nitrogen are measured by active carbon and ACE protein content, respectively, and these portions of the soil organic matter serve as easy food for microbes. The protein content, in particular, can be indicative of the amount of nitrogen in the soil that can be made plant available. The Haney Soil Health Tool includes water extractable organic C and N, which also indicate the easily cycled portion of organic matter. Both Cornell and Haney include measures of soil respiration, which can indicate how active the microbes are. The Haney Soil Health Tool also includes a Soil Health Calculation, which is derived from the water extractable C and N as well as the measure of soil respiration.

There are over 30 individual parameters measured among the three commercial soil health tests, so for this report we selected the measures that seemed to better detect the differences among treatments. We also focused on sites that had a cover vs. no-cover comparison in their field (some sites had cover crop over the whole field and then different N fertilizer treatments or different strip-till or vertical till treatments). Results from the three commercial soil health tests show some improvements from the use of cover crops within a no-till system for a number of the soil health measures (Table 1 and 2); however, these improvements are not consistent across sites. In many cases, the improvement in the soil health property was too small to be significantly different. These sites have all been in long-term no-till systems prior to the addition of cover crops. More time may be necessary to show evidence of improvement from cover crops in systems with already high soil health.

We also compared soil health under cover crops/no-till with conventional neighbors (no cover crops/conventional tillage) at five of the farmer cooperator sites (Table 3). While the improvements vary from site to site, in general, there were more significant differences between the cover crop/no-till system and the conventional system than there was between cover/no-till and no-cover/no-till. We can see this more noticeably when we look at one site (DeSutter) and the response ratios of all of the soil health measures for both comparisons of cover/NT to no-cover/NT and cover/NT to conventional neighbor (Figure 1). A response ratio allows us to compare all of the measures at once and is calculated by dividing the cover crop average by the average value measured under the comparison (either no cover or conventional). These response ratios are now unitless and values greater than 1 indicate that cover crop had a positive effect on that soil parameter compared to no cover or to conventional. The response ratios for cover versus conventional are much larger that the response ratios for cover versus no-cover, illustrating the much greater improvement from the conventional system to the cover crop/no-till system. These results suggest that when shifting from a conventional tillage system, we would expect to see more rapid evidence of improvement in soil health measures.

Two of the commercial soil health tests, Cornell Soil Health Assessment and Haney Soil Health Tool, both include similar measures that aim to evaluate the same aspects of the soil system. Soil respiration measures the carbon dioxide released by the microbes and the soil during an incubation period. The primary difference between the soil respiration tests as measured by Cornell and Haney are the length of these incubation periods with Cornell's lasting 96 hours compared to the much shorter 24 hours of Haney's Solvita test. The shorter 24 hours incubation represents the rapid microbial activity occurring after quick wetting and drying patterns, such as those that may occur in the fields. The longer 96 hour incubation would represent more longer term favorable conditions with adequate moisture. In general, most sites saw an increase in soil respiration with cover crops compared to no cover, although this difference was not significant at all sites, as can be seen in Figure 2 where we focus on just four of the sites. At two of the sites with both single species cover crop and cover crop mix, the single species cover crop led to greater soil respiration than the mix. This is somewhat surprising as we would expect to see greater plant diversity leading to greater microbial diversity as the microbes get a more varying supply of food; however, this apparently does not necessarily lead to more microbial activity. While both Cornell and Haney tests detected significantly greater soil respiration for single species cover crop at one site (Rulon), this was an exception as most significant differences detected were for one test but not both. While we see different results for the two tests, we cannot determine at this point that either is better at detecting improvements in soil health.

Another aspect of the soil that both the Cornell and Haney commercial tests evaluate is the rapidly cycled portion of soil organic matter carbon and nitrogen. For the carbon component Cornell's active carbon (Figure 3A) and Haney's water extractable organic C (Figure 3C) both show some improvements under cover crops compared to no cover, but this was not consistent across sites or between tests. Similar results but with less significant differences were found for the nitrogen tests, Cornell's protein content (Figure 3B) and Haney's water extractable organic N (Figure 3D). As with soil respiration, cover crops were able to increase this measure of soil health at some sites, but often not to a significantly different degree, and neither Cornell nor Haney's versions were more successful at detecting change.

Cover crop growth, N uptake, soil nitrate, and crop yields

Cover crop establishment and growth varied widely across the sites, as expected with such a diverse group of sites, harvest timings, cover crop seeding methods, and fall weather. About half of the sites had enough fall cover crop growth to sample in fall 2015, while the others had minimal growth. Of the sites with sufficient growth to sample, above-ground biomass generally ranged between 100-1300 lb/A dry material, with most sites less than 500 lb/A. Because the plants were small and young, the nitrogen concentration in the biomass was relatively high, ranging from about 2.5 to 5% N. Total N content of the biomass ranged from about 5-30 lb N/A, scavenged from the soil. On those sites with reasonable amount of fall growth and N uptake, there was also a lower concentration of nitrate in the soil, reflecting the scavenging of the nitrate by the cover crop. This lower soil nitrate concentration would lower the potential for nitrate losses to drainage waters over the fall, winter, and early spring.

Cover crop growth in spring 2016 also varied widely, depending on cover crop species, specific management practices, and weather. Some cover crops were planned to winter-kill, such as daikon radish and oats, and so no live biomass was present (except perhaps weeds). For cover crops that overwintered, above ground biomass ranged from about 100-900 lb/A dry material when terminated before corn, and for the later kill before soybeans at the Purdue farms it ranged from about 2200-3200 lb/A. As is typical with the more mature but still vegetative plants in spring, the N% was lower than fresh growth in the fall and ranged from 1.6 to 2.5% N. Total N in biomass ranged from 10-20 lb N/A before corn and 30-40 lb N/A before soybeans, due to the greater growth allowed before soybeans. Soil nitrate on those sites with sufficient spring cover crop growth, showed lower nitrate at the time of cover crop termination than the control areas with no cover crops, again reflecting the N in the cover crop biomass. This lower soil nitrate at the early part of the season means that nitrate has been protected from leaching and is contributing to the “soil N bank account.” It also reinforces the idea that starter N fertilizer may be more important for corn following cover crops than where cover crops are not grown, due to the short-term lower nitrate concentration resulting from good cover crop growth.

A few farmer cooperators have experimented with diverse cover crop mixtures, or “cover crop cocktails”, as a way to produce greater amounts of biomass with greater diversity than just one or two species. These cocktails generally fit best in a corn-soybean-wheat rotation or in another crop that is harvested very early. We’ll discuss results from one cooperator (DeSutter) who planted a cocktail mix in summer 2015 after harvest of wheat and application of chicken litter, in preparation for planting corn in 2016. As shown in Fig. 4A, the cover crop mix produced a tremendous amount of growth by the time of sampling in fall. Although volunteer wheat was present in the “no cover” control strips, the cocktail mix had much greater biomass and diversity of species. Total biomass was over 5000 lb/A dry material for the cocktail mix vs slightly over 1000 lb/A for the volunteer wheat. The N% was higher in the wheat than in the mix (Fig. 4B), due to the wheat being vegetative while the mix had some summer grass species flowering or already mature. Total amount of N in the biomass was 130 lbs N/A for the cocktail mix vs. 54 lbs N/A for the volunteer wheat (Fig. 4C). The large amount of N in the cocktail mix biomass was also reflected in the lower soil nitrate concentration (only 2ppm in mix vs. 27ppm in volunteer wheat control, Fig. 4D), again illustrating the cover crop scavenging soil nitrate and protecting it from leaching losses. This can be especially important when applying manures, as was the case on this field, to make full use of the N from the manure rather than allowing significant portions of this to be leached away over winter.

Corn and soybean yields from most sites have not been significantly affected by cover crops in the first few years of the project. Most of these sites had already been in long-term no-till and had good soil health, so the additional benefits of cover crops may take longer to become apparent in crop yields than from just a few years of cover crop growth.

Summary and Extension/Outreach

The commercial soil health tests are beginning to show a few differences between cover and no cover treatments on some of the sites. Differences may be small in part due to the overall good soil health of the long-term no-till fields that were the basis of much of the study. New conventional comparisons were found for some of the farmer sites in 2016, and in general they showed greater differences. This suggests that the soil health tests may be more useful over the short term for farmers first converting from conventional systems to using no-till and/or cover crops. For farmers already using long-term no-till and now adding cover crops, the additional improvements in soil health may take a longer time to detect. All of this of course depends on the amount of cover crop growth achieved, with greater growth leading to greater/faster improvements. Some of the sites achieved very little cover crop growth in either fall or spring for a variety of reasons, and so it is expected that there will not be much change in soil health resulting from such small amounts of growth. The environmental impact of scavenging soil nitrate in fall to protect it from losses over the fall, winter, and early spring, also of course depends on the amount of cover crop growth, but these effects were more commonly detected as long as there was sufficient growth in any given year.

Preliminary results have been presented at various Extension/research field days, winter programs, and conferences. Kladivko regularly helps organize and speaks at workshops, trainings, field days, and other Extension and conservation cropping events throughout Indiana. The results are also being shared through the conservation partnership staff who help with sample collection and with coordinating workshops and other outreach events at the cooperating farmers' fields. Within the next year, we anticipate writing some Extension factsheets about the project and posting summaries on the Purdue site as well as on the CCSI website (www.ccsin.org). We do not yet have sufficient evidence to recommend these soil health tests to farmers as a routine test, but there may be some usefulness to doing these tests periodically to monitor change, especially when converting from conventional no-cover systems to those with cover crops and no-till.

Tables

Table 1. Mean values of 12 soil health parameters measured in 2016 for cover (CC) and no cover (NC) treatments at sites in NE and SE regions of Indiana. Some sites also included cover crop mixtures (CC Mix) and single species cover crops (CC one). Significant differences between treatment means within a single location are indicated by different letters at significance level of 0.10.

	NE Region								SE Region	
	NEPAC			Scott			Shuter		SEPAC	
PLFA	CC Mix	CC One	NC	CC Mix	CC One	NC	CC	NC	CC Mix	NC
Total Microbial Biomass (nmol/g)	94.7	92.6	80.6	60.4	59.2	54.8	95.8	87.7	66.0	59.3
Total Bacteria (nmol/g)	50.8	48.8	41.4	34.7	33.7	30.7	53.7	50.2	35.5	30.5
Total Fungi (nmol/g)	0.72	1.92	0.62	0.71 a	0.55 ab	0.46 b	1.15	0.86	0.81	0.60
Mycorrhizal Fungi (nmol/g)	3.45	2.92	2.66	2.62	2.53	2.32	4.24	3.92	2.62	2.14
Cornell										
Organic Matter (%)	2.77	3.00	2.68	1.85	2.02	2.00	2.86	2.56	2.25	2.25
Active Carbon (ppm)	486	505	471	399	425	447	707	644	356	317
ACE Protein Content	3.80	4.04	4.28	4.10	4.44	4.54	5.54	5.38	4.15	3.88
Soil Respiration (ppm in 96 hrs)	354	363	337	339	357	363	512	533	322 a	265 b
Soil Health Tool (Haney)										
Solvita CO2 (ppm in 24hrs)	79.5 a	100.8 a	68.3 b	35.7	29.2	36.3	115.6 a	87.4 b	86.6	66.1
Soil Health Calculation	12.5 b	15.2 a	11.1 c	6.3	5.7	6.6	17.2 a	11.7 b	11.9	9.3
Water Extractable Organic C (ppm)	250.5	286.4	232.0	148.2	154.5	162.1	250.8 a	170.8 b	168.6	149.7
Water Extractable Organic N (ppm)	20.8	22.4	19.3	12.8	12.7	13.7	31.0	34.7	15.6 a	12.1 b

Table 2. Mean values of 2016 soil health measures for cover (CC) and no cover (NC) treatments at sites in NW and SW regions of Indiana. Some sites also included single species cover crops (CC one) and mixtures (CC Mix). Significant differences between treatment means within a single location are indicated by different letters below the means at significance level of 0.10.

	NW Region								SW Region					
	DeSutter		DTC			Rulon			Brocksmith		Stahl		Villwock	
	CC	NC	CC Mix	CC One	NC	CC Mix	CC One	NC	CC	NC	CC	NC	CC	NC
PLFA														
Total Microbial Biomass (nmol/g)	73.5	69.0	62.9	65.1	58.1	56.5	55.1	49.7	72.3	86.5	68.7	68.6	72.2	61.9
Total Bacteria (nmol/g)	38.9	37.1	33.8	34.8	30.6	31.6	30.4	26.8	38.8	47.1	36.9	37.2	40.2	34.5
Total Fungi (nmol/g)	0.49	0.51	0.73	1.14	0.99	0.41	0.42	0.43	1.10	0.82	0.80	0.77	1.29	1.13
Mycorrhizal Fungi (nmol/g)	2.62	2.68	2.27	2.50	1.99	2.21 a	2.12 a	1.86 b	2.70	3.18	2.35	2.45	2.96	2.36
Cornell														
Organic Matter (%)	3.29	3.08	1.87 a	1.89 a	1.82 b	2.43 a	2.43 a	1.98 b	2.19	2.21	2.02	1.98	1.83 a	1.57 b
Active Carbon (ppm)	576	525	285	333	261	391	393	354	411 a	397 b	367	365	427	387
ACE Protein Content	5.33 a	4.91 b	3.52	3.54	3.47	3.91	3.71	3.25	4.45	4.49	4.42	4.27	4.50 a	4.01 b
Soil Respiration (ppm in 96 hrs)	337	324	249	283	237	220 b	324 a	235 b	375 a	354 b	353 b	380 a	472 a	394 b
Soil Health Tool (Haney)														
Solvita CO2 (ppm in 24hrs)	131.0	124.9	63.4 b	77.4 a	55.9 c	61.0 c	88.8 a	75.3 b	98.1	84.5	74.1	94.1	72.1	50.1
Soil Health Calculation	18.2	17.4	8.7	10.1	7.7	10.5 b	13.2 a	11.7 b	13.5	11.6	11.5	13.5	11.4	8.7
Water Extractable Organic C (ppm)	264.6	254.7	115.7	114.8	108.9	232.2	237.2	220.9	184.0 a	155.3 b	218.4	218.4	216.8	187.8
Water Extractable Organic N (ppm)	24.5	23.5	11.5	11.9	10.5	20.4	19.1	19.3	19.0	16.1	19.3	19.0	20.7	18.0

Table 3. Mean values for cover crops (CC) and conventional (Conv) comparison at four Indiana sites for 2016 soil health measures. Significant differences between treatment means within a single location are indicated by different letters below the means at significance level of 0.10.

	Brocksmith (SW)		DeSutter (NW)		Scott (NE)		Villwock (SW)		Werling (NE)	
PLFA	CC	Conv	CC	Conv	CC	Conv	CC	Conv	CC	Conv
Total Microbial Biomass (nmol/g)	—	—	73.5 a	54.9 b	59.8	66.4	72.2	75.3	93.1	85.5
Total Bacteria (nmol/g)	—	—	38.9 a	28.9 b	34.2	35.8	40.2	40.5	51.5	46.9
Total Fungi (nmol/g)	—	—	0.49	0.81	0.63 b	0.87 a	1.29	1.17	0.70	0.80
Mycorrhizal Fungi (nmol/g)	—	—	2.62 a	1.45 b	2.58	2.53	2.96 a	2.48 b	2.83	3.24
Cornell										
Organic Matter (%)	2.19 b	2.72 a	3.29	2.96	1.94	1.59	1.83 b	2.96 a	3.42	3.20
Active Carbon (ppm)	411	442	576 a	354 b	412 a	306 b	427	517	407	466
ACE Protein Content	4.45	4.61	5.33	5.22	4.27 a	3.13 b	4.50	4.82	3.96 a	3.50 b
Soil Respiration (ppm in 96 hrs)	375 a	295 b	337 a	250 b	348 b	420 a	472	470	364 b	426 a
Soil Health Tool (Haney)										
Solvita CO2 (ppm in 24hrs)	98.1	107.2	131.0 a	82.1 b	32.4	39.2	72.1	86.5	34.2	44.4
Soil Health Calculation	13.5	13.6	18.2 a	13.1 b	6.0	6.7	11.4	12.9	8.3	8.8
Water Extractable Organic C (ppm)	184.0 a	154.2 b	264.6	245.1	151.3	151.0	216.8	225.9	282.3	249.9
Water Extractable Organic N (ppm)	19.0 a	13.3 b	24.5	24.1	12.7	13.1	20.7	19.6	20.3	18.2

Figures

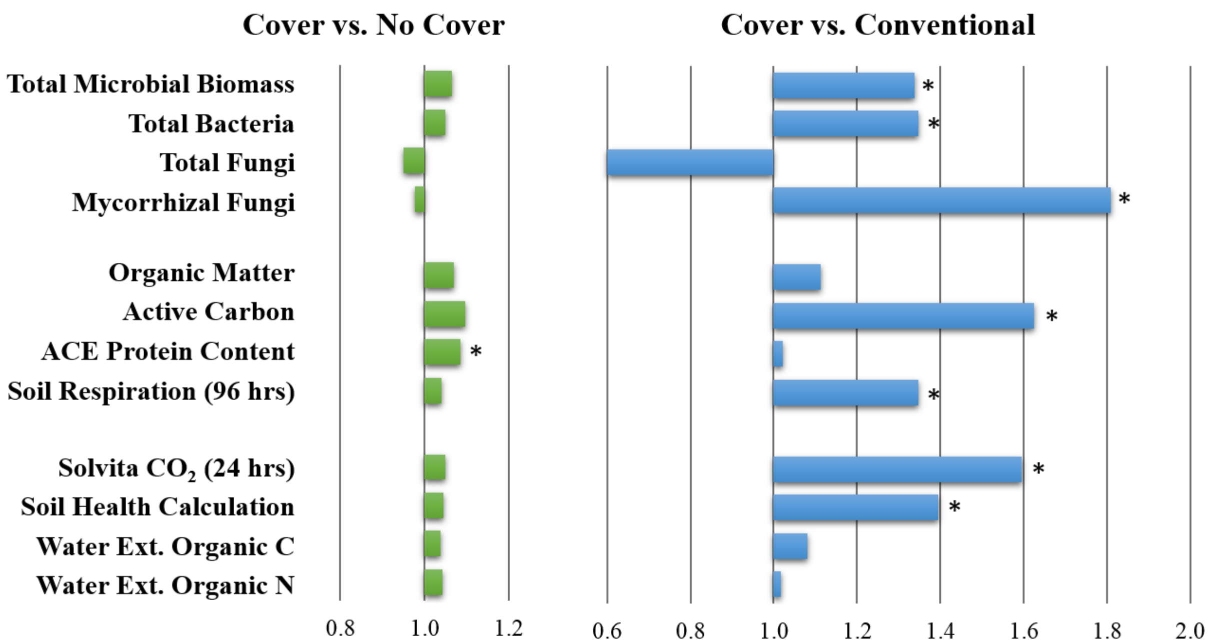

Figure 1. Response ratios of 12 soil health measures for 2016 sampling at DeSutter cooperator site in NW Indiana. Values greater than 1 indicate a positive effect of cover crop compared to either no cover (left) or the conventional neighbor (right) while values below 1 indicate a negative effect of cover crops relative to their comparison. Treatment pairs that were significantly different at 0.10 level are indicated by asterisk.

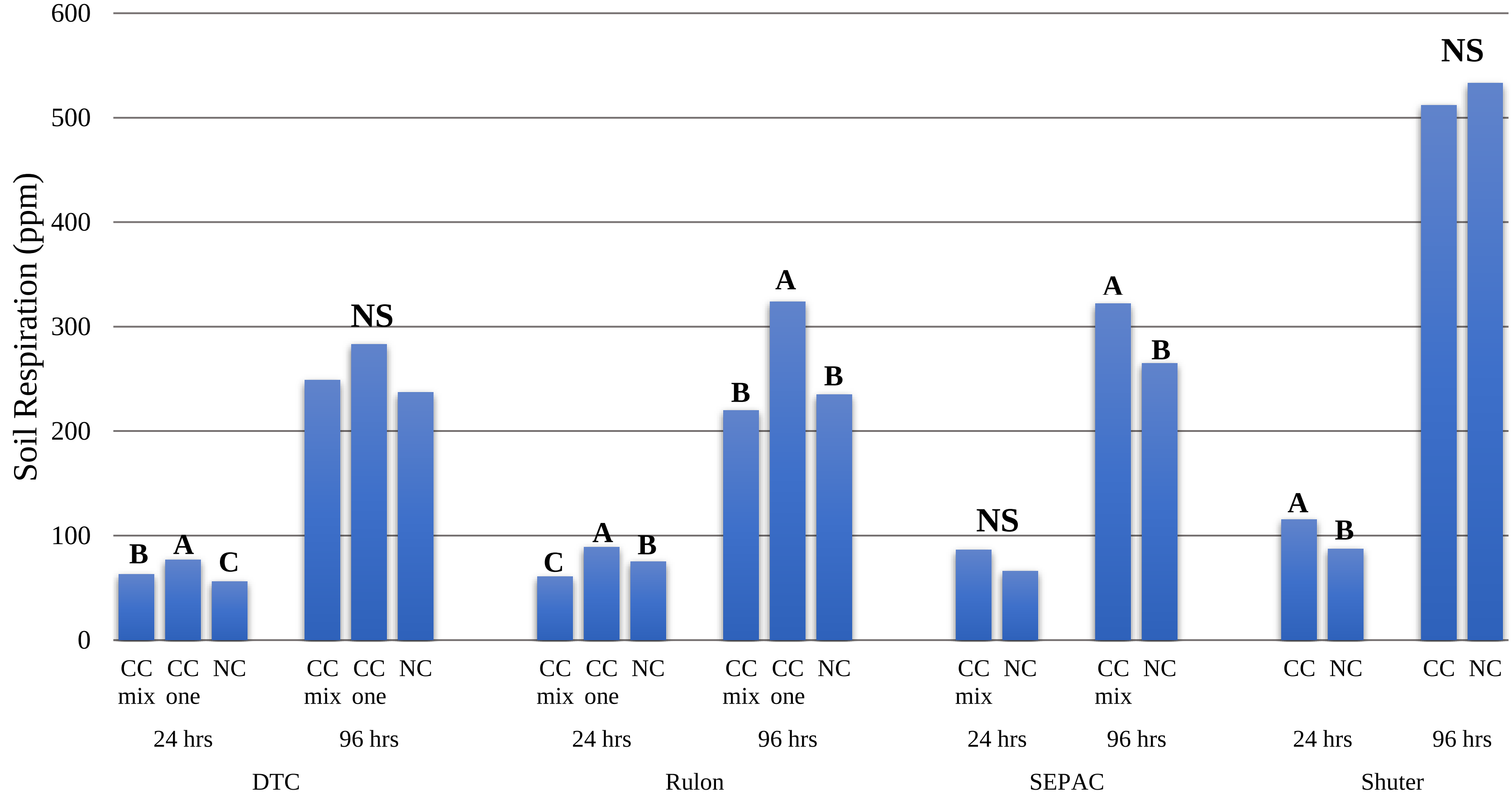

Figure 2. Soil respiration from four Indiana sites in 2016 as measured in two commercial soil health. The Haney Soil Health Tool uses a 24-hour Solvita CO_2 respiration test while the Cornell Soil Health Assessment measures respiration over a 96-hour period. Treatments include no cover (NC) or cover crop (CC) with some sites also including cover crop mixtures (CC Mix) and single species cover crops (CC one). For each site, cover crop treatments with different letters are significantly different at 0.10 level, and treatments that were not significantly different from one another are indicated by "NS".

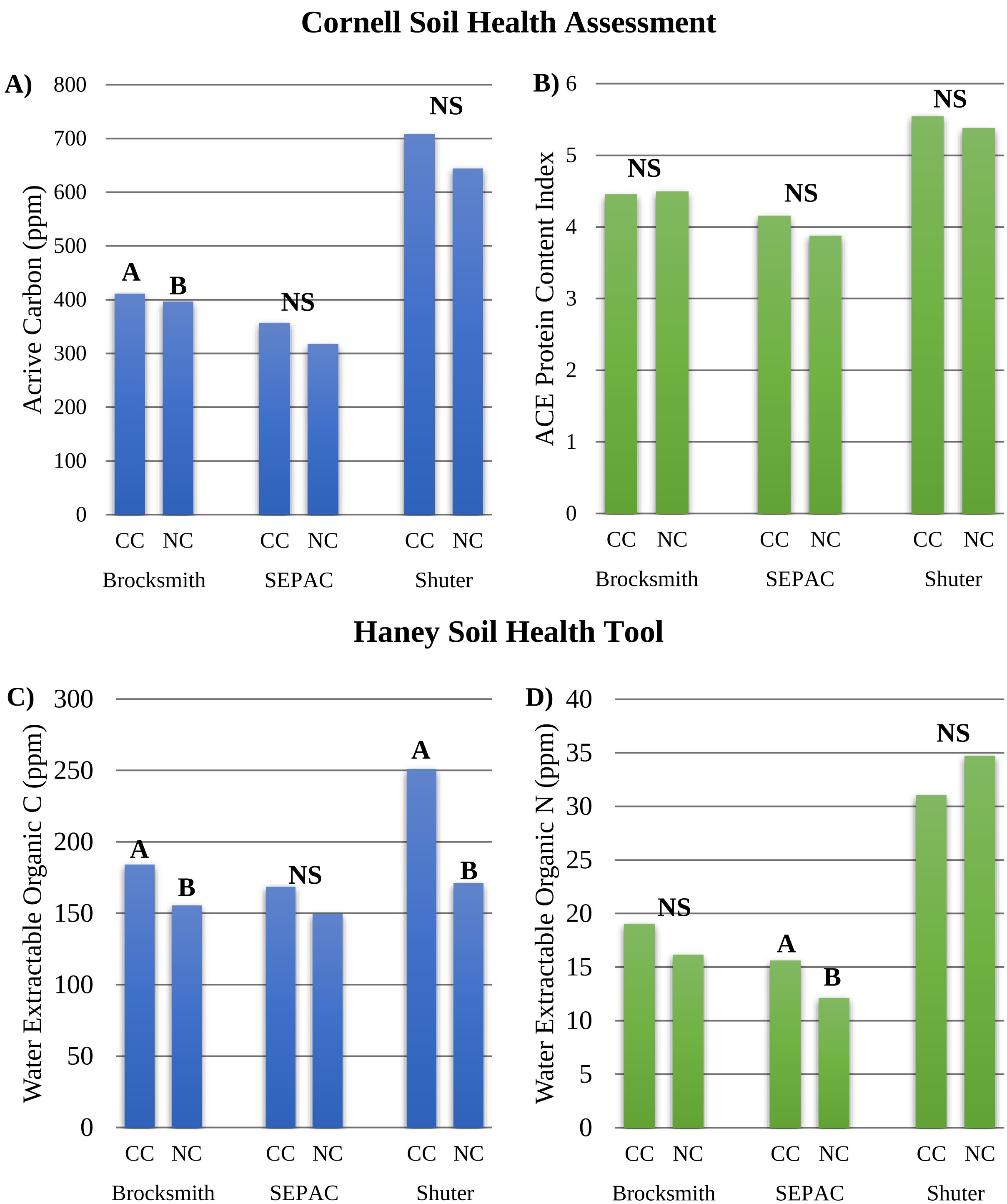

Figure 3. Means for the commercial soil health tests evaluating the most rapidly cycled portion of soil organic matter measured in 2016 at three Indiana sites comparing cover crops (CC) and no cover (NC). The tests include A) active carbon and B) ACE protein content from Cornell Soil Health Assessment and C)water extractable organic carbon and D) water extractable organic nitrogen from Haney Soil Health Tool For each site, cover crop treatments with different letters are significantly different at 0.10 level. Treatments that were not significantly different from one another are indicated by “NS”.

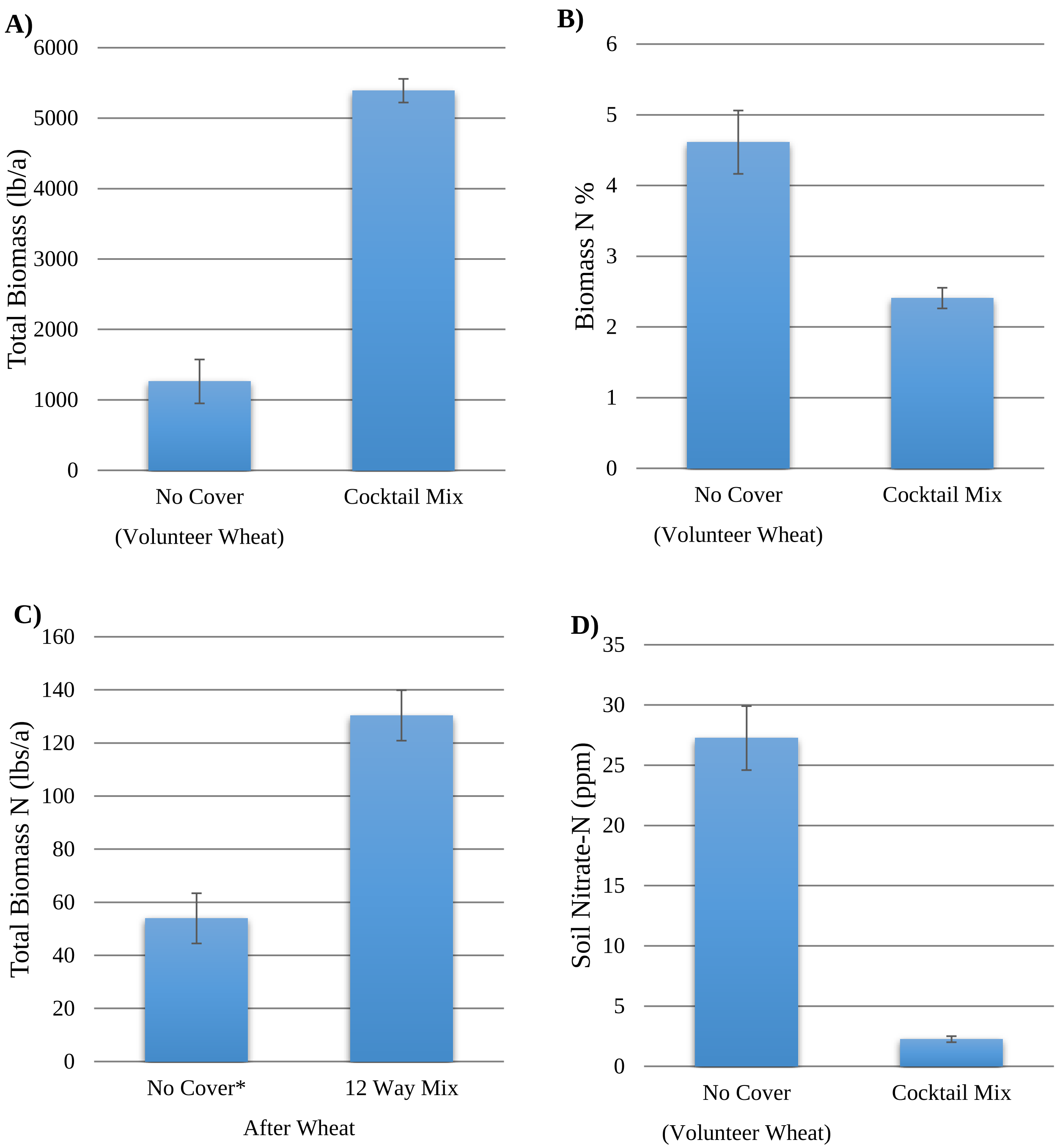

Figure 4. Fall 2015 means and standard errors of A) total biomass, B) N%, C) biomass N, and D) 0-12" soil nitrate-N at DeSutter with a cover crop cocktail mix treatment compared to a no cover treatment. The no cover plots contained volunteer wheat growth.