SOIL AGGREGATION AND SOIL CARBON MEASUREMENTS TO ASSESS COVER CROP IMPROVEMENTS TO SOIL HEALTH IN INDIANA

by

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To my family.

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LIST OF ABBREVIATIONS

MWD = Mean weight diameter

SAC = Soil active carbon

TSAC = Weighted average concentration of soil active carbon

SOM = Soil organic matter

TSOM = Weighted average concentration of soil organic matter

CC = Cover crop treatment

NC = No cover crop treatment

NT = No tillage with cover crop use treatment

ST = Strip tillage with cover crop use treatment

CT = Conventional tillage with cover crop use treatment

CONV = Conventional tillage with no cover crop use treatment

Mix = Large cover crop multispecies mixture treatment

One = Small cover crop multispecies mixture or Single species cover crop treatment

CR13 = Cereal rye cover crop planted in 2013 treatment

WH13 = Wheat cover crop planted in 2013 treatment

Low = 101 kg ha^{-1} Nitrogen application treatment

Medium = 145 kg ha^{-1} Nitrogen application treatment

High = 201 kg ha^{-1} Nitrogen application treatment

AR = Annual ryegrass cover crop treatment

CR = Cereal rye cover crop treatment

O/R = Oat and radish cover crop treatment

NC-Corn = No cover crop following corn cash crop treatment

CR-Corn = Cereal rye cover crop following corn cash crop treatment

O/R/CR-Corn = Oat, radish, and cereal rye cover crop mix following corn cash crop treatment

NC-Soybean = No cover crop following soybean cash crop treatment

O/R-Soybean = Oat and radish cover crop mix following soybean cash crop treatment

O/R/CC/CR-Soybean = Oat, radish, crimson clover, and cereal rye cover crop mix following soybean cash crop treatment

ABSTRACT

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Cover crop use, especially in no-till systems, is an evolving practice to maintain or improve soil health. There are many possible indicators of soil health, but this study focuses on the analysis of soil aggregate stability, soil active carbon, and soil organic matter. Soil aggregate stability is related to water infiltration and potential for soil erosion, while active carbon serves as an indicator of a readily-available food source for microbial activity, and soil organic matter serves as a mediator for the soil physical, chemical, and biological processes. The sites involved in this study were: three Purdue Agricultural Centers, two soil and water conservation district sites, 12 farmer sites with conservation cropping systems, and seven conventional comparison sites. The treatments consisted of cover crop versus no cover crop use, or cover crop use with different tillage systems or nitrogen rates.

In 2016 and 2017, mostly in the summer, soil samples were collected at a depth of 0-5 cm, air-dried, and separated into two soil size fractions: 0-2 mm and 2-8 mm. The wet sieve method was used to measure the mean weight diameter of the water stable soil aggregates from the 2-8 mm soil size fraction in both years. The potassium permanganate method was used to measure the soil active carbon from the 0-2 mm and 2-8 mm soil size fractions in both years. The dry combustion method was used to measure the soil organic matter from the 0-2 mm and 2-8 mm soil size fractions for the samples taken in 2017 only.

Results showed relatively small improvements in soil active carbon and aggregate stability with the addition of three to four years of cover crops to the long-term no-till systems. However, these improvements were greater when comparing the cover crops plus no-till treatments to the conventional-till without cover crop systems. More work is needed to understand the dynamics of soil aggregate stability, soil active carbon, and soil organic matter in relation to soil health and cover crop use. Cover crops will likely have more

impact on soil aggregate stability, soil active carbon, and soil organic matter with a longer duration of use.

CHAPTER 1. INTRODUCTION

According to the Food and Agriculture Organization of the United Nations, cover crops are a central component in conservation agriculture and improve the probability of achieving success with continuous no-till farming (Islam and Reeder, 2014; Kassam et al., 2015). Cover crops provide ground cover and root activity at the times of year where no cash crop is growing (Acuña and Villamil, 2014). Benefits of cover crops can include: reduce soil erosion, conserve soil moisture, protect water quality, reduce the need for herbicide and pesticides, and in the long term improve yield and cut fertilizer (Sustainable Agriculture Research and Education Program, 1992). In this study, cover crops were investigated as a way to improve the soil health on agricultural farms in the state of Indiana. Soil health is described as “the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans” (USDA NRCS, 2018a)

History of conservation agriculture, no-till, and cover crop use

In the middle ages, conventional tillage was primarily in the form of a moldboard plow. This technique lifts, twist, and inverts soil while incorporating crop residue and animal wastes into the plow layer. Conventional tillage was important then, because it killed weeds before herbicides existed and broke up clods encouraging seed emergence (Brady and Weil, 2010). In previous studies, tillage has been helpful to accelerate biological decomposition of plant biomass due to the higher availability of oxygen. The better soil contact with residue, and more consistent moisture. However tillage breaks up soil and exposes the stored soil organic carbon, which reduces the soil organic matter in the topsoil layer (Kumar et al., 2017). Overall, tillage systems affect the physical and chemical environment of soil such as the soil water content, temperature, aeration, and the degree of mixing of crop residue into the soil (Kladivko, 2001).

In the 1930s during the Dust Bowl, the United States (US) began to adopt the concept of reduced tillage and keeping the soil covered as an option to reduce wind and water erosion (Kassam et al., 2015). It wasn’t until the 1960s that no-till farming began in the US but it was mostly successful in soils that were well drained on sloping areas. Now it has evolved to include using cover crops, which made it more adaptable for all soil types (Islam and Reeder, 2014). No-till when managed with other conservation practices like the inclusion of cover crops may increase the soil organic matter content (Sharma et al., 2013; Kinoshita et al., 2017). These beneficial effects are stimulated due to the increase of biomass produced by cover crops, which could enhance soil health and productivity by the addition of soil biological diversity and thereby increase the viability of no-till systems.

Soil health and some soil health indicators

The term soil health, also referred to as soil quality, involves many types of soil physical, biological, and chemical properties and processes that simultaneously occur in the soil all the time. Soil quality and productivity are directly linked to soil organic matter and soil organic carbon (Kaspar and Singer, 2011). In no-till management, soil aggregate stability increases with the concentrations of soil organic carbon and soil active carbon (Acuña and Villamil, 2014; Kibet et al., 2016). The additional soil organic matter of continuously growing root systems regulates carbon inputs and stimulates soil microbial activity due to the increased supply of root exudates, water, nutrients and oxygen to microorganisms (Kumar et al., 2017).

Soil aggregates are the fundamental unit of soil function (Kittredge, 2015) and are the dynamic soil property found in the surface (Brady and Weil, 2010). They are indicators of the soil physical properties and create protected space for carbon (Kittredge, 2015). Soil aggregate stability is commonly referred to as its resistance against water and wind erosion forces, however the aggregates remain porous enough to let air, water, and roots move through them (Kittredge, 2015). Aggregate stability is commonly measured as water-stable aggregates, due to the important relationship with minimizing crusting and erosion plus maximizing water and air entry into the soil for good seedling emergence (Kladivko et al., 1986).

Soil active carbon is often measured as Permanganate-Oxidizable Carbon (POXC), which is part of the chemical and biological properties of soil (Cambardella and Elliott, 1992; Brady and Weil, 2010). It is part of the easily decomposable pool of soil organic matter, which can account for few to large amounts of soil carbon (USDA NRCS, 2014) and is a readily available food and energy source for soil microbial life (Weil et al., 2003). Soil organic matter serves as a mediator for many of the physical, chemical, and biological soil processes (Doran and Parkin, 1994; Lehmann and Kleber, 2015).

Cover crop use today

Only 3 to 7 percent of farms incorporate cover crops in their rotations in the United States (Wallander, 2013). Even with the farmers that use cover crops, only 1 percent incorporate all of their land into cover crops (Wallander, 2013). One of the risks for farmers to transition into using cover crops involves the financial responsibility to invest in a management practice that pays for itself in the long term but does not show immediate results (Singer, 2008; Blanco-Canqui et al., 2015; Christianson et al., 2017). However, most farmers who commit to transitioning to cover crops are interested to control their soil loss from erosion and increase their soil organic matter across their fields (Singer et al., 2007). Some farmers are also creating their own cover crop mixtures for the purpose of different plant benefits, such as: height, rooting patterns i.e. legume and non-legumes, growth patterns, nutrient contents, allelopathic chemical contents, and adaptability to work together (Islam and Reeder, 2014).The cover crop mixtures are a variety of species and are colloquially called the number of species in the mixture followed by “way mix”, such as “14-way mix.” Cover crops (Sustainable Agriculture Research and Education Program, 1992) and cover crop mixtures help recycle above and below ground biomass, nutrients, and carbon that is accumulated during the growing season (Islam and Reeder, 2014).

Background and objectives of study

The Conservation Cropping Systems for Soil Health and Productivity (CCSSHP) Project began in 2012. The CCSSHP project is focused on developing more sustainable agriculture and improving soil health to help meet the demands of our growing world population. This project is built upon Indiana’s Conservation Cropping Systems Initiative (CCSI) that promotes a management strategy and sustainable cropping system to protect our natural resources and improve our soil. This approach allows farmers to efficiently produce food, feed, and fiber in an environmentally manner. As the CCSI philosophy goes "a farmer disturbs the soil as little as possible allowing plants, microbes, insects, and mother nature to do the work. The result is healthier, more productive soil." (Indiana Association of Soil and Water Conservation Districts, 2016)

In collaboration with CCSI, the CCSSHP project involved seventeen sites with a range of different soil types and varying climate conditions, established across Indiana for research and outreach activities. Indiana was subdivided into four regions, with each region containing four to five regional "hub farms". Three of these sites were owned and operated by Purdue University, two by Soil and Water Conservation Districts, and the remaining twelve by farmer cooperators. In 2016, six conventional farmer comparison sites were added to the project for that year. The objectives of this study were to:

1) measure the soil aggregate stability in the 2-8 mm soil size fraction for the 2016 and 2017 sampling years;
2) measure the soil active carbon content in both soil size fractions: 0-2 mm and 2-8 mm for 2016 and 2017 sampling years;
3) measure the soil organic matter content in both soil size fractions: 0-2 mm and 2-8 mm for 2017 sampling year;
4) determine the relationship of the soil aggregate stability, soil active carbon, and soil organic matter measurements with one another and if one or a combination is better at detecting differences than the other measurements;
5) determine if the 0-2 mm and/or 2-8 mm soil size fractions of the soil active carbon or soil organic matter indicates a significant change with cover crop use or management.

The hypotheses of this study were:

1) soil aggregate stability, soil active carbon, and soil organic matter measurements will be greater in fields with cover crops and no-tillage than in no cover and conventional tillage fields;
2) the multispecies cover crop mixture treatments will have greater soil aggregate stability, soil active carbon, and soil organic matter measurements than the no cover crop treatments;

3) the multispecies cover crop mixture treatments will have greater soil aggregate stability, soil active carbon, and soil organic matter measurements than the single species cover crop treatments;
4) the single species cover crop treatments will have greater soil aggregate stability, soil active carbon, and soil organic matter measurements than the no cover crop treatments;
5) the 2-8 mm soil size fraction will have greater soil active carbon and soil organic matter measurements than the 0-2 mm soil size fraction.

CHAPTER 2. METHODS AND MATERIALS

Site Selection

In this study, three Purdue Agricultural Centers (PAC), two Soil and Water Conservation Districts (SWCD) affiliated sites, 12 farmer sites with conservation cropping systems, and six conventional comparison sites were sampled in the summer or late fall of 2016 and a selected few in the summer of 2017. The sites were established in fall 2012 as part of the CCSHP project. Since then, one PAC and two farmer sites have been modified and six conventional comparison sites were added to the project in 2016. The PAC referred to as "DTC" in this thesis was retired after harvest in fall 2016 and a new field was established in its place, referred to as "NewDTC." Both the DTC and NewDTC fields were sampled in 2016, however only the NewDTC field was sampled again in summer 2017. In 2016, the Werling farm consisted of four cover crop plots but was altered to four blocks of three treatments in 2017, and the Werling conventional comparison site remained the same for both 2016 and 2017 samplings. Shuter Farm established a new field beginning fall 2015 in place of the original CCSHP field.

Site Descriptions and Experimental Designs

Information regarding the site locations, annual precipitation, and annual temperature are located in Table 1 provided by the CCSI Reports (Zuber and Kladivko, 2018). The soil classification information can be found in Table 2 (California Soil Resource Lab and USDA NRCS; USDA NRCS, 2018b).

Alford Farm (Alford)

The Alford farm is located in Southeast Indiana (Figure 1) and is managed in a corn-soybean (*Zea mays* L. – *Glycine max* L. Merr.) rotation under no-till. Alford used cover crops prior to a corn cash crop beginning 2006 (Hauenstein, 2015). Four blocks were established as a randomized complete block design. Each of the plots have the dimensions of 18.3 m by 152.4 m. The last time there were cover crops planted in these plots was in fall 2013, therefore the two treatments at this site and thesis refer to: 1) cereal rye (*Secale* *cereal* L.) with crimson clover (*Trifolium incarnatum* L.) mixture (CR13) and 2) wheat (*Triticum aestivum* L.) with crimson clover mixture (WH13).

Brocksmith Farm and Conventional Comparison (Brocksmith)

The Brocksmith farm is located in Southwest Indiana (Figure 1) and was established in 2012 however cover crops were not planted until fall 2013. The main plots were managed in a corn-soybean rotation under no-tillage for at least twenty years prior. It uses a randomized complete block design with three blocks each having a cover crop and no cover crop control treatment under no-till. The plot dimensions are 13.7 m by 189.6 m. Four plots were created at the conventional comparison. Although conventional comparisons were carefully selected to have similar soil series and characteristics of the conservation cropping systems farmer sites, the Brocksmith conventional comparison had higher clay content and was located in a lower landscape position. For the remainder of this thesis the Brocksmith Farm and Conventional Comparison will be referred to as Brocksmith with three treatments: 1) cover crops with no-till (CC), 2) no cover crops with no-till (NC), and 3) no cover crops with conventional tillage (CONV).

DeSutter Farm and Conventional Comparison (DeSutter)

The Desutter Farm main plots and conventional comparison plots were established when the CCSHP Project began in fall 2012, but did not have cover crop establishment until fall 2013. It is located in West Central Indiana (Figure 1). The main plots use a randomized block design with four blocks each having a cover crop and no cover crop control treatment under no-till. There were four plots created at the conventional comparison that do not use cover crops and was under conventional tillage. The main plots are 37.8 m by 152.4 m and the conventional comparison plots are about 18 m by 152 m. For the remainder of this thesis the Desutter Farm and Conventional Comparison will be referred to as the Desutter Site with three treatments: 1) CC, 2) NC, and 3) CONV.

Diagnostic Training Center (DTC)

The Diagnostic Training Center (DTC) is located in West Central Indiana (Figure 1) at the Purdue University Agronomy Center for Research and Education. As mentioned previously, the DTC site was retired after harvest in fall 2016. It had a modified split-plot design with four replicated blocks with two cash crops, corn and soybean, per block with three cover crop treatments following its designated cash crop. The cover crop treatments following soybean (before corn) are: 1) no cover crop control (NC-Soybean), 2) oat (*Avena sativa* L.) and radish (*Raphanus sativus* L.) mixture (O/R-Soybean), and an 3) oat, radish, crimson clover, and cereal rye mixture (O/R/CL/CR-Soybean). The cover crop treatments following corn (before soybean) are: 1) no cover crop control (NC-Corn), 2) cereal rye (CR-Corn), and an 3) oat, radish, and cereal rye mixture (O/R/CR-Corn). Each year the cash crops rotate and their respective cover crop treatments follow. Each of the plot dimensions were 3.0 m by 19.8 m and were managed as no-till.

Huffmeyer Farm and Conventional Comparison (Huffmeyer)

The Huffmeyer farm is located in Southeastern Indiana (Figure 1). Four replications of cover crop use under conventional tillage and strip till were created at the main plots, measuring about 0.28 ha each and were in a corn-soybean rotation. Four plots were created at the conventional comparison that does not use cover crops and uses conventional tillage. For the remainder of this thesis the Huffmeyer Farm and Conventional Comparison will be referred to as the Huffmeyer Site with three treatments: 1) cover crops with conventional-till (CT), 2) cover crops with strip-till (ST), and 3) CONV.

Mills Farm (Mills)

The Mills farm is located in the Northwest Region of Indiana (Figure 1) and consists of three different nitrogen rates that are applied at the time of a corn cash crop. All the plots use cover crops and are in a no-till system. The treatments are: 1) 101 kg ha^{-1} N (Low), 2) 145 kg ha^{-1} N (Medium), and 3) 201 kg ha^{-1} (High). The plot sizes range from 0.2 to 0.24 ha in size.

Northeast Purdue Agricultural Center (NEPAC)

The Northeast Purdue Agricultural Center (NEPAC) is located in Northeast Indiana (Figure 1) and was established in fall of 2012. Similar to the DTC site, NEPAC had a modified split-plot design with four replicated blocks and two cash crops, corn and soybean, per block with three cover crop treatments following its designated cash crop. The plot dimensions were 9.1 m by 99 m and was managed as no-till.

New Diagnostic Training Center (NewDTC)

As mentioned before, after the DTC plots were terminated in the fall of 2016, the NewDTC plots were created. The NewDTC field is located north of the original DTC field. There were four blocks with three treatments of: 1) small-species cover crop mixture (One), 2) large-species cover crop mixture (Mix), and 3) NC. Each of the plot dimensions were approximately 4.5 m by 9.1 m and managed as no-till.

Rulon Farm (Rulon)

The Rulon farm is located in Central Indiana (Figure 1). The site was established in 2012 and is in a corn-soybean rotation under no-tillage. The plots were established using a randomized complete block design with the same four cover crop treatments every year: 1) NC, 2) annual ryegrass (*Lolium multiflorum*) (AR), 3) CR, and 4) oat and radish mixture (O/R). The plot dimensions are approximately 68.3 m by 494.7 m, however the southernmost CR plot and block was slightly altered in 2016 due to a gravel driveway being built in it.

Scott Farm and Conventional Comparison (Scott)

The Scott farm is located in the Northeast Region of Indiana (Figure 1) and is managed as a corn-soybean-wheat rotation with no-tillage. The plots are in a randomized block design with four replicated blocks of three treatments: NC, One, and Mix, which had the plot dimensions approximately 0.24 ha each. Four plots were established at the CONV. For the remainder of this thesis the Scott Farm and Conventional Comparison will be referred to as the Scott Site with four treatments: 1) Mix, 2) One, 3) NC, and 4) CONV.

Southeast Purdue Agricultural Center (SEPAC)

The Southeast Purdue Agricultural Center (SEPAC) is located in Southeast Indiana and are also a modified split-plot design, similar to the DTC and NEPAC sites, however with only three replicated blocks. Each of the plot dimensions are 9.1 m by 109.7 m and managed as no-till.

Shuter Farm (Shuter)

The Shuter farm is located in East Central Indian (Figure 1). Beginning fall 2016, the Shuter site consisted of four replicated plots with two treatments in strip-tillage: 1) CC and 2) NC. The plots were approximately 0.49 to 0.61 ha each.

Stahl Farm (Stahl)

The Stahl farm is the most Southwestern site in Indiana (Figure 1). It has three replications of two treatments in no-till: 1) NC and 2) CC. The plot dimensions are about 0.2 ha in size.

Villwock Farm and Conventional Comparison (Villwock)

The Villwock farm is located in the Southwest region of Indiana (Figure 1). It has three replications of two treatments under no-till 1) CC and 2) NC. The plots are 0.32 ha each. Four plots were established for the CONV, which has greater clay content than the main plots. For the remainder of this thesis the Villwock Farm and Conventional Comparison will be referred to as the Villwock Site with three treatments: 1) CC, 2) NC, and 3) CONV.

Vincennes University Jasper Campus (VUJC)

The VUJC site is one of the SWCD sites and is located in Southern Indiana (Figure 1). It has two plots, one in no-till (NT) and the other in conventional till (CT), both planted in cover crops. This site does not have replications but is used for demonstration in the local area.

Wabash Farm (Wabash)

The Wabash farm is the other SWCD site and is located in Northern Indiana (Figure 1) and was established in Fall 2012 along with the CCSHP. Beginning Fall 2013, four replications of the two treatments 1) One and 2) Mix were created. Each plot is approximately 0.16 ha in size and is managed as no-till in a corn-soybean-wheat rotation.

Wenning Farm and Conventional Comparison (Wenning)

The Wenning farm is located in Southeastern Indiana (Figure 1) and was established in 2012 as a randomized complete block design with four replications of two tillage treatments, similar to Huffmeyer. Each plot approximately 0.16 ha in size and follows a corn-soybean rotation. Four plots were established at the CONV. For the remainder of this thesis the Wenning Farm and Conventional Comparison will be referred to as the Wenning Site with three treatments: 1) cover crops with no-till (NT), 2) ST, and 3) CONV.

Werling Farm and Conventional Comparison (Werling)

The Werling farm is located in Northeast Indiana (Figure 1). Prior to the fall 2016, four cover crop plots of all the same treatment were established, but there was no control treatment. In fall 2016 the plots were redesigned on the same field to a randomized block design with four replicated blocks of three treatments: Mix, One, and NC. Despite the change in plots, the site was managed as no-till in a corn-soybean-oat rotation. The main plots were approximately 0.85 ha each. Four plots were established at the CONV. For the remainder of this thesis the Werling Farm and Conventional Comparison will be referred to as the Werling Site with four treatments: 1) Mix, 2) One, 3) NC, and 4) CONV.

Crop Management

See Table 3 for a summary of the site management that includes: tillage, cover crop, and cash crops, along with its treatment ID and date of soil sampling for this study. With the exception of the NewDTC site, soil samples were taken in early or late summer 2016 and some again in summer 2017. Table 4 shows the pesticide trade and chemical names (Woodyard, 2018). Table 5 indicates the sand, silt, and clay percentages of the soil health tests taken at each site at a depth of 0 - 20 cm (Zuber and Kladivko, 2018).

Alford

As mentioned before, cover crops have not been planted at Alford since fall 2013. The cash crop in summer 2016 was corn. When soil sampling occurred on June 27, 2016, the corn was approximately at the V3/V4 stage.

Brocksmith

On September 19, 2015, diammonium phosphate (DAP, 18-46-0, N-P_2O_5-K_2O, equal to 20 kg N ha^{-1} and 52 kg P_2O_5 ha^{-1}), potash (0-0-60, N-P_2O_5-K_2O equal to 56 kg K ha^{-1}), and pelletized calcium sulfate (SUL4R-Plus, 21% Ca and 17% S equal to 24 kg Ca ha^{-1} and 19 kg S ha^{-1}) fertilizers were each applied at a rate of 112 kg ha^{-1}. In the CC plots, cereal rye (49 kg ha^{-1}) and rapeseed (*Brassica napus* L.) (2.2 kg ha^{-1}) was drilled on September 21, 2015. In Spring 2016, the main plots were planted with soybeans and the conventional comparison plots were planted in corn. At the time of sampling on June 14, 2016 the cereal rye was not terminated on the CC plots.

On October 7, 2016, the CC plots were planted with an oat, cereal rye, and crimson clover mixture at a rate of 22 kg ha^{-1}. On April 10, 2017, the whole field was sprayed with Gramoxone (rate of 3.5 L ha^{-1}), Bicep (rate of 3.5 L ha^{-1}), and 2,4-D (rate of 0.58 L ha^{-1}) mixture, as well as liquid N (rate of 84 L ha^{-1}, 28% N, equal to 30 kg N ha^{-1}) and nitrogen stabilizer (Agrotain Advanced with a rate of 0.12 L ha^{-1}). Corn was planted on April 14, 2017 at 83,980 seeds ha^{-1} along with a 5 cm below and 5 cm to the side of the seed (5 x 5) placement of starter fertilizer (liquid N, rate of 84 L ha^{-1}, 28% N, equal to 30 kg N ha^{-1}). On May 15, 2017 the corn was sidedressed with liquid N (rate of 356 L ha^{-1}, 32% N, equal to 146 kg N ha^{-1}) and thiosulfate (rate of 9.4 L ha^{-1}, 12-0-0, N-P_2O_5-K_2O, 26% S equal to 1.48 kg N ha^{-1} and 3.18 kg S ha^{-1}). On May 27, 2017, Roundup (rate of 2.3 L ha^{-1}), Armezon (rate of 0.07 L ha^{-1}), and Atrazine 4L (rate of 1.2 L ha^{-1}) was applied for corn post emergence. When soil samples were collected on June 28, 2017 the corn at the main plots were silking and the soybeans at the CONV plots were flowering.

DeSutter

After wheat harvest, an application of chicken manure was applied across the main field. On August 1, 2015, a 12-way mix was planted. The mixture consisted of crimson clover, radish, cowpeas (*Vigna unguiculata* L. Walp.), cahaba vetch (*Vicia* spp.), sunn hemp (*Crotalaria juncea* L.), sorghum-sudan grass (*Sorghum X drummondii* Nees ex. Steud. Millsp. & Chase), pearl millet (Pennisetum glaucum L. R.BR.), rapeseed (*Brassica napus* L.), turnip (*Brassica rapa* L.), brown flax (*Linum* spp.), sunflower (*Helianthus* L.), and buckwheat (*Fagopyrum esculentum* L. Moench). In spring 2016, corn was planted at the main field and CONV. On June 8, 2016 the main plots were sampled, but due to weather the CONV was sampled the next day. On October 1, 2016, after the corn was harvested at the main plots, 4.5 metric tons ha^{-1} of chicken manure was applied on to the whole field. Then cereal rye (at a rate of 133 kg ha^{-1}) was planted to the main field except for the NC plots. DeSutter started to transition to organic farming at this time, therefore no synthetic fertilizers or chemicals were used from here on. In spring 2017, the cereal rye was grown to maturity. On May 15, 2017, soybeans (Illini 2643 non-GMO non-treated) were drilled at a rate of 407,550 seeds ha^{-1} and the cereal rye was roller crimped on May 17. During the first week of June, soybeans were replanted in 76 cm rows at a rate of 247,000 seeds ha^{-1}. On June 6, 2017, the soybeans at the main plots were at VC plus the NC plots had a lot of weeds, and the CONV soybeans were barely emerging,

DTC

On June 30, 2016 soil samples were taken. On April 25, 2016, Roundup PowerMAX and AMS (ammonium sulfate) was applied at a rate of 1.61 L ha^{-1} and 2.8 kg ha^{-1} (0.6 kg N ha^{-1}) respectively. A 5 x 5 placement starter fertilizer application (10-34-0, N-P_2O_5-K_2O) was made on May 24, 2016 when the corn and soybeans were planted. The corn was later side dressed on June 10, 2016 with liquid urea ammonium nitrate (UAN, 28%) at a rate of 202 kg N ha^{-1}. Later in the season, Roundup PowerMAX, Class Act, and AMS was applied at a rate of 2.3 ha^{-1}, 0.01 L product L^{-1} water, and 2.8 kg ha^{-1} (0.6 kg N ha^{-1}), respectively. Soybeans were harvested on October 17, 2016 and corn was harvested on October 25, 2016.

Huffmeyer

At the Huffmeyer main plots, cereal rye was planted across the whole field in fall 2015. In spring 2016, the main plots and CONV were drilled with soybeans at 38 cm rows. At the time of sampling, on June 27, 2016 the soybeans in the main plots were approximately at V2 and the CONV was at V4. By observation the main plots had more residue (left behind from previous corn cash crop) and less weeds than the CONV. The weeds present at the CONV include some trumpet creeper (*Campsis radicans*), volunteer corn, grass, and dandelions (*Taraxacum*). The CONV plots were also at a steeper slope compared to the main plots, where most of field was leveled and flat.

NEPAC

The cover crop treatments following soybean (before corn) were drilled on September 29, 2015 and the cover crops following corn (before soybean) were drilled on October 1, 2015. A mixture of glyphosate, 2,4-D, and AMS, was applied (at rates of 2.3 L ha^{-1}, 1.2 L ha^{-1}, and 0.58 L ha^{-1}, respectively) to burndown the weeds in the plots. On May 24, 2016, both corn (Pioneer P0825 AMXT at a rate of 81,510 seeds ha^{-1}) and soybeans (Asgrow 2632 treated at a rate of 419,000 seeds ha^{-1}) were seeded. The corn plots also had a starter fertilization application (18-16-0, N-P_2O_5-K_2O, 2% S) equal to 33.7 kg N ha^{-1}, 30.3 kg P_2O_5 ha^{-1} (13.2 kg P ha^{-1}), and 3.4 kg S ha^{-1}. To control the pre-emerging grass and broadleaf weeds, both plots were sprayed on May 25, 2016. The plots planted to corn were sprayed with a mixture of Corcus, atrazine, and 2,4-D mixture and the plots planted to soybeans were sprayed with Sonic herbicide. On June 9, 2016, the corn plots were sidedressed with liquid N at a rate of 183 kg N ha^{-1}. On June 13, 2016, the soybean plots were sprayed with a mixture of glyphosate and Assure II for grass and broadleaf weed control. The soybean plots were harvested on October 10, 2016 and the corn plots were harvested on October 19, 2016.

On October 19, 2016 the cover crops were drilled at 19 cm spacing. Both cash crops were planted on May 16, 2017. The soybeans (Pioneer 31T21L) were drilled at a rate of 345,800 seeds ha^{-1}. The corn (Dekalb 55-20) was planted at a rate of 74,100 seeds ha^{-1} and 34 kg N ha^{-1} was applied as starter. On May 23rd 2017, the corn plots were sprayed with a pre-emergence application of Corvus (rate of 0.41 L ha^{-1}) and Atrazine (rate of 3.5 L ha^{-1}). On June 1, 2017, all the plots were sprayed with a post-emergence application of Liberty (rate of 2.3 L ha^{-1}), and only the soybean plots were sprayed again (with the same product and rate) on July 5, 2017. On June 14, 2017, the corn was sidedressed with 200 kg N ha^{-1} of N fertilizer and a dry fertilizer was applied using variable rate applications according to soil fertility test results.

NewDTC

Soil sampling occurred during the cover crop growth period, October 25, 2016, and in the following summer after cover crop termination, June 12, 2017. Prior to the study, the field was in a soybean cash crop and was mowed prior to cover crop planting. On August 10, 2016, the Mix treatment was planted with a 14-way mix and in the One treatment with oats. For consistency the drill was also ran across the NC plots. The Mix was drilled at 42.8 kg ha^{-1} and the One was drilled at 67.4 kg ha^{-1}. The Mix treatment consisted of crimson clover, radish, cowpeas, rapeseed, turnip, buckwheat, sunn hemp, cahaba vetch, oats, sorghum-Sudan grass, pearl millet, sunflower, flax, and yellow sweet clover (*Melilotus officinalis* L. Pall.).

Most of the One and Mix cover crops winterkilled, but some clover species and radish grew back in spring 2017 within the Mix treatment, possibly due to a mild winter. On April 26, 2017, glyphosate was applied for an initial herbicide burndown but was not successful due to the temperature drop and plants metabolizing the chemical (Woodyard, 2018). Shortly after there was a second application of glyphosate. Corn (Mycogen MY11C27RA) was planted perpendicular to the direction of the treatment plots on May 18, 2017 (at a rate of 79,040 seeds ha^{-1}). A starter fertilizer (at a rate of 112 L ha^{-1}, 19-17-0, N-P_2O_5-K_2O, equal to 27 kg N ha^{-1} and 10 kg P ha^{-1}) was also applied at planting with a 5 x 5 placement. On June 2, 2017, Interline (glufosinate) was applied at a rate of 6.07 mL L^{-1}. On June 22, 2017, the plots were sidedressed with 202 kg N ha^{-1} of liquid N (28% N). On October 12, 2017, the inner 2.74 m of the four rows in each plot were hand harvested to estimate the grain yield.

Mills

In both fall 2015 and 2016, annual ryegrass was planted as the cover crop across all the plots. As mentioned before, the three treatments at this site were three nitrogen rates: Low, Medium, and High. In 2016, the cash crop was soybean and was sampled on August 23.

Rulon

On September 26, 2015, the cover crop (AR, CR, and O/R) treatments were planted. In spring 2016, soybeans were planted as the cash crop and samples were taken on June 16, 2016. The same cover crops were planted in fall 2016 and the corn was planted in spring 2017. When sampled on June 29, 2017 the corn was at V8. During the 2015-2016 growing season no nitrogen was applied due to the soybean cash crop but in the 2016-2017 growing season four different nitrogen rates (107, 129, 152, and 197 kg ha^{-1}) were applied during the corn cash crop. All samples for this thesis were collected from the 152 kg N ha^{-1} rate.

Scott

Wheat was planted on September 27, 2015 at a rate of 4,446,000 seeds ha^{-1} and harvested in summer 2016. In spring 2016, the conventional comparison was planted to a soybean cash crop. On July 28, 2016 the wheat was harvested at the main plots, the Mix plots were planted with a 14-way mix (similar to the NewDTC), and the soybean was not harvested at the conventional comparison. The One treatment was planted to peas after sampling. In spring of 2017, both the main plots and conventional comparison plots were planted to corn as the cash crop and samples were collected again on June 5, 2017.

SEPAC

Cover crops were drilled on September 28, 2015, unfortunately there was a planting error that resulted in the O/R-Soybean treatment to be planted in cereal rye and the CR-Corn treatment to planted with the oat and radish mix plus a full rate of cereal rye. On April 15, 2016, the cover crop plots going to corn were sprayed with Roundup PowerMAX (rate of 1.61 L ha^{-1}), Sharpen (rate of 0.07 L ha^{-1}), and Sunburst MSO adjuvant (rate of 1.9 L ha^{-1}). On April 26, 2016, corn (Pioneer 1479AM) was planted at a rate 76,570 seed ha^{-1} in 76 cm rows. Starter fertilizer was also applied (22-11-0, N-P_2O_5-K_2O, at a rate of 154 L ha^{-1}) equal to 44 kg N ha^{-1} and 22 kg P ha^{-1}. On May 25, 2016, the cover crop plots going to soybean were sprayed (with same herbicide mixture used for the cover crop plots going to corn) and the soybeans (Pioneer 35T58R) were also planted at a rate of 296,000 seeds ha^{-1} in 38 cm rows. The corn was sidedressed on June 7, 2016 with 28% liquid N (28-0-0, N-

P_2O_5-K_2O, equal to 157 kg N ha^{-1}). On June 8, 2016 the corn plots were sprayed with a Halex GT (rate of 4.7 L ha^{-1}), and Halfpynt (rate of 0.18 L ha^{-1}), and HENO D surfactants (rate of 0.95 L ha^{-1}). On June 27, 2016, the soybeans were sprayed with a Roundup PowerMAX (rate of 1.61 L ha^{-1}), First Rate (rate of 0.02 L ha^{-1}), HENO D (at 0.95 L ha^{-1}), and 28% UAN (rate of 4.7 L ha^{-1}, equal to 2 kg N ha^{-1}) mixture. On October 7, 2016, both cash crops were harvested.

On October 8, 2016 the fall 2016 cover crops were drilled. On October 31, 2016 lime was applied at 1445 kg ha^{-1} and on November 2, 2016 potash (0-0-60, N-P_2O_5-K_2O, equal to 126 kg K ha^{-1}) was applied as 250 kg ha^{-1}. On April 12, 2017, the plots going to corn and the NC-Soybean plots were sprayed with a Roundup PowerMAX (rate of 1.61 L ha^{-1}) and Sharpen (rate of 0.07 L ha^{-1}) herbicide mixture. On April 26, 2017 the remaining cover crop plots (O/R-Soybean and O/R/CC/CR-Soybean) were sprayed with same herbicide mixture used for the cover crop plots going to corn and NC-Soybean plots. On the same day, corn (Pioneer P1479AM) was planted as 74,100 seed ha^{-1} in 76 cm rows with starter fertilizer (22-11-0, N-P_2O_5-K_2O, equal to 45 kg N ha^{-1} and 10 kg P ha^{-1}) and soybean (Pioneer P33T58R) were planted at 296,400 seeds ha^{-1} in 38 cm rows. On June 1, 2017, Halex GT (rate of 4.67 L ha^{-1}) was applied for post corn emergence. On June 12, 2017, corn was sidedressed with 28% liquid UAN (rate of 440 L ha^{-1}, 28-0-0, N-P_2O_5-K_2O, equal to 158 kg N ha^{-1}). On June 21, 2017, FlexStar GT (at a rate of 4.1 L ha^{-1}) was applied on all soybean plots for post soybean emergence. The soybeans were harvested on September 26, 2017 and the corn was harvested on September 27, 2017.

Shuter

In fall 2015, a 14-way mix was planted in the CC treatment plots after wheat harvest. In spring 2016, corn was planted and soil sampling occurred on June 16.

Stahl

In fall 2015, cereal rye was planted in the CC plots. In spring 2016, corn was planted as the cash crop and soil sampled on June 13. After the corn was harvested in fall 2016, a cereal rye and wheat (32 kg ha^{-1} and 9 kg ha^{-1}, respectively) cover crop mixture was planted in the CC plots. In spring 2017, soybeans had to be vertical tilled and replanted due to a wet spring and slug (*Gastropoda*) problems. When soil was sampled on June 27, 2017, the soybean was at V5.

Villwock

In fall 2015, a crimson clover, radish, oat, and rapeseed cover crop mixture was planted in the CC plots. In spring 2016, corn was planted at the main field and CONV. On June 14, 2016 when soil samples were taken, the corn at the main plots were approximately V7/V9 and the CONV was at V11. At the main plots, the soil was extremely dry, sandy, and the corn was showing signs of drought stress.

VUJC

On June 13, 2016, VUJC was sampled and both the CT and NT treatments did not have a cash crop planted. A week prior, the top 3 inches of the plots were disked therefore an alternative method of sampling was used mentioned in the Soil Sampling section.

Wabash

In fall 2015, wheat was planted in 17.8 cm rows and the Mix plots also had radish seeded along with the wheat. On June 21, 2016, the wheat was approximately 90 cm tall when soil samples were collected. On July 5 and 8, 2016 after the wheat was harvested, a 14-way mix was planted in the Mix treatment (at a rate of 40.8 kg ha^{-1}). The One treatments remained unplanted, but experienced more volunteer wheat and weed growth. The 14-way mix consisted of cowpeas, sunn hemp, cahaba vetch, yellow sweet clover, crimson clover, oats, sorghum-sudan grass, pearl millet, radish, rapeseed, turnip, buckwheat, sunflower, and flax. A week after the Mix was planted, 9 metric tons ha^{-1} of chicken litter was applied to the whole field. On June 9, 2017 corn was planted as the cash crop and samples were taken on June 20.

Wenning

In fall 2015, cereal rye was planted across the main plots (ST and NT). In spring 2016, soybean was planted as the cash crop at the main and CONV. On June 27, 2016, the soybean was approximately V4 at the NT and ST plots and the CONV was approximately at V6. The main plots were sprayed prior to sampling but the CR was still growing in some areas and the soil had plenty of coverage from previous corn residue. The CONV soil was very bare, dry, with few weeds. In fall 2016, a mixture of annual ryegrass, crimson clover, and rapeseed was planted over the main field. In spring 2017, the main field was planted to double row corn and the CONV was planted to soybean. When sampled on June 27, 2017 the corn was approximately V7 with volunteer annual ryegrass and the CONV soybean was approximately V4.

Werling

In fall 2015, oats were planted as the cash crop in 19 cm rows at the main plots. In spring 2016, the CONV plots were planted in corn as the cash crop. The soil was sampled on June 21, 2016 and the oats were about 28 inches tall and the corn was at V7. By observation the CONV had little to no soil coverage compared to the main plots and the main plots had volunteer cereal rye growing (from fall 2014 cover crop). As mentioned before, the main plots were altered after oat harvest in fall 2016, new plots were established with three treatments (NC, One, and Mix). The One treatment plots were planted to oats and the Mix treatment plots were planted to a 14-way mix. The Mix was seeded at 42.8 kg ha^{-1} and consisted of the following cover crop species: cowpeas, sunn hemp, cahaba vetch, yellow sweet clover, crimson clover, oats, sorghum-Sudan grass, pearl millet, radish, rapeseed, turnips, buckwheat, sunflower, and soybeans. In spring 2017, corn was planted as the cash crop in both the main field and CONV. When sampled on June 20, 2017 the corn at the main plots was approximately at V3 and the CONV were further along.

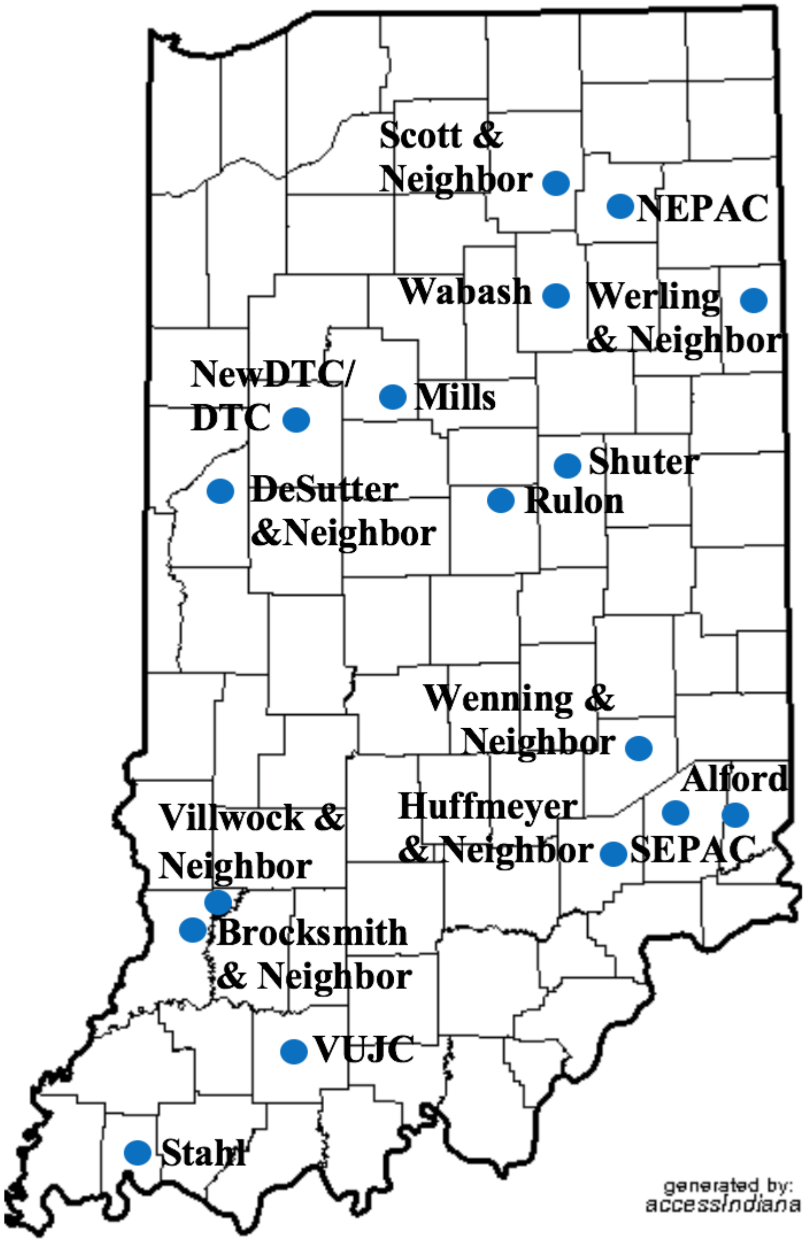

Figure 1 Map of sites involved in study.

Table 1 Site latitude, longitude, county within Indiana, mean annual temperature, and mean annual total precipitation.

Site	Latitude	Longitude	County	Mean Annual Temperature		Mean Annual Total Precipitation	
	˚N	˚W		˚F	˚C	Inches	Centimeters
Alford	39.10	85.10	Dearborn	53.2	11.8	43.2	109.7
Brocksmith	38.67	87.46	Knox	54.7	12.6	46.0	116.8
Brocksmith Neighbor	38.67	87.46					
Desutter	40.25	87.19	Fountain	51.3	10.7	38.9	98.8
Desutter Neighbor	40.25	87.19					
DTC	40.47	86.99	Tippecanoe	50.8	10.4	38.2	97.0
Huffmeyer	39.17	85.35	Ripley	53.2	11.8	43.2	109.7
Huffmeyer Neighbor	39.18	85.35					
Mills	40.70	86.22	Cass	50.2	10.1	42.9	109.0
NEPAC	41.10	85.40	Whitley	49.1	9.5	39.9	101.3
NewDTC	40.47	86.99	Tippecanoe	50.8	10.4	38.2	97.0
Rulon	40.19	85.98	Hamilton	51.9	11.1	40.4	102.6
Scott	41.21	85.73	Kosciusko	49.1	9.5	39.9	101.3
Scott Neighbor	41.21	85.67					
SEPAC	39.04	85.54	Jennings	53.0	11.7	47.4	120.4
Shuter	40.17	85.75	Madison	51.9	11.1	40.4	102.6
Stahl	38.02	87.45	Warrick	56.4	13.6	45.3	115.1
Villwock	38.77	87.19	Daviess	53.9	12.2	45.7	116.1
Villwock Neighbor	38.73	87.17					
VUJC	38.38	86.90	Dubois	53.0	11.7	45.7	116.1
Wabash	40.83	85.80	Wabash	50.8	10.4	40.5	102.9
Wenning	39.35	85.41	Decatur	53.2	11.8	43.2	109.7
Wenning Neighbor	39.36	85.40					
Werling	40.90	85.03	Adams	50.5	10.3	38.3	97.3
Werling Neighbor	40.92	84.96					

Table 1 Notes:
Information provided by the CSSI Interim Reports: Soil Health Investigations (http://ccsin.iaswcd.org/publications/reportresults-2/)
Mean annual temperature and precipitation information were collected from the nearest weather station to each site.
The data shown are the means from 1981-2010.

Table 2 Site soil information.

Site	% Field	Series	Texture	% Slope	Drainage	Native Vegetation	Parent Material
Alford	54	Rossmoyne	SiL	0-2	MWD	Forest	Loess over loamy till
	52	Avonburg	SiL	0-2	SPD	Forest	Loess over loamy till
	4	Cincinnati	SiL	2-6	WD	Forest	Loess over loamy till
Brocksmith	73	Patton	SiL	0-2	VPD	Transition	Loamy glaciolacustrine deposits
	27	Sylvan	SiL	2-6	WD	Forest	Loess
Brocksmith Neighbor	100	Patton	SiL	0-2	VPD	Transition	Loamy glaciolacustrine deposits
Desutter	46	Waupecan	SiL	0-2	WD	Prairie	Loess over loamy outwash
	44	Lafayette	SiL	0-2	SPD	Prairie	Loess over loamy outwash
	10	Waupecan	SiL	2-6	WD	Prairie	Loess over loamy outwash
Desutter Neighbor	100	Waupecan	SiL	0-2	WD	Prairie	Loess over loamy outwash
DTC	55	Starks	SiL	0-2	SPD	Forest	Loess over loamy outwash
	35	Fincastle	SiL	0-2	SPD	Forest	Loess over glacial till
Huffmeyer	55	Cobbsfork	SiL	0-1	PD	Forest	Loess over loamy till
	40	Avonburg	SiL	0-2	SPD	Forest	Loess over loamy till
	5	Nabb	SiL	2-6	MWD	Forest	Loess over till
Huffmeyer Neighbor	50	Nabb	SiL	2-6	MWD	Forest	Loess over till
	50	Cincinnati	SiL	6-12	WD	Forest	Loess over till
Mills	57	Cyclone	SiL	0-2	PD	Transition	Loess over loamy till
	43	Fincastle	SiL	0-3	SPD	Forest	Loess over loamy till
NEPAC	32	Glywood	L	2-6	MWD	Forest	Loess and till
	30	Blount	SiL	1-4	SPD	Forest	Till
	26	Morley	L	3-6	MWD	Forest	Loess and till
	12	Morley	L	5-12	MWD	Forest	Loess and till
NewDTC	59	Toronto	SiL	0-2	SPD	Forest	Loess over loamy till
	41	Rockfield	SiL	1-3	MWD	Forest	Loess over loamy outwash
Rulon	49	Brookston	SiCL	0-2	PD	Transition	Loamy till
	49	Crosby	SiL	0-3	SPD	Forest	Loess over loamy till

Table 2 Continued.

Site	% Field	Series	Texture	% Slope	Drainage	Native Vegetation	Parent Material
Scott	100	Wawasee	FSL	2-6	WD	Forest	Till
Scott Neighbor	50	Wawasee	FSL	2-6	WD	Forest	Till
	50	Crosier	L	0-1	SPD	Forest	Till
SEPAC	86	Ryker-Muscatatuck	SiL	Rolling	WD	Forest	Loess over loamy till
	14	Oldenburg	SiL	0-2	MWD	Forest	Loamy alluvium
Shuter	50	Crosby	SiL	0-2	SPD	Forest	Loess over loamy till
	35	Brookston	SiCL	0-2	PD	Transition	Loess over loamy till
	10	Miami	SiL	2-6	MWD	Transition	Loess over loamy till
Stahl	92	Hosmer	SiL	2-6	MWD	Forest	Loess
	8	Hosmer	SiL	6-12	MWD	Forest	Loess
Villwock	74	Lyles	L	0-1	VPD	Transition	Loamy outwash
	18	Lyles	L	0-2	VPD	Transition	Loamy outwash
	8	Ayrshire	FSL	0-2	SPD	Forest	Eolian sands
Villwock Neighbor	100	Lyles	L	0-1	VPD	Transition	Loamy outwash
VUJC	90	Zanesville	SiL	1-6	MWD	Forest	Loess over loamy residuum
	10	Steff	SiL	0-2	MWD	Forest	Acid loamy alluvium
Wabash	100	Blount	SiL	1-4	SPD	Forest	Loess over clayey till
Wenning	85	Xenia	SiL	0-2	MWD	Forest	Loess under loamy till
	15	Xenia	SiL	2-4	MWD	Forest	Loess under loamy till
Wenning Neighbor	100	Xenia	SiL	0-1	MWD	Forest	Loess under loamy till
Werling	81	Pewamo	SiCL	0-2	VPD	Forest	Till
	19	Blount	SiL	0-2	SPD	Forest	Till
Werling Neighbor	60	Blount	SiL	0-2	VPD	Forest	Till
	40	Pewamo	SiCL	0-2	SPD	Forest	Till

Table 2 Notes:
Information provided by the CCSI Interim Reports: Soil Health Investigations (http://ccsin.iaswcd.org/publications/reportresults-2/)
Abbreviations: SiL = Silt Loam; L = Loam; FSL = Fine Sandy Loam; SiCL = Silty Clay Loam; WD = Well Drained; MWD = Moderately Well Drained; SPD = Somewhat Poorly Drained; PD = Poorly Drained.

Table 3 Site sampling dates, treatments, tillage, and cover crop/cash crop management information.

Site	Sampling Date(s)	Treatment	Tillage	2015 – 2016 Cover Crop	2016 Cash Crop	2016 – 2017 Cover Crop	2017 Cash Crop
Alford £	June 27, 2016	CR13	NT	No Cover Crop	CN	—	—
		WH13	NT	No Cover Crop	CN	—	—
Brocksmith	June 14, 2016 and June 28, 2017	CC	NT	Cereal Rye	SB	Oat/Cereal Rye/Crimson Clover	CN
		NC	NT	No Cover Crop	SB	No Cover Crop	CN
Brocksmith Neighbor	June 14, 2016 and June 28, 2017	CONV	CT	No Cover Crop	CN	No Cover Crop	SB
Desutter	June 8, 2016 and June 6, 2017	CC	NT	12-Way Mix	CN	Cereal Rye	SB
		NC	NT	No Cover Crop	CN	No Cover Crop	SB
Desutter Neighbor	June 9, 2016 and June 2017	CONV	CT	No Cover Crop	CN	No Cover Crop	SB
DTC	June 30, 2016	O/R-Soybean	NT	Oat/Radish	CN	—	—
		O/R/CC/CR-Soybean	NT	Oat/Radish/Crimson Clover/Cereal Rye	CN	—	—
		NC-Soybean	NT	No Cover Crop	CN	—	—
		CR-Corn	NT	Cereal Rye	SB	—	—
		O/R/CR-Corn	NT	Oat/Radish/Cereal Rye	SB	—	—
		NC-Corn	NT	No Cover Crop	SB	—	—
Huffmeyer	June 27, 2016	ST	ST	Cereal Rye	SB	—	—
		CT	CT	Cereal Rye	SB	—	—

Table 3 Continued.

Site	Sampling Date(s)	Treatment	Tillage	2015 – 2016 Cover Crop	2016 Cash Crop	2016 – 2017 Cover Crop	2017 Cash Crop
Huffmeyer Neighbor	June 27, 2016	CONV	CT	No Cover Crop	SB	—	—
Mills	August 23, 2016	Low	NT	Annual Ryegrass	SB	—	—
		Medium	NT	Annual Ryegrass	SB	—	—
		High	NT	Annual Ryegrass	SB	—	—
NEPAC	June 29, 2016 and June 21, 2017	O/R-Soybean	NT	Oat/Radish	CN	Cereal Rye	SB
		O/R/CC/CR-Soybean	NT	Oat/Radish/Crimson Clover/Cereal Rye	CN	Oat/Radish/Cereal Rye	SB
		NC-Soybean	NT	No Cover Crop	CN	No Cover Crop	SB
		CR-Corn	NT	Cereal Rye	SB	Oat/Radish	CN
		O/R/CR-Corn	NT	Oat/Radish/Cereal Rye	SB	Oat/Radish/Crimson Clover/Cereal Rye	CN
		NC-Corn	NT	No Cover Crop	SB	No Cover Crop	CN
NewDTC	October 25, 2016 and June 12, 2017	Mix	NT	—	SB ¤	12-Way Mix	CN
		One	NT	—	SB ¤	Oat	CN
		NC	NT	—	SB ¤	No Cover Crop	CN

Table 3 Continued.

Site	Sampling Date(s)	Treatment	Tillage	2015 – 2016 Cover Crop	2016 Cash Crop	2016 – 2017 Cover Crop	2017 Cash Crop
Rulon	June 16, 2016 and June 29, 2017	AR	NT	Annual Ryegrass	SB	Annual Ryegrass	CN
		CR	NT	Cereal Rye	SB	Cereal Rye	CN
		O/R	NT	Oat/Radish	SB	Oat/Radish	CN
		NC	NT	No Cover Crop	SB	No Cover Crop	CN
Scott	July 28, 2016 and June 7, 2017	Mix	NT	Wheat €	WH	14-Way Mix	CN
		One	NT	Wheat €	WH	Peas	CN
		NC	NT	Wheat €	WH	No Cover Crop	CN
Scott Neighbor	July 28, 2016 and June 7, 2017	CONV	CT	No Cover Crop	SB	No Cover Crop	CN
SEPAC	June 20, 2016 and June 5, 2017	O/R-Soybean	NT	Oat/Radish #	CN	Cereal Rye	SB
		O/R/CC/CR-Soybean	NT	Oat/Radish/Crimson Clover/Cereal Rye	CN	Oat/Radish/Cereal Rye	SB
		NC-Soybean	NT	No Cover Crop	CN	No Cover Crop	SB
		CR-Corn	NT	Cereal Rye #	SB	Oat/Radish	CN
		O/R/CR-Corn	NT	Oat/Radish/Cereal Rye	SB	Oat/Radish/Crimson Clover/Cereal Rye	CN
		NC-Corn	NT	No Cover Crop	SB	No Cover Crop	CN

Table 3 Continued.

Site	Sampling Date(s)	Treatment	Tillage	2015 – 2016 Cover Crop	2016 Cash Crop	2016 – 2017 Cover Crop	2017 Cash Crop
Shuter	June 16, 2016	CC	ST	14-Way Mix	CN	—	—
		NC	ST	No Cover Crop	CN	—	—
Stahl †	June 13, 2016 and June 28, 2017	CC	NT	Cereal Rye	CN	Cereal Rye/Wheat	SB
		NC	NT	No Cover Crop	CN	No Cover Crop	SB
Villwock	June 14, 2016	CC	NT	4-Way Mix	CN	—	—
		NC	NT	No Cover Crop	CN	—	—
Villwock Neighbor	June 14, 2016	CONV	CT	No Cover Crop	CN	—	—
VUJC	June 13, 2016	NT	NT	3-Way Mix	CN	—	—
		CT	CT	3-Way Mix	CN	—	—
Wabash	June 21,2016 and June 20, 2017	Mix	NT	Radish/Wheat €	WH	14-Way Mix	CN
		One	NT	No Cover Crop/Wheat €	WH	No Cover Crop	CN
Wenning	June 27, 2016 and June 27, 2017	NT	NT	Cereal Rye	SB	Cereal Rye	CN
		ST	ST	Cereal Rye	SB	Cereal Rye	CN
Wenning Neighbor	June 27, 2016 and June 27, 2017	CONV	CT	No Cover Crop	SB	No Cover Crop	SB
Werling ‡	June 21, 2016 and June 20, 2017	Mix	NT	Oat €	OA	13-Way Mix	CN
		One	NT	—	—	Oat/Radish	CN
		NC	NT	—	—	No Cover Crop	CN

Table 3 Continued.

Site	Sampling Date(s)	Treatment	Tillage	2015 – 2016 Cover Crop	2016 Cash Crop	2016 – 2017 Cover Crop	2017 Cash Crop
Werling Neighbor	June 21, 2016 and June 20, 2017	CONV	CT	No Cover Crop	CN	No Cover Crop	CN

Table 3 Notes:
— No samples were collected for this research project, therefore does not apply
€ Indicates that the site was planted in wheat or oat as the cash crop
¤ Indicates that soybean was grown prior to cover crop establishment but was mowed to at a similar timing of wheat
† Indicates that there was a change in tillage at Stahl in spring 2017 which was vertical tilled due to wet soil and slug problems
‡ Indicates a change in plot designs at Werling
# Indicates that there was a seeding error in Fall 2015, where the O/R-Soybean was planted with cereal rye instead and the CR-Corn was planted with a oat, radish, and cereal rye mixture
Abbreviations: CR13 = Cereal rye cover crop planted in 2013 treatment; WH13 = Wheat cover crop planted in 2013 treatment; CC = Cover crop treatment; NC = No cover crop treatment; CONV = Conventional tillage with no cover crop use treatment; O/R-Soybean = Oat and radish cover crop mix following soybean cash crop treatment; O/R/CC/CR-Soybean = Oat, radish, crimson clover, and cereal rye cover crop mix following soybean cash crop treatment; NC-Soybean = No cover crop following soybean cash crop treatment; CR-Corn = Cereal rye cover crop following corn cash crop treatment; O/R/CR-Corn = Oat, radish, and cereal rye cover crop mix following corn cash crop treatment; NC-Corn = No cover crop following corn cash crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Low = 101 kg ha^{-1} Nitrogen application treatment; Medium = 145 kg ha^{-1} Nitrogen application treatment; High = 201 kg ha^{-1} Nitrogen application treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; AR = Annual ryegrass cover crop treatment; CR = Cereal rye cover crop treatment; O/R = Oat and radish cover crop treatment; NT = No tillage with cover crop use treatment

Table 4 Trade and chemical names of the pesticides used on the PACs and Farmer Cooperator sites (Woodyard, 2018).

Trade Name	**Active Ingredient (A.I.)**	**% Product that is A.I.**	**Kg A.I. L product^{-1}**
Armezon	Topramezone {[3-(4,5-dihydro-isoxazolyl)-2-methyl-4-(methylsulfonyl)phenyl](5-hydroxy-1-methyl-1H-pyrazol-4-yl)methanone}	29.7	0.34
Assure II	Quizalofop P-Ethyl {Ethyl(R)-2-[4-(6-chloroquinoxalin-2-yloxy)-phenoxy]propionate}	10.3	0.11
Atrazine	6-chloro-4-N-ethyl-2-N-propan-2-yl-1,3,5-triazine-2,4-diamine	42.2	0.48
Bicep II Magnum	Atrazine (6-chloro-4-N-ethyl-2-N-propan-2-yl-1,3,5-triazine-2,4-diamine) and related compounds	33	0.37
	s-Metolachlor {acetamide, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl]-,(S)}	26.1	0.29
Class Act Adjuvant			
Corvus	Thiencarbazone-methyl (Methyl 4-[[[(4,5-dihydro-3-methoxy-4-methyl- 5-oxo-1H-1,2,4-triazol-1-yl)carbonyl]amino]sulfonyl]-5-methyl-3-thiophenecarboxylate)	7.6	0.09
	Isoxaflutole [5-cyclopropyl-4-(2-methylsulfonyl-4-trifluoromethylbenzoyl) isoxazole]	19	0.23
Destiny Adjuvant			
FirstRate	Cloransulam-methyl {N-(2-carbomethoxy-6-chlorophenyl)-5-ethoxy-7-fluoro(1,2,4)triazolo-[1,5-c]pyrimidine-2-	84	0.10
FlexStar GT	Fomesafen Sodium Salt {5-[2-chloro-4-(trifluoromethyl)phenoxy]-N-(methylsulfonyl)-2-nitrobenzamide, sodium	5.88	0.07
	Glyphosate [N-(phosphonomethyl)glycine]	22.4	0.27
Gramoxone	Paraquat dichloride (1,1’-dimethyl-4,4'-bipyridinium dichloride)	30.1	0.33

Table 4 Continued.

Trade Name	Active Ingredient (A.I.)	% Product that is A.I.	Kg A.I. L product^{-1}
Haf-Pynt Adjuvant			
Halex GT	Glyphosate [N-(phosphonomethyl)glycine]	20.5	0.25
	Mesotrione {2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione}	2.05	0.03
	s-Metolachlor {acetamide, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl]-,(S)}	20.5	0.25
HENO D Surfactant			
Interline	Glufosinate-ammonium [2-amino-4-(hydroxymethylphosphoryl)butanoic acid]	24.5	0.28
Liberty	Glufosinate-ammonium [2-amino-4-(hydroxymethylphosphoryl)butanoic acid]	24.5	0.28
Roundup PowerMAX	Glyphosate [N-(phosphonomethyl)glycine]	48.7	0.66
Sharpen	Saflufenacil {N'-[2-chloro-4-fluoro-5-)3-methyl-2,6-dioxo-4-(trifluoromethyl)-3,6-dihydro-1(2H)-pyrimidinyl)benzoyl]-N-isopropyl-N-methylsulfamide}	29.74	0.34
Sonic	Sulfentrazone {N-[2,4-dichloro-5-[4-(difluoromethyl)-3-methyl-5-oxo-1,2,4-triazol-1-yl]phenyl]methanesulfonamide}	62.1	0.07
	Cloransulam-methyl {methyl 3-chloro-2-[(5-ethoxy-7-fluoro-[1,2,4]triazolo[1,5-c]pyrimidin-2-yl)sulfonylamino]benzoate}	7.9	0.01
Sunburst MSO Adjuvant			
Poncho/Votivo seed treatment	Clothianidin {1-[(2-chloro-1,3-thiazol-5-yl)methyl]-2-methyl-3-nitroguanidine}	40.3	0.50
	Bacillus firmus I-1582	8.1	0.10
2,4-D	2,4-D amine (2,4-dichlorophenoxyacetic acid)	47.2	0.46

Table 5 Purdue Agricultural Centers and Farmer Sites' soil sand, silt, and clay content from the Cornell Soil Health Tests at a 0-20 cm depth (Zuber and Kladivko, 2018).

Site	Treatment	Tillage	% Sand	% Silt	% Clay
Alford	CR13	NT	16	69	14
	WH13	NT	17	69	14
Brocksmith	CC	NT	11	76	13
	NC	NT	10	77	13
Brocksmith Neighbor	CONV	CT	7	73	21
Desutter	CC	NT	6	75	19
	NC	NT	5	76	19
Desutter Neighbor	CONV	CT	6	75	19
DTC†	Mix	NT	17	66	17
	One	NT	16	67	17
	NC	NT	16	67	17
Huffmeyer	ST	ST	20	68	12
	CT	CT	19	68	12
Huffmeyer Neighbor	CONV	CT	28	58	14
Mills	Low	NT	14	68	18
	Medium	NT	17	69	15
	High	NT	16	68	16
NEPAC†	Mix	NT	27	48	24
	One	NT	27	48	25
	NC	NT	29	47	24
NewDTC‡	Mix	NT	16	66	18
	One	NT	17	66	17
	NC	NT	16	67	17
Rulon	AR	NT	21	60	20
	CR	NT	21	58	22
	O/R	NT	20	59	21
	NC	NT	21	62	17
Scott	Mix	NT	58	30	11
	One	NT	55	33	12
	NC	NT	55	32	12
Scott Neighbor	CONV	CT	53	32	15
SEPAC†	Mix	NT	12	69	19
	One	NT	10	71	19
	NC	NT	10	72	18
Shuter	CC	ST	26	56	18
	NC	ST	22	61	17
Stahl	CC	NT	4	83	13
	NC	NT	4	82	14
Villwock	CC	NT	69	20	10
	NC	NT	72	20	9
Villwock Neighbor	CONV	CT	61	23	16

Table 5 Continued.

Site	Treatment	Tillage	% Sand	% Silt	% Clay
VUJC	NT	NT	21	65	14
	CT	CT	15	69	16
Wabash	Mix	NT	15	61	23
	One	NT	15	60	24
Wenning	NT	NT	14	65	21
	ST	ST	15	63	22
Wenning Neighbor	CONV	CT	16	60	25
Werling ¥	CC	NT	18	49	32
Werling Neighbor	CONV	CT	9	56	35

Table 5 Notes:
† DTC, NEPAC, and SEPAC treatments are as follows: Mix = O/R/CC/CR-Soybean and O/R/CR-Corn treatments; One = O/R-Soybean and CR-Corn treatments; NC = NC-Soybean and NC-Corn treatments
‡ NewDTC was established in late 2016, therefore the sand, silt, and clay percentages come from the 2017 Cornell Soil Health Test Results
¥ Werling site is from the cover crop treatments established in 2016 prior to the change in plot design
Abbreviations: CR13 = Cereal rye cover crop planted in 2013 treatment; WH13 = Wheat cover crop planted in 2013 treatment; CC = Cover crop treatment; NC = No cover crop treatment; CONV = Conventional tillage with no cover crop use treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Low = 101 kg ha^{-1} Nitrogen application treatment; Medium = 145 kg ha^{-1} Nitrogen application treatment; High = 201 kg ha^{-1} Nitrogen application treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; AR = Annual ryegrass cover crop treatment; CR = Cereal rye cover crop treatment; O/R = Oat and radish cover crop treatment; NT = No tillage with cover crop use treatment

Soil Sampling and Analyses

Using a golf cup cutter (diameter of 10.8 cm), a total of four samples were taken in each plot at a 0-5 cm depth. An alternative method was used at VUJC due to the soil not staying intact within the golf cup cutter. A flat shovel was marked at a 5 cm depth and four 5 cm by 5 cm samples were taken from each plot. Samples were taken between the growing cash or cover crop rows and areas with animal and/or equipment disturbance were avoided. Samples were stored in plastic bags to retain field moisture and kept cool for a few days until they could be prepared for and then analyzed for soil aggregate stability, active carbon, and organic matter.

Samples were hand-sieved through an 8 mm screen while field moist. Obvious stones, bugs, residue, and plant roots were removed. The samples were air dried on butcher paper before sieving through a 2 mm screen. The samples that went through the 2 mm sieve were kept and referred to as the 0-2 mm soil size fraction. The samples that did not go through the 2 mm sieve were also kept and referred to as the 2-8mm soil size fraction. Each of the soil size fractions (0-2 and 2-8 mm) were kept in paper bags, weighed and recorded to the nearest 0.01 g. Samples were stored in paper bags in a cold room until analyzed.

Soil Aggregate Stability Analysis

The wet sieve method (Kemper and Rosenau, 1986) was used to measure the mean weight diameter (MWD) of the stable soil aggregates from the 2-8 mm soil size fraction only. This method involves a nest of sieves (4.76, 2.00, 1.00, and 0.21 mm) being oscillated in a tank of water at room temperature by a mechanical oscillator. The soil aggregates were broken down by the water and collected by size, according to the sieve they remained on. The weight of the soil in each sieve was used to estimate the average size of the aggregates, known as the MWD.

Soil Active Carbon Analysis

Approximately 20 g (+/- 1 g) of each soil size fraction (0-2 and 2-8 mm) was sent to the Soil Health Assessment Center in Missouri to be analyzed for soil active carbon (SAC), using the Potassium Permanganate method (Kellogg Biological Station, 2018).

Soil Organic Matter Analysis

Another 20g +/- 1g soil subsample was analyzed for percent soil organic matter (SOM) using the loss on ignition method, as described by Moore et al. (2014). The soil samples were oven-dried at 105 degrees Celsius for 24 hours prior to ignition to remove any existing moisture. After moisture removal, samples were placed in desiccators to cool and then weighed (oven-dry soil) to the nearest 0.0001 g. After being weighed, the samples were placed in a muffle furnace at 360 degrees Celsius. The samples remained in the furnace for 24 hours after the furnace reached a constant 360 degrees Celsius. At 24 hours the furnace was turned off and left to cool with the samples still in the furnace. If more time was needed to cool the samples, the samples were placed in desiccators. Once the samples were cool enough to touch, the samples were weighed (soil weight after ignition) to the nearest 0.0001 g. The following equation was used to calculate the percent soil organic matter estimate:

$$SOM\ estimate\ \% = \frac{(Oven\ dry\ soil\ weight\ (g) - Soil\ weight\ after\ ignition\ (g))}{Oven\ dry\ soil\ weight\ (g)} \times 100$$

Weighted Average Concentrations of Soil Active Carbon and Soil Organic Matter

To calculate the weighted average concentrations of the soil active carbon (TSAC) and soil organic matter (TSOM) for the whole sample (0-8 mm), a weighted average (WtAv) was calculated using the following equation:

$$\begin{aligned} WtAv = {} & (0\text{–}2\ mm\ soil\ measurement \times \%\ mass\ in\ 0\text{–}2\ mm\ size\ range) \\ & + (2\text{–}8\ mm\ soil\ measurement \times \%\ mass\ in\ 2\text{–}8\ mm\ size\ range) \end{aligned}$$

The soil size percent mass was calculated by dividing the soil size fraction weight by the sum of both (0-2 mm and 2-8 mm) soil size fractions, as shown by the following equation:

$$Soil\ size\ fraction\ \% = \frac{Soil\ size\ fraction\ weight}{Sum\ of\ soil\ size\ fractions\ weight} \times 100$$

Cover Crop Biomass

The cover crop biomass data were collected in the CCSI project (Woodyard, 2018).

Statistical Analysis

Data analyses were performed in SAS 9.4 software (SAS Institute Inc., Cary, NC) using the MIXED procedure. Prior to these statistical analyses, the normality and homogeneity of variances of the model residuals were checked using a BOXGLM macro in SAS; no transformation were necessary. For each variable, site and year were analyzed separately. Fixed effects at all sites included treatment, as well as soil fraction for SAC and SOM measurements, while block was considered a random effect.

For the statistical analyses of the PACs, cover crop treatments were nested within each cash crop because the cover crop treatments varied depending on the cash crop; cash crop was considered a fixed effect along with treatment. Estimate statements were used to reduce the number of comparisons for the cover crop treatments nested within cash crops, by excluding the comparisons between the cash crops. However, the adjusted p-values were similar to those obtained from the LSMEANS statement in the MIXED procedure, which included all of the comparisons across the cash crops. Therefore, the estimate statements were not utilized in the final analysis.

Each treatment at the main farmer site was compared separately to the conventional comparison sites (CC vs CONV and NC vs CONV) with a T-test. Block was not included in the model due to the conventional neighbor plots being in separate fields. Least square means were separated using a Tukey adjustment at $\alpha = 0.10$.

The CORR procedure in SAS was used to perform correlations for this study to determine: 1) the relationship between soil aggregate stability, TSAC, SAC, TSOM, and SOM 2) the relationship between the soil aggregate stability ratios, SAC ratios, and SOM ratios to the quantity of cover crop biomass grown in the current fall and current spring of the cover crop season and 3) the relationship between the PAC's soil aggregate stability ratios, SAC ratios, and SOM ratios to the additional cover crop biomass periods.

To evaluate the relationship between the quantity of cover crop biomass and the soil measurement (aggregate stability, TSAC, SAC, TSOM, and SOM) ratios were calculated for sites that only had a cover crop and no cover crop treatment using the following equation:

$$Soil\ measurement\ ratio = \frac{Cover\ crop\ soil\ measurement}{No\ cover\ soil\ measurement}$$

Cover crop and no cover treatments were paired within each block at a site. If there were multiple cover crop treatments at a site, each cover crop treatment was paired with the same no cover treatment in the block to calculate the response ratio. The sites included in the correlation are ones that distinctly have a cover crop and no cover crop treatment. The Current Fall (CF) and Current Spring (CS) cover crop biomass periods were analyzed separately. To determine if there was a cash crop effect or cover crop biomass timing influence on the correlations, the PACs were analyzed independently with additional cover crop biomass periods. In addition to the CF and CS periods, the Previous Spring (PS), Net PS, Net CF, Net CS, Sum of PS and CF, and Net Sum of PS and CF were also analyzed. The following equations were used to calculated the additional cover crop biomass periods:

$$Net\ PS = (PS\ cover\ crop\ biomass) - (PS\ no\ cover\ crop\ biomass)$$

$$Net\ CF = (CF\ cover\ crop\ biomass) - (CF\ no\ cover\ crop\ biomass)$$

$$Net\ CS = (CS\ cover\ crop\ biomass) - (CS\ no\ cover\ biomass)$$

$$Sum\ of\ PS\ and\ CF = (PS\ cover\ crop\ biomass) + (CF\ cover\ crop\ biomass)$$

$$Net\ Sum\ of\ PS\ and\ CF = (Net\ PS) + (Net\ CF)$$

CHAPTER 3. RESULTS AND DISCUSSIONS

Percent Mass Distribution

With the exception of the sandy soil at Villwock, most of the soil samples had approximately 40 to 60% of their mass in the 2-8 mm soil size fraction and 60 to 40% of their mass in the 0-2 mm size fraction. The reason we measured the relative amount of soil in the two fractions was to evaluate the soil mass distribution in different size fractions before wet sieving and to calculate the TSAC and TSOM. We expected to see that the sites would have more soil in the 2-8 mm size fraction than in the 0-2 mm size fraction, because that could indicate that there is lower risk of erosion, especially with the use of conservation practices such as cover crops and no till. At NEPAC and SEPAC, the cover crop treatments had significantly more mass in the 2-8 mm size fraction than the no cover crop treatments (Table 6). However, the farmer site soils varied in the relative amount in the 2-8 mm size fraction, even when compared to the CONV.

About 5 of the 15 farmer sites, including NewDTC, showed that cover crop treatment was significantly different in the mass distribution. Four of the 5 sites had greater mass in the 2-8 mm in the CC versus NC treatments. Another 5 out of the 15 farmer sites, including NewDTC, showed that year was significantly different in the mass distribution, with most sites being greater in 2016, except at Wabash where it was greater in 2017 than in 2016. In 12 of the 29 comparisons of the farmer site treatments to CONV, the CONV had lower % mass in the 2-8 mm size fraction compared to the farmer sites, except for Villwock, which was reversed. Detailed results from each site are presented next.

Alford

There were no significant differences in the percent mass in the 2-8 mm size fraction between the WH13 and CR13 treatments (Table 7). Averaged across both treatments, 55% of the soil was in the 2-8 mm soil size fraction when sampled in 2016. The lack of significant treatment difference may be due to Alford not establishing cover crops since the fall of 2013.

Brocksmith

There were no significant differences in the percent mass in the 2-8 mm soil size fraction between the cover crop CC and NC treatments at Brocksmith, but there was a significant difference of the soil size fractions between the years (Table 7). The 2-8 mm soil size fraction was significantly greater in 2016 (60%) than in 2017 (44%), $P < 0.01$. Overall, approximately 50% and 54% of the CC and NC soil samples, respectively, were in the 2-8 mm size fraction. The CONV (53%) and the NC (63%) treatments were significantly different from one another in 2016, $P < 0.01$ (Table 8), but not significantly different in 2017. The CONV and CC treatments were not significantly different from one another in either 2016 or 2017.

DeSutter

Averaged across years, the CC (63%) treatment had significantly greater amounts of 2-8 mm soil aggregates than the NC (55%) treatment. $P < 0.01$ (Table 7). The CC treatment also had significantly more 2-8 mm soil aggregates than the CONV in both 2016 and 2017, $P < 0.01$ (Table 8). In 2016, the CC had 62% and in 2017 had 64% of its soil percent mass in the 2-8 mm size fraction, while the CONV had about 50% in both 2016 and 2017 (Table 8).

DTC

There were no significant differences with the percent mass in the 2-8 mm soil fraction among the cash crops or cover crop treatments at DTC (Table 6), but approximately 42% of the soil's mass was in the 2-8 mm soil size fraction.

Huffmeyer

Approximately, 55% of the soil sampled in 2016 was in the 2-8 mm soil fraction (Table 7). There was no significant difference between the CT (53%) and ST (57%) treatments (Table 7), but they both had significantly more mass in the 2-8 mm soil size fraction than the CONV (40%), $P < 0.01$ (Table 8).

Mills

There were no significant differences among the different rates of nitrogen (Low, Medium, and High) with cover crop use (Table 7), but approximately 50% of the soil sample's mass was in the 2-8 mm soil size fraction.

NEPAC

There was a significant difference among the treatments within the cash crops, $P < 0.05$. When the cash crop was corn, both cover crop treatments (O/R/CC/CR-Soybean and O/R-Soybean) had significantly more percent mass in the 2-8 mm fraction than the NC-Soybean treatment (Table 6). In the soybean cash crop, the CR-Corn had significantly more percent mass in the 2-8 mm fraction than the NC-Corn treatment, but the O/R/CR-Corn was not significantly different than the CR-Corn and NC-Corn (Table 6).

There was also a significant interaction among the cash crop and year, $P < 0.05$ (Table 6), with the 2016 soybean cash crop (64%) having greater percent mass in the 2-8 mm fraction than the 2016 corn (57%), 2017 soybean (50%), and 2017 corn (48%). The 2016 corn also had significantly greater percent mass in 2-8 mm soil size fraction than the 2017 soybean and 2017 corn, but both 2017 cash crops were not significantly different from one another (Table 6). Overall, the soybean cash crop had significantly greater percent mass in the 2-8 mm soil size fraction than corn and the 2016 year had significantly more 2-8 mm size fraction than 2017.

NewDTC

There was a significant interaction among the treatments and year, $P < 0.05$ (Table 7). The 2016 NC (50%) and 2017 One (50%) treatments had significantly more mass in the 2-8 mm soil fraction than the 2016 Mix (46%), 2016 One (45%), and 2017 NC (45%); while the 2017 Mix (48%) treatment was not significantly different. Across both years, about 47% of the soil among all the treatments were in the 2-8 mm soil size fraction (Table 7). When the samples were taken during the cover crop growing period in fall 2016, the NC treatment had significantly more percent mass in the 2-8 mm soil size fraction than the Mix and One treatments. After the cover crops were terminated and the site was sampled in 2017, the One treatment had significantly more mass in the 2-8 mm size fraction than the NC treatment; the Mix was not significantly different from the One and NC treatments. In general, the percent mass in the 2-8 mm soil size fraction increased from the time the cover crop treatments (Mix and One) were actively growing to after termination; while the NC treatment decreased.

Rulon

There were significant differences in the mass of soil within the 2-8 mm size fraction among the treatments ($P < 0.05$) and between years ($P < 0.01$), however there was no significant interaction (Table 7). The soil in 2016 (57%) had significantly more mass in the 2-8 mm size fraction than in 2017 (42%). The CR (57%) treatment had significantly more mass in the 2-8 mm soil size fraction than the O/R (46%) and NC (44%) treatment. The AR (51%) treatment was not significantly different from the CR, O/R, and NC treatments (Table 7).

Scott

There were no significant differences among the treatments or years at Scott. However, less than 50% of the soil mass was in the 2-8 mm size fraction (Table 7). The treatments were also not significantly different from the CONV treatments in either 2016 or 2017, but the CONV tended to have more mass in the 2-8 mm size fraction (Table 8). This could be due to the CONV having 3-4% more clay than the main plots (Table 5).

SEPAC

There was a significant difference among the treatments within the cash crops at SEPAC, $P < 0.01$ (Table 6). Within the corn cash crop, the O/R-Soybean (55%) percent mass in the 2-8 mm soil fraction was significantly greater than the NC-Soybean (51%). The O/R/CC/CR-Soybean (54%) was not significantly different than the O/R-Soybean and NC-Soybean. In the soybean cash crop, the O/R/CR-Corn (59%) and CR-Corn (59%) had significantly greater percent mass in the 2-8 mm fraction than the NC-Corn (52%). The O/R/CR-Corn and CR-Corn were similar. There was also significantly more percent mass of the 2-8 mm fraction in 2016 than in 2017, $P < 0.01$. Overall, the treatments in the soybean cash crop (after corn) in 2016 had the most percent mass in the 2-8 mm soil fraction.

Shuter

When sampled in 2016, the CC (58%) treatment had significantly more percent mass in the 2-8 mm size fraction than the NC (44%), $P < 0.01$ (Table 7).

Stahl

Overall, the samples taken in 2016 (49%) had significantly more mass in the 2-8 mm soil size fraction than in 2017 (39%), $P < 0.01$ (Table 7). The CC treatments tended to have more mass in the 2-8 mm soil size fraction, but was not significantly different than the NC treatment.

Villwock

Only 24% of the soil mass was in the 2-8 mm size fraction (Table 7). This could be due to the soil consisting of 70% sand, which is the most compared to the rest of the sites including Scott (Table 5). However, the CC (28%) treatment had significantly more soil in the 2-8 mm size fraction than the NC (21%) treatment, $P < 0.1$ (Table 7). The CONV (51%) had significantly greater mass in the 2-8 mm size fraction than the CC treatment ($P < 0.05$) and NC treatment ($P < 0.01$) (Table 8). Similar to the Scott site, the CONV had more clay than the main plots, approximately 6-7% (Table 5).

VUJC

The NT (65%) plot tended to have more mass in the 2-8 mm soil fraction than the CT (54%) plot (Table 7).

Wabash

There were no significant differences among the treatments at Wabash. However, the samples collected in 2016 had significantly smaller 2-8 mm soil fraction (56%) than when samples were collected in 2017 (64%), $P < 0.01$ (Table 7). This could be due to the addition of chicken litter across the field in fall 2016. It is reported that chicken manure increased soil aggregation properties and can be ascribed to increasing microbial activity in the soil related to increasing levels of organic manure (Cayci et al., 2017). Therefore, the chicken litter application could have aided with the development of more 2-8 mm soil size aggregates in 2017.

Wenning

The NT (59%) and ST (61%) treatments were not significantly different from one another, but the soil mass in the 2-8 mm size fraction was significantly greater in 2016 (63%) than in 2017 (56%), $P < 0.05$ (Table 7). Both the NT and ST treatments had significantly greater mass in the 2-8 mm size fraction than the CONV (Table 8).

Werling

In 2016, the CC (61%) treatment had significantly more mass in the 2-8 mm size fraction than the CONV (47%), $P < 0.05$ (Table 8). In 2017, after the treatments changed, there were no significant differences among the treatments (Table 7), nor between each treatment and CONV (Table 8). However, approximately 70% of the soil mass existed in the 2-8mm soil size fraction at Werling, which is the largest amount of all the sites. Werling also has the most percent clay compared to the rest of the sites (Table 5).

Table 6 Purdue Agricultural Centers percent mass in the 2-8 mm soil size fraction (ANOVA test with the cover crop treatment nested within the cash crop).

Site	Cash Crop	Treatment	2016		2017		Ave Both Yrs	
DTC	Corn	O/R-Soybean	44		—		—	
		O/R/CC/CR-Soybean	45		—		—	
		NC-Soybean	43		—		—	
		Average	44		—		—	
	Soybean	CR-Corn	42		—		—	
		O/R/CR-Corn	40		—		—	
		NC-Corn	40		—		—	
		Average	41		—		—	
		Site Average	42		—			
NEPAC	Corn	O/R-Soybean	58		49		53	S
		O/R/CC/CR-Soybean	59		50		54	S**
		NC-Soybean	54		44		49	T
		Average	57	B	48	C	52	k
	Soybean	CR-Corn	66		54		60	X**
		O/R/CR-Corn	64		48		56	XY
		NC-Corn	63		47		55	Y
		Average	64	A**	50	C	57	j***
		Site Average	60	a***	49	b		
SEPAC	Corn	O/R-Soybean	58		52		55	S***
		O/R/CC/CR-Soybean	56		53		54	ST
		NC-Soybean	54		49		51	T
		Average	56		51		54	k
	Soybean	CR-Corn	62		56		59	X
		O/R/CR-Corn	62		57		59	X***
		NC-Corn	55		49		52	Y
		Average	60		54		57	j***
		Site Average	58	a***	52	b		

Table 6 Notes:
— Indicates that there were no samples taken, therefore averages of both years cannot be determined
* Indicates a significance level of P < 0.1
** Indicates a significance level of P < 0.05
*** Indicates a significance level of P < 0.01
a and b letters located in the 'Site Average' rows indicate that there was a significant difference between years at each site
j and k letters located in the 'Ave Both Yrs' columns indicate that there was a significant difference between the cash crops at each site
Uppercase letters within the 'Average' rows indicate that there was a significant interaction among the cash crops and years at each site
Uppercase letters within the 'Ave Both Yrs' column indicates that there was a significant interaction among the treatments within the cash crops at each site
Same letters indicate that there was no significant difference
Abbreviations: Ave Both Yrs = Average across both years; O/R-Soybean = Oat and radish cover crop mix following soybean cash crop treatment; O/R/CC/CR-Soybean = Oat, radish, crimson clover, and cereal rye cover crop mix following soybean cash crop treatment; NC-Soybean = No cover crop following soybean cash crop treatment; CR-Corn = Cereal rye cover crop following corn cash crop treatment; O/R/CR-Corn = Oat, radish, and cereal rye cover crop mix following corn cash crop treatment; NC-Corn = No cover crop following corn cash crop treatment

Table 7 Farmer Sites and NewDTC percent mass in the 2-8 mm soil size fraction (ANOVA test).

Site	Treatment	2016		2017		Ave Both Yrs	
Alford	CR13	55		—		—	
	WH13	57		—		—	
	Average	56		—			
Brocksmith	CC	58		44		51	
	NC	63		45		54	
	Average	60	x***	44	y		
Desutter	CC	62		64		63	a***
	NC	57		53		55	b
	Average	60		58			
Huffmeyer	ST	57		—		—	
	CT	53		—		—	
	Average	55		—			
Mills	Low	52		—		—	
	Medium	49		—		—	
	High	48		—		—	
	Average	50		—			
NewDTC	Mix	46	B	48	AB	47	
	One	45	B	50	A	48	
	NC	50	A**	45	B	48	
	Average	47		48			
Rulon	AR	57		45		51	ab
	CR	62		52		57	a**
	O/R	53		38		46	b
	NC	58		31		44	b
	Average	57	x***	42	y		
Scott	Mix	43		42		43	
	One	47		43		45	
	NC	48		43		46	
	Average	46		43			
Shuter	CC	58	a***	—		—	
	NC	44	b	—		—	
	Average	51		—			
Stahl	CC	50		42		46	
	NC	49		36		43	
	Average	49	x***	39	y		
Villwock	CC	28	a*	—		—	
	NC	21	b	—		—	
	Average	24		—			
VUJC	NT	£ 65		—		—	
	CT	£ 54		—		—	
	Average	59		—			

Table 7 Continued.

Site	Treatment	2016		2017		Ave Both Yrs
Wabash	Mix	57		65		61
	One	56		62		59
	Average	56	y	64	x***	
Wenning	NT	63		55		59
	ST	64		57		61
	Average	63	x**	56	y	
Werling	CC	61		—		—
	Mix	—		72		—
	One	—		75		—
	NC	—		72		—
	Average	—		73		

Table 7 Notes:
₤ Indicates that the values were not included in the statistical analysis due to the site only have one replication of each treatment
— Indicates that there were no samples taken, therefore averages of both years cannot be determined
* Indicates a significance level of P < 0.1
** Indicates a significance level of P < 0.05
*** Indicates a significance level of P < 0.01
Upper case letters within the '2016' and '2017' columns indicate that there was a significant interaction among the treatments and year at each site
Lower case letters located in the 'Ave Both Yrs' columns indicate that there was a significant difference between the treatments at each site
x and y letters located in the 'Average' rows indicate that there was a significant difference between the years at each site
Abbreviations: Ave Both Yrs = Average across both years; CR13 = Cereal rye cover crop planted in 2013 treatment; WH13 = Wheat cover crop planted in 2013 treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Low = 101 kg ha^{-1} Nitrogen application treatment; Medium = 145 kg ha^{-1} Nitrogen application treatment; High = 201 kg ha^{-1} Nitrogen application treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; AR = Annual ryegrass cover crop treatment; CR = Cereal rye cover crop treatment; O/R = Oat and radish cover crop treatment; NT = No tillage with cover crop use treatment

Table 8 Farmer Sites with a Conventional Neighbor percent mass in the 2-8 mm soil size fraction (T-test between the CONV and treatments).

Site	Treatment	2016		2017	
Brocksmith	CONV	54		43	
	CC	58	ns	44	ns
	NC	63	***	45	ns
Desutter	CONV	50		50	
	CC	62	***	64	***
	NC	57	ns	53	ns
Huffmeyer	CONV	40		—	
	ST	57	***	—	
	CT	53	***	—	
Scott	CONV	54		45	
	CC	45	ns	43	ns
	Mix	43	ns	42	ns
	One	47	ns	43	ns
	NC	48	ns	43	ns
Villwock	CONV	51		—	
	CC	28	**	—	
	NC	21	***	—	
Wenning	CONV	42		43	
	NT	63	***	55	**
	ST	64	***	57	***
Werling	CONV	48		70	
	CC	61	**	74	ns
	Mix	—		72	ns
	One	—		75	ns
	NC	—		72	ns

Table 8 Notes:
— Indicates that there were no samples taken
* Indicates the CONV was significantly different than the treatment, P < 0.1, at each site
** Indicates the CONV was significantly different than the treatment, P < 0.05, at each site
*** Indicates the CONV was significantly different than the treatment, P < 0.01, at each site
ns Indicates the CONV was not significantly different than the treatment at each site
CC at the Scott and Werling sites, combine and test the Mix and One treatments to the CONV
Abbreviations: CONV = Conventional tillage with no cover crop use treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; NT = No tillage with cover crop use treatment

Soil Aggregate Stability

Overall soil aggregate stability results showed that within the PACs, the cover crop mixes tended to perform the same or better than the NC treatments. There were more significant differences among treatments at SEPAC than at NEPAC, DTC, and NewDTC. This could be because of SEPAC establishing more cover crop growth due to its location in Southern Indiana which has a longer growing season compared to the rest of the PACs. At most sites, both PACs and farmer cooperators, greater amounts of biomass grown (Woodyard, 2018) was an indicator for greater soil aggregate stability. There were no significant differences among the treatments' soil aggregate stability if the site had wheat or oats as its previous cash crop (Desutter, Scott, Wabash, and Werling), and if the treatments compared were tillage treatments (Huffmeyer and Wenning) or N rate treatments (Mills). Usually the greatest positive differences in soil aggregate stability occurred when comparing no-till and cover crop use to the neighboring conventional-till without cover crops (CONV) systems. Five of the 15 farmer sites including NewDTC showed a significant difference between the treatments with a cover crop treatment having the largest MWD, 4.0-4.5 mm. About 20 of the 29 comparisons of the farmer site treatments to CONV differed in the MWD where the MWDs were 3.0-4.7 mm and the CONV were 1.4-3.7 mm. Detailed results from each site are presented next (Table 9-11).

Alford

The WH13 and CR13 cover crop treatments were not significantly different from each other (Table 10). This lack of a difference could be due to the site not having a cover crop planted since fall 2013.

Brocksmith

The CC treatment was significantly greater in MWD than the NC treatment, $P < 0.05$, when averaged across years (Table 10). This could be due to the amount of biomass produced by the cover crops prior to sampling for soil aggregate stability. Prior to the soil aggregate stability measurement in 2016, the CC total biomass was an accumulation of 806 kg ha^{-1} in fall 2015 and 2,072 kg ha^{-1} in spring 2016; while prior to the 2017 sampling there was an accumulation of 989 kg ha^{-1} in fall 2016 and 1,261 kg ha^{-1} in spring 2017. The NC total biomass was only an accumulation of 456 kg ha^{-1} in fall 2015 and 717 kg ha^{-1} in spring 2017 (Woodyard, 2018). When Brocksmith was sampled in 2016, it also had a significantly greater MWD than when it was sampled in 2017, $P < 0.01$ (Table 10). This could have been due in part to the cereal rye in spring 2016 having greater biomass growth than the oat/cereal rye/crimson clover mixture in 2017. When compared to the MWD of the CONV treatment (2016 = 3.1 mm and 2017 = 2.8 mm), the CC treatments were significantly greater in 2016 (4.3 mm) and 2017 (3.6 mm), $P < 0.01$, but were not significantly different than the NC treatments in either 2016 (3.8 mm) or 2017 (3.0 mm) (Table 11).

DeSutter

The MWD of the CC treatment was significantly greater than the NC treatment (Table 10), which relates to the amount of biomass produced by the cover crops. The CC total biomass was significantly greater than the NC at Desutter (Woodyard, 2018). Prior to the soil aggregate stability sampling in 2016, the CC treatment produced 6,041 kg ha^{-1} and the NC produced 1,415 kg ha^{-1}. Prior to the 2017 soil aggregate sampling, the CC treatment produced 6,682 kg ha^{-1} total biomass and the NC produced 1,021 kg ha^{-1}(Woodyard, 2018). As previously mentioned, there was a 12-way mix planted prior to 2016 sampling and cereal rye planted prior to 2017 sampling. Overall the MWD in 2017 (4.0 mm) was significantly larger than the MWD in 2016 (2.9 mm); which could be associated with the main plots transitioning to organic hence the vast amount of biomass grown from the cereal rye in the CC plots and weeds in the NC plots. It could also be that the residue from the wheat cash crop prior to 2016 sampling was not as effective as the corn cash crop residue prior to 2017 sampling. When compared to the MWD of the CONV treatment (2016 = 2.2 mm and 2017 = 2.8 mm), the CC treatments were significantly greater than the CONV in 2016 (3.3 mm) and 2017 (4.7 mm), $P < 0.01$. Yet, the MWD of the NC treatments were not significantly different from the CONV treatment in either 2016 (2.6 mm) or 2017 (3.3 mm) (Table 11).

DTC

There were no significant differences among the treatments within the cash crops when sampled in 2016, but the cover crop treatments in corn did had a tendency for larger

MWD than the no cover crop treatment (Table 9). The O/R/CC/CR-Soybean (891 kg ha^{-1}) total biomass was significantly more than the O/R-Soybean (214 kg ha^{-1}) and NC-Soybean (334 kg ha^{-1}) (Woodyard, 2018). Respectively the O/R/CC/CR-Soybean MWD was 3.4 mm, O/R-Soybean 3.1 mm, and NC-Soybean 2.8 mm (Table 9).

Huffmeyer

The MWD of the CT (3.0 mm) and ST (3.2 mm) treatments were not significantly different from one another while using cover crops (Table 10), but the cover crop growth was small. Although the total cover crop biomass produced by the cereal rye, prior to sampling in the CT treatment was 47 kg ha^{-1} and in the ST treatment was 99 kg ha^{-1}, They were not significantly different from one another (Woodyard, 2018). There was also no significant difference when comparing the CONV to the CT and ST treatments, however it tended to have higher MWD than the CT and ST treatments (Table 11).

NEPAC

There were no significant differences among the treatments at NEPAC, however the overall MWD in 2016 (3.6 mm) was significantly greater than the overall MWD in 2017 (3.0 mm), $P < 0.01$ (Table 9).

NewDTC

The overall aggregate stability in 2017, when sampled during late spring-early summer, was significantly greater than in fall 2016, when sampled while the cover crops were still growing (Table 10). This suggests that the aggregate stability can significantly change depending on the time of soil aggregate stability sampling. In 2016, the samples were collected the same day as the biomass sampling, October 25. Although there were no significant differences among the treatments' MWD, Woodyard (2018) found the Mix and One treatments to have greater total biomass than the NC treatment. The total biomass of the Mix (5,190 kg ha^{-1}) and One (3,676 kg ha^{-1}) was much greater than the NC (626 kg ha^{-1}) treatment (Woodyard, 2018). This also resembles the MWD of the Mix (3.2 mm) and One (3.2 mm) tending to be larger than the NC (2.3 mm) treatment in 2016.

Mills

The MWD of the cover crop plots at Mills were not significantly different among the different nitrogen treatments (Table 10). There also had been no significant differences in cover crop biomass among treatments.

Rulon

There was a significant interaction between MWD of the cover crop treatments and years, $P < 0.05$ (Table 10). The 2017 CR (4.2 mm), 2016 CR (3.9 mm), 2016 O/R (3.8 mm), 2017 AR (3.8 mm), and 2016 AR (3.7 mm) treatments were not significantly different from one another; the 2016 AR (3.7 mm) was similar to the 2016 NC (3.5 mm) treatment; the 2016 NC (3.5 mm) was similar to the 2017 O/R (3.0 mm) treatment; however, the 2017 NC treatment had the significantly smallest MWD (2.0 mm) of all the treatments at Rulon (Table 10). Across both years, the CR treatments had the highest MWD (4.0 mm) and the NC treatments had the smallest MWD (2.8 mm); the AR treatment had a similar MWD as the CR (4.0 mm) and O/R (3.4 mm) treatments, but was still significantly different from the NC treatment (2.8 mm). Overall the MWD during the 2016 sampling (3.7 mm) was significantly larger than the 2017 sampling (3.3 mm), $P < 0.05$ (Table 10). In the fall prior to sampling, the O/R treatment (fall 2015 = 301 kg ha^{-1} and fall 2016 = 1,522 kg ha^{-1}) tended to produced greater amounts of total biomass than the CR treatment (fall 2015 = 233 kg ha^{-1} and fall 2016 = 956 kg ha^{-1}) and AR treatment (fall 2015 = 294 kg ha^{-1} and fall 2016 = 1,246 kg ha^{-1}) (Woodyard, 2018). Since the O/R winter kills, only the CR (spring 2016 = 2,734 kg ha^{-1} and spring 2017 = 1,946 kg ha^{-1}) and AR (spring 2016 = 1,336 kg ha^{-1} and spring 2017 = 1,040 kg ha^{-1}) treatments continue to grow in the spring prior to sampling.

Scott

There was a significant interaction among the treatments and years at Scott, $P < 0.05$ (Table 10). The Mix treatment in 2017 had the greatest MWD (4.5 mm) than the rest of the treatments in both years. Averaged across both years, the MWD of the Mix treatment (4.2 mm) was significantly larger than the One treatment (3.8 mm), however the NC treatment (3.9 mm) was not significantly different from the Mix and One treatments (Table

10). As previously mentioned, the main plots at Scott were planted to a wheat cash crop prior to the 2016 sampling, therefore could be the reason no differences were detected among the treatments. In 2016, the MWD of the CONV treatment (3.6 mm) was only significantly different from the 2016 One treatment (4.0 mm), $P < 0.1$ (Table 11). In 2017, the MWD of the CONV (2.6 mm) was significantly different from the Mix ($P < 0.01$), One ($P < 0.05$), and NC ($P < 0.01$) treatments. Also, the MWD of the CONV treatment in 2017 tended to be smaller than in 2016 MWD (Table 11), which could be due to the soybeans growing at the time of sampling in 2016 and the corn barely emerging in 2017.

SEPAC

There was a significant interaction between the cash crop and years, $P < 0.01$, and treatments within the cash crop, $P < 0.01$ (Table 9). The MWD in 2017 Soybean (4.4 mm) and 2016 Corn (4.2 mm) were significantly larger than the MWD in 2016 Soybean (3.9 mm) and 2017 Corn (3.6 mm). Within the corn cash crop, the O/R/CC/CR-Soybean MWD (4.1 mm) was significantly greater than the NC-Soybean MWD (3.7 mm), but the O/R-Soybean MWD (3.9 mm) was not significantly different from the O/R/CC/CR-Soybean and NC-Soybean MWD (Table 9). Within the soybean cash crop, the CR-Corn (4.5 mm) and O/R/CR-Corn (4.4 mm) MWD were significantly greater than the NC-Corn MWD, 3.6 mm (Table 9). Averaged across years, the treatments in a Soybean cash crop had significantly greater MWD than the treatments in the Corn cash crop at a $P < 0.05$ (Table 9).

Shuter

The MWD of the CC and NC treatments were not significantly different from each other at Shuter. However, the CC had a tendency for a larger MWD than the NC treatment (Table 10), which might be associated with the 14-way mix grown prior. The lack of significant difference could be due to the site being in its first year of cover crop use and may be too early to detect a difference.

Stahl

The MWD of the CC treatment was not significantly different from the NC treatment at Stahl (Table 10), even though the cereal rye produced 1,462 kg ha^{-1} of total biomass in fall 2015 (Woodyard, 2018). As previously mentioned, in spring 2017 the whole field was vertical tilled and soybeans had to be replanted due to a wet spring and slug problems. This incident could explain why the overall MWD tended to be smaller in 2017 than in 2016 (Table 10).

Villwock

The MWD of the CC and NC treatments were not significantly different from each other (Table 10). However, the MWD of the CC (4.7 mm) and NC (4.6 mm) treatments was significantly larger than the CONV (3.7 mm), $P < 0.01$ (Table 11). Although the soil is similar to Scott, a fine sandy loam soil texture (Table 2), it performed similarly to the rest of sites that didn't have a sandy texture.

VUJC

The cover crop plot under conventional tillage tended to have a larger MWD than the cover crop plot under no-till (Table 10).

Wabash

There was a significant interaction, $P < 0.05$, among the MWD between the treatments and years at Wabash (Table 10). The MWD of the 2017 One treatment (4.3 mm) was significantly larger from the 2016 One (3.4 mm), 2016 Mix (3.7 mm), and 2017 Mix (3.7 mm) treatments. It was unanticipated that the 2017 One treatment had a greater MWD than the Mix treatments because prior to sampling, the Mix tended to have more biomass than the One, which was primarily volunteer wheat and weeds at the time (Woodyard, 2018). Prior to the 2016 sampling, the Mix treatment (112 kg ha^{-1}) tended to produce more biomass than the One treatment (fall 2015 = 74 kg ha^{-1}) due to the added radish being planted with the wheat in the Mix treatment. Prior to the 2017 sampling, the Mix treatment (fall 2016 = 13,405 kg ha^{-1} and spring 2017 = 222 kg ha^{-1}) produced significantly more biomass than the One treatment (fall 2016 = 2,451 kg ha^{-1} and spring 2017 = 1,655 kg ha^{-}

^{1}) (Woodyard, 2018). However, as previously mentioned, a week after the Mix was planted in fall 2016 chicken litter was applied to the whole field, which could have had stronger effects on the soil aggregate stability than the cover crop biomass growth. Overall the MWD in 2017 was significantly greater than the MWD in 2016, $P < 0.05$ (Table 10), again which could be due to the chicken litter application and Wabash being in a wheat cash crop prior to the 2016 sampling similar to Scott.

Wenning

Across both years, the NT and ST treatments had similar MWD, but the overall MWD in 2016 (4.0 mm) was significantly larger than in 2017 (3.1 mm), $P < 0.01$(Table 10). The cereal rye in 2016 (NT = 261 kg ha^{-1} and ST = 309 kg ha^{-1}) tended to produce more biomass than in 2017 (NT = 125 kg ha^{-1} and ST = 98 kg ha^{-1}) (Woodyard, 2018). In comparison to the CONV treatment, the NT treatment (2016 = 4.0 mm and 2017 = 3.2 mm) and ST treatment (2016 = 4.1 mm and 2017 = 3.0 mm) had significantly larger MWD than the CONV treatment (2016 = 1.9 mm and 2017 = 1.4 mm), $P < 0.01$(Table 11).

Werling

In 2016 the MWD of the field tended to be larger than in 2017, which could be in part of the field being in an oat cash crop at the time and before the plots were adjusted to the current (Mix, One and NC) treatments. In 2017, the Mix, One, and NC treatments were not significantly different from one another, but the cover crop (Mix and One) treatments tended to have larger MWD than the NC (Table 10). The lack of significant difference among the treatments could be due to its first year with the new treatments plus it being too early. In comparison to the CONV, the CC treatment in 2016 had a significantly larger MWD, $P < 0.01$(Table 11). The Mix, One, and NC treatments also had significantly larger MWD than the CONV in 2017, $P < 0.01$ (Table 11). The CONV tended to have a larger MWD in 2016 (2.8 mm) than in 2017 (1.7 mm).

Table 9 Purdue Agricultural Centers soil aggregate stability measured as a Mean Weight Diameter in mm (ANOVA test with the cover crop treatment nested within the cash crop).

Site	Cash Crop	Treatment	2016	2017	Ave Both Yrs
DTC	Corn	O/R-Soybean	3.1	—	—
		O/R/CC/CR-Soybean	3.4	—	—
		NC-Soybean	2.8	—	—
		Average	3.1		
	Soybean	CR-Corn	3.3	—	—
		O/R/CR-Corn	3.4	—	—
		NC-Corn	3.3	—	—
		Average	3.3	—	—
		Site Average	3.2	—	
NEPAC	Corn	O/R-Soybean	3.7	3.0	3.3
		O/R/CC/CR-Soybean	3.5	3.0	3.3
		NC-Soybean	3.1	3.1	3.1
		Average	3.5	3.0	3.2
	Soybean	CR-Corn	3.8	3.1	3.4
		O/R/CR-Corn	3.6	3.0	3.3
		NC-Corn	3.9	3.0	3.4
		Average	3.7	3.0	3.4
		Site Average	3.6 a***	3.0 b	
SEPAC	Corn	O/R-Soybean	4.4	3.4	3.9 ST
		O/R/CC/CR-Soybean	4.3	3.9	4.1 S***
		NC-Soybean	3.8	3.5	3.7 T
		Average	4.2 A	3.6 B	3.9 k
	Soybean	CR-Corn	4.4	4.6	4.5 X***
		O/R/CR-Corn	4.2	4.5	4.4 X
		NC-Corn	3.1	4.1	3.6 Y
		Average	3.9 B	4.4 A***	4.1 j**
		Site Average	4.0	4.0	

Table 9 Notes:
— Indicates that there were no samples taken, therefore averages of both years cannot be determined
* Indicates a significance level of P < 0.1
** Indicates a significance level of P < 0.05
*** Indicates a significance level of P < 0.01
a and b letters located in the 'Site Average' rows indicate that there was a significant difference between years at each site
j and k letters located in the 'Ave Both Yrs' columns indicate that there was a significant difference between the cash crops at each site
Uppercase letters within the 'Average' rows indicate that there was a significant interaction among the cash crops and years at each site
Uppercase letters within the 'Ave Both Yrs' column indicates that there was a significant difference among the treatments within the cash crops at each site
Same letters indicate that there was no significant difference
Abbreviations: Ave Both Yrs = Average across both years; O/R-Soybean = Oat and radish cover crop mix following soybean cash crop treatment; O/R/CC/CR-Soybean = Oat, radish, crimson clover, and cereal rye cover crop mix following soybean cash crop treatment; NC-Soybean = No cover crop following soybean cash crop treatment; CR-Corn = Cereal rye cover crop following corn cash crop treatment; O/R/CR-Corn = Oat, radish, and cereal rye cover crop mix following corn cash crop treatment; NC-Corn = No cover crop following corn cash crop treatment

Table 10 Farmer Sites and NewDTC soil aggregate stability measured as a Mean Weight Diameter in mm (ANOVA test).

Site	Treatment	2016		2017		Ave Both Yrs	
Alford	CR13	3.9		—		—	
	WH13	4.1		—		—	
	Average	4.0		—		—	
Brocksmith	CC	4.3		3.6		4.0	a**
	NC	3.8		3.0		3.4	b
	Average	4.1	x***	3.3	y		
Desutter	CC	3.3		4.7		4.0	a***
	NC	2.5		3.3		2.9	b
	Average	2.9	y	4.0	x***		
Huffmeyer	ST	3.2		—		—	
	CT	3.0		—		—	
	Average	3.1		—		—	
Mills	Low	3.2		—		—	
	Medium	3.2		—		—	
	High	3.2		—		—	
	Average	3.2		—		—	
NewDTC	Mix	3.2		3.2		3.2	
	One	3.2		3.2		3.2	
	NC	2.3		3.3		2.8	
	Average	2.9	y	3.2	x*		
Rulon	AR	3.7	AB	3.8	A	3.8	ab
	CR	3.9	A	4.2	A**	4.0	a***
	O/R	3.8	A	3.0	C	3.4	b
	NC	3.5	BC	2.0	D	2.8	c
	Average	3.7	x**	3.3	y		
Scott	Mix	3.9	B	4.5	A**	4.2	a*
	One	4.0	B	3.6	B	3.8	b
	NC	3.9	B	3.9	B	3.9	ab
	Average	3.9		4.0			
Shuter	CC	3.3		—		—	
	NC	2.9		—		—	
	Average	3.1		—		—	
Stahl	CC	3.6		3.3		3.4	
	NC	3.7		3.4		3.5	
	Average	3.6		3.3			
Villwock	CC	4.7		—		—	
	NC	4.6		—		—	
	Average	4.7		—		—	
VUJC	NT	£ 2.7		—		—	
	CT	£ 3.3		—		—	
	Average	3.0		—		—	

Table 10 Continued.

Site	Treatment	2016		2017		Ave Both Yrs
Wabash	Mix	3.7	B	3.7	B	3.7
	One	3.4	B	4.3	A**	3.8
	Average	3.5	y	4.0	x**	
Wenning	NT	4.0		3.2		3.6
	ST	4.1		3.0		3.6
	Average	4.0	x***	3.1	y	
Werling	CC	4.5		3.6		—
	Mix	—		3.7		—
	One	—		3.7		—
	NC	—		3.5		—
	Average	—		3.6		—

Table 10 Notes:
£ Indicates that the values were not included in the statistical analysis due to the site only have one replication of each treatment
— Indicates that there were no samples taken and averages of both years cannot be determined
* Indicates a significance level of $P < 0.1$
** Indicates a significance level of $P < 0.05$
*** Indicates a significance level of $P < 0.01$
Lower case letters located in the 'Average Both Years' columns indicate that there was a significant difference among the treatments at each site
x and y letters located in the 'Year Average' rows indicate that there was a significant difference between the years at each site
Upper case letters within the '2016' and '2017' columns indicate that there was a significant interaction among the treatments and year at each site
Abbreviations: Ave Both Yrs = Average across both years; CR13 = Cereal rye cover crop planted in 2013 treatment; WH13 = Wheat cover crop planted in 2013 treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Low = 101 kg ha^{-1} Nitrogen application treatment; Medium = 145 kg ha^{-1} Nitrogen application treatment; High = 201 kg ha^{-1} Nitrogen application treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; AR = Annual ryegrass cover crop treatment; CR = Cereal rye cover crop treatment; O/R = Oat and radish cover crop treatment; NT = No tillage with cover crop use treatment

Table 11 Farmer Sites with a Conventional Neighbor soil aggregate stability measured as a Mean Weight Diameter in mm (T-test between the CONV and treatments).

Site	Treatment	2016		2017	
Brocksmith	CONV	3.1		2.8	
	CC	4.3	***	3.6	***
	NC	3.8	ns	3.0	ns
Desutter	CONV	2.2		2.8	
	CC	3.3	***	4.7	***
	NC	2.5	ns	3.3	ns
Huffmeyer	CONV	3.3		—	
	ST	3.2	ns	—	
	CT	3.0	ns	—	
Scott	CONV	3.6		2.6	
	CC	3.9	ns	4.1	***
	Mix	3.9	ns	4.5	***
	One	4.0	*	3.6	**
	NC	3.9	ns	3.9	***
Villwock	CONV	3.7		—	
	CC	4.7	***	—	
	NC	4.6	***	—	
Wenning	CONV	1.9		1.4	
	NT	4.0	***	3.2	***
	ST	4.1	***	3.0	***
Werling	CONV	2.8		1.7	
	CC	4.5	***	3.6	***
	Mix	—		3.5	***
	One	—		3.7	***
	NC	—		3.5	***

Table 11 Notes:
— Indicates that there were no samples taken
* Indicates the CONV was significantly different than the treatment, P < 0.1, at each site
** Indicates the CONV was significantly different than the treatment, P < 0.05, at each site
*** Indicates the CONV was significantly different than the treatment, P < 0.01, at each site
ns Indicates the CONV was not significantly different than the treatment at each site
CC at the Scott and Werling sites, combine and test the Mix and One treatments to the CONV
Abbreviations: CONV = Conventional tillage with no cover crop use treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; NT = No tillage with cover crop use treatment

SAC and TSAC

Similarly, to the soil aggregate stability, most differences were between the original farmer sites and their CONV. Overall, the TSAC results showed relatively small improvements with the use of cover crops to most systems, but most of sites' SAC content significantly differed between the 0-2 mm and 2-8 mm soil size fractions. There was not a consistent trend of the SAC across sites or years or soil size fraction. One out of the 15 farmer sites, including NewDTC, showed that there was a significant year*treatment interaction with the SAC, where the Mix at Wabash has the greatest SAC in 2016, but the least in 2017 and the One treatment did not differ. Seven out of the 15 farmer sites, including NewDTC, showed that the TSAC was significantly different between the years. There were 24 of the 29 comparisons of the farmer site treatments to CONV that differed in TSAC, and 45 of the 56 comparisons of the farmer site treatments to CONV that differed in SAC. For each site discussed next, the TSAC will be discussed first followed by the SAC in the 0-2 mm and 2-8 mm soil size fractions (Tables 12 - 17).

Alford

There were no significant differences among the TSAC (Table 14) and SAC contents of the different soil size fractions (Table 15), which could be due to Alford not having a cover crop established since 2013. However, the 0-2 mm soil size fraction (590 mg kg^{-1}) tended to have more SAC than the 2-8 mm fraction (576 mg kg^{-1}) in both treatments (Table 15).

Brocksmith

There was a significant interaction among the treatments and year with the TSAC, $P < 0.1$, but they were not significantly different from one another when it came to the separation of means (Table 14). Averaged across years, the 0-2 mm soil size fraction (662 mg kg^{-1}) had significantly more SAC than the 2-8 mm soil size fraction (637 mg kg^{-1}), $P < 0.1$ (Table 15). The CONV in both 2016 (512 mg kg^{-1}) and 2017 (487 mg kg^{-1}) had significantly lower TSAC than the CC (2016 = 629 mg kg^{-1} and 2017 = 678 mg kg^{-1}) and NC (2016 = 671 mg kg^{-1} and 2017 = 621 mg kg^{-1}) treatments (Table 16). The CONV in both 0-2 mm and 2-8 mm soil size fractions within each year, also had significantly lower SAC than the CC and NC treatments (Table 17).

Desutter

The 2016 (773 mg kg^{-1}) TSAC was significantly greater than in 2017 (708 mg kg^{-1}), P < 0.01 (Table 14). There were no significant differences with the TSAC in the treatments, however, the NC treatment tended to have more TSAC content than the CC treatment across years (Table 14). Averaged across years, the SAC was significantly greater in the 2-8 mm soil size fraction (758 mg kg^{-1}) than in the 0-2 mm fraction (717 mg kg^{-1}), P < 0.01 (Table 15). The TSAC was significantly greater in the CC (2016 = 764 mg kg^{-1} and 2017 = 698 mg kg^{-1}) and NC (2016 = 781 mg kg^{-1} and 2017 = 718 mg kg^{-1}) treatments than in the CONV within both 2016 (366 mg kg^{-1}) and 2017 (415 mg kg^{-1}), P < 0.01 (Table 16). Similar to Brocksmith, the CONV in both 0-2 mm and 2-8 mm soil size fractions within each year, also had significantly lower SAC than the CC and NC treatments (Table 17).

DTC

There were no significant differences among the TSAC content in the treatments or cash crop (Table 12). However, when sampled in 2016, the SAC in the 2-8 mm size fraction (406 mg kg^{-1}) was significantly greater than the SAC content in the 0-2 mm fraction (380 mg kg^{-1}), P < 0.01 (Table 13).

Huffmeyer

When sampled in 2016, there were no significant differences between the treatments but the CT (552 mg kg^{-1}) treatment tended to have more TSAC than the ST (527 mg kg^{-1}) treatment (Table 14). There was a significant difference between the soil size fractions with the 0-2 mm size fraction (573 mg kg^{-1}) having significantly more SAC than the 2-8 mm fraction (512 mg kg-1), P < 0.01 (Table 15). Both the ST (P < 0.05) and CT (P < 0.01) treatments had greater SAC than the CONV (367 mg kg^{-1}) treatment (Table 16).

Mills

There were no significant differences with the TSAC (Table 14), but the 0-2 mm soil size fraction (605 mg kg^{-1}) had more SAC than the 2-8 mm fraction (550 mg kg^{-1}), $P < 0.1$ (Table 15).

NEPAC

There were no significant treatment differences with the TSAC content, but averaged across both years the NC treatments within each cash crop tended to have the lowest TSAC (Table 12). There was a significant interaction of the year*fraction SAC, $P < 0.01$, with the 2016 0-2 mm (528 mg kg^{-1}) soil size fraction having greater SAC than the 2016 2-8 mm (457 mg kg^{-1}), 2017 0-2 mm (475 mg kg^{-1}), and 2017 2-8 mm (465 mg kg^{-1}) fractions (Table 13). The 2016 2-8 mm, 2017 0-2 mm, and 2017 2-8 mm fractions were not significantly different from one another. There was also a significant interaction among the year*fraction*cash crop SAC, but mean separations were not attainable.

NewDTC

The TSAC was not significantly different among the treatments, but there was a significant difference between the years, $P < 0.1$ (Table 14). In 2017, after cover crop termination (367 mg kg^{-1}), the TSAC was significantly greater than in 2016, during cover crop growing period (325 mg kg^{-1}). However, at both timings the NC treatment tended to have the lowest TSAC compared to the Mix and One (Table 14). There was also a significant interaction among the fraction*year SAC, $P < 0.01$ (Table 15). Overall, the SAC in the 2017 2-8 mm, 2016 0-2 mm, and 2017 0-2 mm fractions were significantly greater than the 2016 2-8 mm (297 mg kg^{-1}) fraction. The 2017 2-8 mm (386 mg kg^{-1}) and 2016 0-2 mm (350 mg kg^{-1}) were not different from one another and the 2016 0-2mm and 2017 0-2 mm (347 mg kg^{-1}) fractions were not different from one another. This suggests that the best time to measure the SAC to detect the most significant differences either after the cover crop termination because the cover crop residue has had time to break down, or within the 2-8 mm soil size fraction at either timing.

Rulon

There were no significant differences with the TSAC among the treatments at Rulon, but the 2016 TSAC (645 mg kg^{-1}) was significantly greater than in 2017 (475 mg kg^{-1}), $P < 0.05$ (Table 14). There were no significant differences with the SAC among the treatments or soil size fractions, but the SAC tended to be more in the CR treatment and in the 2-8 mm fraction (Table 15).

Scott

There was significantly more TSAC in 2017 (549 mg kg^{-1}) than in 2016 (509 mg kg^{-1}), $P < 0.05$ (Table 14). Averaged across years, the SAC was significantly greater in the 2-8 mm (552 mg kg^{-1}) soil size fraction than the 0-2 mm (517 mg kg^{-1}) fraction, $P < 0.01$ (Table 15). In 2016 when the cover crop treatments were combined and tested against the CONV, it had significantly more TSAC than the CONV treatment, $P < 0.1$, but not when the cover crop treatments were tested separately; the NC treatment in 2016 was not have significantly different than the SAC in the CONV (Table 16). In 2017, the Mix ($P < 0.01$), One ($P < 0.05$), and NC ($P < 0.05$) treatments all had significantly more SAC than the CONV (Table 16). In 2016 the CONV tended to have more SAC in the 2-8 mm soil size fraction, but in 2017 the CONV tended to have more SAC in the 0-2 mm fraction (Table 17). This could be due to soybeans being at flowering stage (still growing) at the time of sampling in 2016, and the corn barely emerging at the time of sampling in 2017.

SEPAC

At SEPAC, the TSAC in 2016 (495 mg kg^{-1}) was significantly greater than in 2017 (449 mg kg^{-1}), $P < 0.05$ (Table 12). There was also a significant interaction among the fractions*year, $P < 0.01$ (Table 13), where the 2016 2-8 mm fraction (527 mg kg^{-1}) had the most SAC (Table 13). The 2016 0-2 mm (452 mg kg^{-1}) and 2017 0-2 mm fraction were not different from one another nor were the 2016 0-2 mm and 2017 2-8 mm fractions. The 2017 0-2 mm (466 mg kg^{-1}) fraction was significantly greater than the 2017 2-8 mm (435 mg kg^{-1}) fraction. When samples were taken during a corn cash crop the SAC also tended to be more in the 2-8 mm soil size fraction in 2016 and then in 2017 the SAC was in the 0-

2 mm fraction (Table 13). In a soybean cash crop, the SAC tended to be more in the 0-2 mm soil size fraction than the 2-8mm fraction, except for the 2016 NC-Corn (Table 13).

Shuter

When sampled in 2016, there were no significant differences with the TSAC between the treatments, however the CC treatment tended to have more TSAC (Table 14). The SAC in the 2-8 mm (673 mg kg^{-1}) soil size fraction was significantly greater than in 0-2 mm fraction (591 mg kg^{-1}), $P < 0.01$ (Table 15).

Stahl

There were no significant differences with the TSAC between the treatments, however there tended to be more TSAC in 2016 than in 2017 (Table 14). There was a significant interaction among the fraction*year SAC, $P < 0.01$ (Table 15). The 2016 2-8 mm (532 mg kg^{-1}) and 2017 0-2 mm (481 mg kg^{-1}) fractions had the greatest SAC content, but the 2017 0-2 mm was not significantly different from the 2016 0-2 mm (427 mg kg^{-1}) size fraction nor were the 2016 0-2 mm and 2017 2-8 mm (431 mg kg^{-1}) fractions (Table 15). Averaged across years, the SAC tended to be more in the 2-8 mm soil size fraction and the treatments were still similar in SAC content (Table 15).

Villwock

When sampled in 2016, there were no significant differences between the treatments' TSAC or SAC. However, the CC treatment tended to have more TSAC than the NC treatment (Table 14) and the 0-2 mm soil size fraction tended to have more SAC than the 2-8 mm fraction (Table 15). In comparison to the CONV (427 mg kg^{-1}), both the CC (645 mg kg^{-1}) and NC (605 mg kg^{-1}) treatments had significantly greater SAC, $P < 0.01$ (Table 16). Although the SAC in the CC and NC treatments were significantly greater than the CONV, the CONV and NC tended to have most of its SAC in the 2-8 mm soil size fraction while the CC tended to have most of its SAC in the 0-2 mm fraction (Table 17).

Wabash

There was a significant interaction among the treatment*year, $P < 0.1$, where the 2016 Mix had the most TSAC (675 mg kg-^{1}) and the 2017 Mix, 2017 One, and 2016 One treatments were not significantly different from one another (Table 14). However, the 2016 sampling time had significantly more TSAC than in 2017, $P < 0.05$ (Table 14), which could have been due to the wheat cash crop planted prior to 2016. There was also a significant interaction among the fraction*year SAC, $P < 0.01$ (Table 15). The 2016 2-8 mm (599 mg kg^{-1}) fraction had the greatest SAC content, followed by the 2016 (585 mg kg^{-1}) and 2017 0-2 mm (526 mg kg^{-1}) fractions which were not significantly different from one another; then the 2017 2-8 mm (453 mg kg^{-1}) soil size fraction had the lowest SAC content (Table 15).

Wenning

There were no significant differences in TSAC among the treatments or between years, however the CT treatment and the 2016 sampling time tended to have the most TSAC (Table 14). There was a significant interaction among the fraction*year SAC, $P < 0.01$, where the 2016 2-8 mm (599 mg kg^{-1}) fraction had the most SAC content (Table 15). The 2016 0-2 mm (514 mg kg^{-1}), 2017 0-2 mm (555 mg kg^{-1}), and 2017 2-8 mm (543 mg kg^{-1}) fractions were not significantly different from one another. Averaged across both years, the 0-2 mm soil size fraction (557 mg kg^{-1}) had significantly greater SAC than the 2-8 mm size fraction (549 mg kg^{-1}), $P < 0.05$ (Table 15). In comparison to the CONV, the NT (2016 = 558 mg kg^{-1}, $P < 0.05$ and 2017 = 539 mg kg^{-1}, $P < 0.01$) and CT (2016 = 577 mg kg^{-1}, $P < 0.01$ and 2017 = 558 mg kg^{-1}, $P < 0.01$) treatments had significantly more SAC than the CONV (Table 16). Interestingly, the NT and CT were not significantly different than the CONV in the 2016 2-8 mm fraction (Table 17).

Werling

There were no significant differences with the TSAC (Table 14) or SAC (Table 15) among the treatments or years. However, the SAC tended to be most in the 2-8 mm soil size fraction before and after the plots were altered on the same field; the One treatment tended to have more SAC content followed by the Mix and NC treatments respectively (Table 15). Before the plots were altered in 2016, the CC treatment had significantly more SAC than the CONV, $P < 0.01$ (Table 16), in both soil size fractions (Table 17). After the plots changed in 2017, the Mix and One treatments had significantly more TSAC than the

CONV, $P < 0.1$ (Table 16). However, the SAC was significantly different in the 0-2 mm size fraction and not the 2-8 mm fraction when all the treatments were compared to the CONV in 2017 (Table 17).

Table 12 Purdue Agricultural Centers total soil active carbon (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) mg kg^{-1} (ANOVA test with the cover crop treatment nested within the cash crop).

Site	Cash Crop	Treatment	2016		2017		Ave Both Yrs
DTC	Corn	O/R-Soybean	415		—		—
		O/R/CC/CR-Soybean	386		—		—
		NC-Soybean	374		—		—
		Average	392		—		—
	Soybean	CR-Corn	416		—		—
		O/R/CR-Corn	354		—		—
		NC-Corn	404		—		—
		Average	392		—		—
		Site Average	391		—		—
NEPAC	Corn	O/R-Soybean	508		520		514
		O/R/CC/CR-Soybean	505		449		477
		NC-Soybean	494		442		468
		Average	502		471		486
	Soybean	CR-Corn	504		463		483
		O/R/CR-Corn	455		473		464
		NC-Corn	438		467		453
		Average	466		468		467
		Site Average	484		469		
SEPAC	Corn	O/R-Soybean	487		423		455
		O/R/CC/CR-Soybean	524		450		487
		NC-Soybean	510		432		471
		Average	507		435		471
	Soybean	CR-Corn	439		460		450
		O/R/CR-Corn	507		473		490
		NC-Corn	502		458		480
		Average	483		464		473
		Site Average	495	a**	449	b	

Table 12 Notes:
— Indicates that there were no samples taken, therefore averages of both years cannot be determined
Letters located in the 'Site Average' row at SEPAC indicate that there was a significant difference between years at a $P < 0.05$
Abbreviations: Ave Both Yrs = Average across both years; O/R-Soybean = Oat and radish cover crop mix following soybean cash crop treatment; O/R/CC/CR-Soybean = Oat, radish, crimson clover, and cereal rye cover crop mix following soybean cash crop treatment; NC-Soybean = No cover crop following soybean cash crop treatment; CR-Corn = Cereal rye cover crop following corn cash crop treatment; O/R/CR-Corn = Oat, radish, and cereal rye cover crop mix following corn cash crop treatment; NC-Corn = No cover crop following corn cash crop treatment

Table 13 Purdue Agricultural Centers soil active carbon mg kg^{-1} for the 0-2 mm and 2-8 mm soil size fractions (ANOVA test with the cover crop treatment nested within the cash crop).

Site	Cash Crop	Treatment	2016 0-2 mm	2016 2-8 mm	2017 0-2 mm	2017 2-8 mm
DTC	Corn	O/R-Soybean	402	430	—	—
		O/R/CC/CR-Soybean	374	400	—	—
		NC-Soybean	370	379	—	—
		Average	382	403	—	—
	Soybean	CR-Corn	411	422	—	—
		O/R/CR-Corn	345	369	—	—
		NC-Corn	380	437	—	—
		Average	378	409	—	—
		Fraction Average	380 b	406 a***		
NEPAC	Corn	O/R-Soybean	507	510	543	499
		O/R/CC/CR-Soybean	540	472	472	426
		NC-Soybean	509	479	438	448
		Average	519 ‡	487 ‡	485 ‡	458 ‡
	Soybean	CR-Corn	593	459	473	454
		O/R/CR-Corn	510	425	470	477
		NC-Corn	507	397	454	485
		Average	537 ‡	427 ‡	465 ‡	472 ‡
		Fraction Average	528 A***	457 B	475 B	465 B
SEPAC	Corn	O/R-Soybean	441	520	449	400
		O/R/CC/CR-Soybean	462	571	473	428
		NC-Soybean	458	556	437	428
		Average	454	549	453	418
	Soybean	CR-Corn	443	433	477	447
		O/R/CR-Corn	455	540	492	459
		NC-Corn	451	545	468	446
		Average	450	506	479	451
		Fraction Average	452 BC	527 A***	466 B	435 C

Table 13 Notes:
— Indicates that there were no samples taken, therefore averages of both years cannot be determined
* Indicates a significance level of $P < 0.1$
** Indicates a significance level of $P < 0.05$
*** Indicates a significance level of $P < 0.01$
lower case letters located in the 'Fraction Average' rows indicate that there was a significant difference between the fractions at DTC
Upper case letters located in the 'Fraction Average' rows indicate that there was a significant interaction among the fractions and years at NEPAC and SEPAC
Same letters indicate that there was no significant difference
‡ there is a significant difference in the Year*Cash*Fraction, but means of separation were not possible
Abbreviations: O/R-Soybean = Oat and radish cover crop mix following soybean cash crop treatment; O/R/CC/CR-Soybean = Oat, radish, crimson clover, and cereal rye cover crop mix following soybean cash crop treatment; NC-Soybean = No cover crop following soybean cash crop treatment; CR-Corn = Cereal rye cover crop following corn cash crop treatment; O/R/CR-Corn = Oat, radish, and cereal rye cover crop mix following corn cash crop treatment; NC-Corn = No cover crop following corn cash crop treatment

Table 14 Farmer Sites and NewDTC total soil active carbon (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) mg kg^{-1} (ANOVA test).

Site	Treatment	2016	2017	Ave Both Yrs
Alford	CR13	587	—	—
	WH13	576	—	—
	Average	582	—	—
Brocksmith	CC	629 ¢	678 ¢	654
	NC	671 ¢	621 ¢	646
	Average	650	649	—
Desutter	CC	765	698	731
	NC	781	718	750
	Average	773 x***	708 y	—
Huffmeyer	ST	527	—	—
	CT	552	—	—
	Average	540	—	—
Mills	Low	572	—	—
	Medium	552	—	—
	High	611	—	—
	Average	578	—	—
NewDTC	Mix	341	382	361
	One	331	362	346
	NC	303	356	329
	Average	325 y	367 x*	—
Rulon	AR	647	473	560
	CR	687	524	606
	O/R	625	482	553
	NC	620	419	520
	Average	645 x**	475 y	—
Scott	Mix	514	574	544
	One	521	525	523
	NC	494	548	521
	Average	509 y	549 x**	—
Shuter	CC	665	—	—
	NC	599	—	—
	Average	632	—	—
Stahl	CC	471	467	469
	NC	488	456	472
	Average	480	461	—
Villwock	CC	645	—	—
	NC	605	—	—
	Average	625	—	—

Table 14 Continued.

Site	Treatment	2016	2017	Ave Both Yrs
VUJC	NT	₤ 522	—	—
	CT	₤ 486	—	—
	Average	₤ 504	—	—
Wabash	Mix	675 A*	458 B	567
	One	550 B	502 B	526
	Average	613 x**	480 y	—
Wenning	NT	558	539	548
	CT	577	558	567
	Average	568	548	—
Werling	CC		—	—
	Mix	—	572	—
	One	—	616	—
	NC	—	525	—
	Average	—	571	—

Table 14 Notes:
— Indicates that there were no samples taken, therefore averages of both years cannot be determined
* Indicates a significance level of $P < 0.1$
** Indicates a significance level of $P < 0.05$
*** Indicates a significance level of $P < 0.01$
¢ Indicates that there was a significant interaction with year*treatment, however it was not significantly different when using the adjusted p-values for mean separations at Brocksmith
x and y letters located in the 'Average' rows indicate that there was a significant difference between the years at each site
₤ Indicates that the values were not included in the statistical analysis due to the site only have one replication of each treatment
Uppercase letters within the 2016 and 2017 columns indicate that there was a significant interaction among the treatment and year at each site
Same letters indicate that there was no significant difference
Abbreviations: Ave Both Yrs = Average across both years; CR13 = Cereal rye cover crop planted in 2013 treatment; WH13 = Wheat cover crop planted in 2013 treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Low = 101 kg ha^{-1} Nitrogen application treatment; Medium = 145 kg ha^{-1} Nitrogen application treatment; High = 201 kg ha^{-1} Nitrogen application treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; AR = Annual ryegrass cover crop treatment; CR = Cereal rye cover crop treatment; O/R = Oat and radish cover crop treatment; NT = No tillage with cover crop use treatment

Table 15 Farmer Sites and NewDTC soil active carbon mg kg^{-1} for the 0-2 mm and 2-8 mm soil size fractions (ANOVA test).

Site	**Treatment**	**2016 0-2 mm**	**2016 2-8 mm**	**2017 0-2 mm**	**2017 2-8 mm**	**Ave Both Yrs 0-2 mm**	**Ave Both Yrs 2-8 mm**
Alford	CR13	592	583	—	—	—	—
	WH13	587	569	—	—	—	—
	Average	590	576	—	—	—	—
Brocksmith	CC	640	622	692	657	666	639
	NC	683	663	635	604	659	634
	Average	661	643	663	630	662 a*	637 b
Desutter	CC	740	779	683	708	712	744
	NC	761	796	685	750	723	773
	Average	750	788	684	729	717 b	758 a***
Huffmeyer	ST	558	503	—	—	—	—
	CT	588	521	—	—	—	—
	Average	573 m***	512 n	—	—	—	—
Mills	Low	596	549	—	—	—	—
	Medium	600	503	—	—	—	—
	High	619	599	—	—	—	—
	Average	605 m*	550 n	—	—	—	—
NewDTC	Mix	349	330	364	402	356	366
	One	359	298	335	387	347	343
	NC	341	264	343	370	342	317
	Average	350 AB	297 C	347 B	386 A***	348	342
Rulon	AR	657	640	484	457	571	548
	CR	685	690	525	523	605	607
	O/R	605	640	462	521	534	581
	NC	607	629	419	410	513	519
	Average	639	650	473	478	556	564

Table 15 Continued.

Site	Treatment	2016 0-2 mm	2016 2-8 mm	2017 0-2 mm	2017 2-8 mm	Ave Both Yrs 0-2 mm	Ave Both Yrs 2-8 mm
Scott	Mix	511	530	550	613	530	572
	One	503	546	515	551	509	548
	NC	480	521	545	550	513	536
	Average	498	533	537	571	517 b	552 a***
Shuter	CC	622	696	—	—	—	—
	NC	559	650	—	—	—	—
	Average	591 n	673 m***	—	—	—	—
Stahl	CC	419	520	492	434	455	477
	NC	436	544	471	427	453	486
	Average	427 BC	532 A***	481 AB	431 C	454	481
Villwock	CC	668	577	—	—	—	—
	NC	610	637	—	—	—	—
	Average	639	607	—	—	—	—
VUJC	NT	£ 438	£ 567	—	—	—	—
	CT	£ 449	£ 518	—	—	—	—
	Average	£ 443	£ 543	—	—	—	—
Wabash	Mix	633	707	505	434	569	571
	One	536	563	548	472	542	517
	Average	585 B	635 A***	526 B	453 C	556	544
Wenning	NT	505	591	547	534	526	562
	CT	523	608	563	552	543	580
	Average	514 B	599 A***	555 B	543 B	557 a**	549 b

Table 15 Continued.

Site	Treatment	2016 0-2 mm	2016 2-8 mm	2017 0-2 mm	2017 2-8 mm	Ave Both Yrs 0-2 mm	Ave Both Yrs 2-8 mm
Werling	CC	402	549	—	—	—	—
	Mix	—	—	565	575	—	—
	One	—	—	587	620	—	—
	NC	—	—	543	518	—	—
	Average	—	—	565	571	—	—

Table 15 Notes:
₤ Indicates that the values were not included in the statistical analysis
— Indicates that there were no samples taken, therefore averages of both years cannot be determined
* Indicates a significance level of P < 0.1
** Indicates a significance level of P < 0.05
*** Indicates a significance level of P < 0.01
a and b letters located in the 'Ave Both Yrs' columns indicate that there was a significant difference between the soil fractions across both years at each site
m and n letters located in the '2016 0-2 mm' and '2016 2-8 mm' columns indicate that there was a significant difference between the soil fractions in a given year at each site
Uppercase letters within the 'Average' rows indicate that there was a significant interaction among the fraction and year at each site
Same letters indicate that there was no significant difference
Abbreviations: Ave Both Yrs = Average across both years; CR13 = Cereal rye cover crop planted in 2013 treatment; WH13 = Wheat cover crop planted in 2013 treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Low = 101 kg ha^{-1} Nitrogen application treatment; Medium = 145 kg ha^{-1} Nitrogen application treatment; High = 201 kg ha^{-1} Nitrogen application treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; AR = Annual ryegrass cover crop treatment; CR = Cereal rye cover crop treatment; O/R = Oat and radish cover crop treatment; NT = No tillage with cover crop use treatment

Table 16 Farmer Sites with a Conventional Neighbor total soil active carbon (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) mg kg^{-1} (T-test between the CONV and treatments).

Site	Treatment	2016		2017	
Brocksmith	CONV	512		487	
	CC	629	**	678	***
	NC	671	***	621	***
Desutter	CONV	366		415	
	CC	764	***	698	***
	NC	781	***	718	***
Huffmeyer	CONV	367		—	
	ST	527	**	—	
	CT	552	***	—	
Scott	CONV	392		402	
	CC	517	*	550	***
	Mix	514	ns	574	***
	One	521	ns	525	**
	NC	494	ns	548	**
Villwock	CONV	427		—	
	CC	645	***	—	
	NC	605	***	—	
Wenning	CONV	402		298	
	NT	558	**	539	***
	CT	577	***	558	***
Werling	CONV	399		484	
	CC	566	***		
	Mix	—		572	*
	One	—		616	*
	NC	—		525	ns

Table 16 Notes:
— Indicates that there were no samples taken
* Indicates the CONV was significantly different than the treatment, $P < 0.1$, at each site
** Indicates the CONV was significantly different than the treatment, $P < 0.05$, at each site
*** Indicates the CONV was significantly different than the treatment, $P < 0.01$, at each site
ns Indicates the CONV was not significantly different than the treatment at each site
CC at the Scott and Werling sites, combine and test the Mix and One treatments to the CONV
Abbreviations: CONV = Conventional tillage with no cover crop use treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; NT = No tillage with cover crop use treatment

Table 17 Farmer Sites with a Conventional Neighbor soil active carbon mg kg^{-1} for the 0-2 mm and 2-8 mm soil size fractions (T-test between the CONV and treatments).

Site	Treatment	2016 0-2 mm	2016 2-8 mm	2017 0-2 mm	2017 2-8 mm
Brocksmith	CONV	502	521	475	503
	CC	640 **	622 **	692 ***	657 **
	NC	683 ***	663 **	635 ***	604 *
Desutter	CONV	380	353	389	438
	CC	740 ***	779 ***	683 ***	708 ***
	NC	761 ***	796 ***	685 ***	750 ***
Huffmeyer	CONV	379	350	—	—
	ST	558 ***	503 ***	—	—
	CT	588 ***	521 ***	—	—
Scott	CONV	373	407	413	389
	CC	507 **	538 *	532 ***	582 ***
	Mix	511 ns	530 ns	550 ***	613 ***
	One	503 ns	546 ns	515 *	551 **
	NC	480 ns	521 ns	545 **	550 **
Villwock	CONV	403	449	—	—
	CC	668 ***	577 ***	—	—
	NC	610 ***	637 **	—	—
Wenning	CONV	308	528	291	307
	NT	505 ***	591 ns	547 ***	534 ***
	CT	523 ***	608 ns	563 ***	552 ***
Werling	CONV	337	468	372	534
	CC	468 ***	629 ***	—	—
	Mix	—	—	565 ***	575 ns
	One	—	—	587 ***	620 ns
	NC	—	—	543 ***	518 ns

Table 17 Notes:
— Indicates that there were no samples taken
* Indicates the CONV was significantly different than the treatment, $P < 0.1$, at each site
** Indicates the CONV was significantly different than the treatment, $P < 0.05$, at each site
*** Indicates the CONV was significantly different than the treatment, $P < 0.01$, at each site
ns Indicates the CONV was not significantly different than the treatment at each site
CC at the Scott and Werling sites, combine and test the Mix and One treatments to the CONV
Abbreviations: CONV = Conventional tillage with no cover crop use treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; NT = No tillage with cover crop use treatment

SOM and TSOM

Loss on ignition estimates the amount of total soil organic matter. Although most of the soil organic matter is slow to decompose, it does serve as a reservoir of nutrients for living plants and organisms. In this study, the 0-2 mm soil size fraction had significantly more SOM than in the 2-8 mm soil size fraction (Table 18-20), except for Scott and SEPAC. However, the SOM in the 0-2 mm soil size fraction was only slightly larger (1-4 g kg^{-1}) than in the 2-8 mm soil size fraction. At Scott, significant amount of SOM were in the 2-8 mm soil size fraction, which could be due to the high sand percent. At SEPAC, the 2-8 mm soil size fraction in O/R/CR-Corn treatment within the soybean cash crop had the most SOM. Two of the 9 farmer sites including NewDTC, showed a significant treatment*fraction interaction. Six of the 9 farmer sites including NewDTC, showed that SOM was significantly different between the soil fractions, where the 0-2 mm soil fraction had the most SOM, except at Scott. In 30 of the 42 comparisons of the farmer site treatments to CONV, they differed in SOM and TSOM. Detailed results for each site are presented next.

Brocksmith

There were no significant differences in SOM between the CC (45.4 g kg^{-1}) and NC (45.0 g kg^{-1}) treatments (Table 19). However, the 0-2 mm soil size fraction (46.5 g kg^{-1}) had significantly more SOM than the 2-8 mm size fraction (44.0 g kg^{-1}), $P < 0.01$ (Table 19). Within the 0-2 mm soil size fraction, both the CC (45.4 g kg^{-1}, $P < 0.01$) and NC (45.4 g kg^{-1}, $P < 0.1$) treatments had significantly more SOM than the CONV (40.9 g kg^{-1}) (Table 20). Within the 2-8 mm soil size fraction, the CC (45.3 g kg^{-1}, $P < 0.05$) treatment had significantly more SOM than the CONV (40.7 g kg^{-1}), but the NC (42.7 g kg^{-1}) treatment was not significantly different from the CONV (Table 20).

DeSutter

There were no significant differences in the SOM among the treatments or soil size fractions, but in general the soil had approximately 55 – 57 g kg^{-1} of SOM (Table 19). In comparison to the CONV (0-2 mm = 46.4 g kg^{-1} and 2-8 mm = 44.1 g kg^{-1}), both treatments and soil size fractions had significantly more SOM than the CONV (Table 20).

NewDTC

There were no significant differences with the SOM at NewDTC (Table 19), but the cover crop treatments (Mix = 34.7 g kg^{-1} and One = 34.6 g kg^{-1}) tended to have more SOM than the NC (33.2 g kg^{-1}) treatment. The cover crop treatments also tended to have more SOM in the 2-8 mm soil size fraction, but the NC treatment tended to have more SOM in the 0-2 mm soil size fraction (Table 19).

NEPAC

There was also a significant cash*fraction interaction with the SOM, where the soil in the current 0-2 mm corn had significantly more SOM than the 2-8 mm corn and 2-8 mm soybean, but the soil in the 0-2 mm soybean was not significantly different than either the 0-2 mm corn, 2-8 mm corn, or 2-8 mm soybean SOM contents, $P < 0.05$ (Table 18). Overall the 0-2 mm soil size fraction had significantly more SOM than the 2-8 mm fraction, $P < 0.01$ (Table 18). When the total SOM weighted average was calculated, both cash crops were significantly different from one another. However mean separations was not attainable within the current soybean cash crop. Within the current corn cash crop, the O/R-Soybean had significantly more SOM than the O/R/CC/CR-Soybean and NC-Soybean treatments, while the O/R/CC/CR-Soybean and NC-Soybean treatments did not differ from one another.

Rulon

There was a significant interaction among the treatment*fractions SOM at Rulon and the mean separations were not achievable, $P < 0.1$ (Table 19). However, the SOM in the AR and CR treatments had most of its SOM in the 0-2mm soil size fraction. The O/R and NC tended to have its SOM evenly in both soil size fraction. Within the 0-2 mm soil size fraction, the CR treatment had the most SOM compared to the AR, O/R, and NC treatments. Within the 2-8 mm soil size fraction, the CR and O/R treatment had the most SOM but the O/R was not significantly different than the AR and NC treatments. Overall, the 0-2 mm soil size fraction had a significantly greater amount of SOM than the 2-8 mm size fraction, $P < 0.1$ (Table 19).

Scott

Overall, the 2-8 mm soil size fraction had greater SOM than the 0-2 mm size fraction, $P < 0.01$ (Table 19). There was no significant difference with the SOM weighted average between the CONV and main plot treatments (Table 20). Similar to the weighted average SOM, the SOM in the 0-2 mm soil size fraction was not significantly different between the main plot treatments and CONV (Table 20). However, in the 2-8 mm soil size fraction, the Mix cover crop had significantly more SOM than the CONV, but the One and NC treatments were not significantly different from the CONV (Table 20).

SEPAC

There was a significant interaction among the treatment*fraction SOM at SEPAC and the mean separations were not achievable, $P < 0.1$ (Table 18). However, within the corn cash crop the SOM in the O/R/CC/CR-Soybean treatment had most of its SOM in the 0-2 mm soil size fraction. The O/R-Soybean and NC-Soybean treatments tended to have its SOM in either soil size fraction. Within each soil size fraction, the treatments did not significantly differ in SOM. Within the soybean cash crop the SOM in the O/R/CR-Corn treatment had most of its SOM in the 2-8 mm soil size fraction, while the other treatments did not significantly differ between the two soil size fractions. The O/R/CR-Corn had significantly more SOM than the CR-Corn treatment in the 2-8 mm soil size fraction but the NC-Corn was not significantly different than either the O/R/CR-Corn or NC-Corn treatments. There was also a significant cash*fraction interaction with the SOM, where the current 2-8 mm soybean had significantly more SOM than the 2-8 mm corn, but the 0-2 mm corn and 0-2 mm soybean were not significantly different than either the 2-8 mm corn or 2-8mm soybean SOM contents, $P < 0.1$ (Table 18).

Stahl

There was a significant interaction among the fraction*treatment at Stahl, $P < 0.01$ (Table 19). The 0-2 mm CC (32.9 g kg^{-1}) had the most SOM than the 2-8 mm CC (30.7 g kg^{-1}), 0-2 mm NC (30.9 g kg^{-1}), and 2-8 mm NC (30.9 g kg^{-1}) fraction-treatments. The 2-8 mm CC, 0-2 mm NC, and 2-8 mm NC fraction-treatments were not different from one another. Overall, the 0-2 mm soil size fraction (31.9 g kg^{-1}) had greater SOM than the 2-8 mm size fraction (30.8 g kg^{-1}), $P < 0.05$ (Table 19).

Wabash

There were no significance differences with the SOM between the treatments, but the 0-2 mm soil size fraction had significantly more SOM compared to the 2-8 mm size fraction, $P < 0.05$ (Table 19). Remarkably the Mix and One treatments had the exact same SOM content within the 2-8 mm soil size fraction.

Wenning

There were no significant differences with the SOM between treatments or soil size fractions at Wenning (Table 19). However, the SOM and Weighted SOM in the NT and ST treatments was significantly more than the CONV, $P < 0.01$ (Table 20).

Werling

There were no significant difference with the SOM among the treatments, but the 0-2 mm soil size fraction (52.7 g kg^{-1}) had significantly greater SOM than the 2-8 mm size fraction (48.5 g kg^{-1}), $P < 0.01$ (Table 19). Overall, the cover crop treatments including the NC treatment had significantly more SOM than the CONV, $P < 0.01$ (Table 20).

Table 18 Purdue Agricultural Centers soil organic matter g kg^{-1} for the 0-2 mm and 2-8 mm soil size fractions and total soil organic matter (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) g kg^{-1} in 2017 (ANOVA test).

Site	Cash Crop	Treatment	0-2 mm	2-8 mm	Weighted Average
NEPAC	Corn	O/R-Soybean	44.9	40.7	42.7 S*
		O/R/CC/CR-Soybean	40.7	36.6	38.6 T
		NC-Soybean	37.1	35.4	36.3 T
		Average	40.9 A**	37.5 B	39.2
	Soybean	CR-Corn	39.4	37.1	38.3 X
		O/R/CR-Corn	39.1	37.9	38.5 X
		NC-Corn	39.1	40.0	39.5 X*
		Average	39.2 AB	38.3 B	38.7
		Fraction Average	40.0 j***	37.9 k	39.0
SEPAC	Corn	O/R-Soybean	35.1 a s	35.3 a** s**	35.1
		O/R/CC/CR-Soybean	37.0 a** s**	35.0 b s	36.0
		NC-Soybean	33.4 a s	33.5 a** s**	33.5
		Average	35.2 AB	34.6 B	34.9
	Soybean	CR-Corn	36.1 a** x	35.4 a y	35.7
		O/R/CR-Corn	36.8 b x**	39.6 a** x**	38.4
		NC-Corn	35.7 a x	36.0 a** xy	35.8
		Average	36.2 AB	37.0 A*	36.7
		Fraction Average	35.7	35.8	35.8

Table 18 Notes:
— Indicates that there were no samples taken, therefore averages of both years cannot be determined
* Indicates a significance level of $P < 0.1$
** Indicates a significance level of $P < 0.05$
*** Indicates a significance level of $P < 0.01$
Uppercase letters in the 'Average' rows indicate that there was a significant interaction among the cash crops and soil size fractions within each site
S and T in the 'Weighted Average' columns indicate that there was a significant difference among the cover crop treatments within each cash crop at each site
X and Y in the 'Weighted Average' columns indicate that there was a significant difference among the cover crop treatments within each cash crop at each site
j and k in the 'Fraction Average' rows indicate that there was a significant difference between the soil size fractions in each site
a and b letters located in the ‘Treatment’ rows indicate that there was a significant difference between the soil size fractions within each cover crop treatment at each site
s and t in the '0-2 mm' column indicate that there was a significant difference among the treatments within the corn cash crop.
s and t in the '2-8 mm' column indicate that there was a significant difference among the treatments within the corn cash crop.
x and y in the '0-2 mm' column indicate that there was a significant difference among the treatments within the soybean cash crop.
x and y in the '2-8 mm' column indicate that there was a significant difference among the treatments within the soybean cash crop.
Same letters indicate that there was no significant difference
Abbreviations: O/R-Soybean = Oat and radish cover crop mix following soybean cash crop treatment; O/R/CC/CR-Soybean = Oat, radish, crimson clover, and cereal rye cover crop mix following soybean cash crop treatment; NC-Soybean = No cover crop following soybean cash crop treatment; CR-Corn = Cereal rye cover crop following corn cash crop treatment; O/R/CR-Corn = Oat, radish, and cereal rye cover crop mix following corn cash crop treatment; NC-Corn = No cover crop following corn cash crop treatment

Table 19 Farmer Sites and NewDTC soil organic matter g kg^{-1} for the 0-2 mm and 2-8 mm soil size fractions and total soil organic matter (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) g kg^{-1} in 2017 (ANOVA test).

Site	Treatment	0-2 mm			2-8 mm			Weighted Average
Brocksmith	CC	48.6			45.3			45.4
	NC	44.5			42.7			45.0
	Average	46.5	x***		44.0	y		45.2
Desutter	CC	55.9			55.2			55.4
	NC	56.7			56.4			56.5
	Average	56.3			55.8			56.0
NewDTC	Mix	34.0			35.5			34.7
	One	34.3			34.8			34.6
	NC	35.1			31.1			33.2
	Average	34.5			33.8			34.2
Rulon	AR	35.4	a*	t	32.5	b	t	34.0
	CR	50.7	a*	s*	47.0	b	s*	48.7
	O/R	34.4	a	t	35.3	a*	st	34.7
	NC	29.6	a	t	30.0	a*	t	29.8
	Average	37.5	x*		36.2	y		36.8
Scott	Mix	32.3			37.8			34.2
	One	31.9			33.5			32.1
	NC	32.4			34.1			33.0
	Average	32.2	y		35.1	x***		33.1
Stahl	CC	32.9	A***		30.7	B		31.4
	NC	30.9	B		30.9	B		30.9
	Average	31.9	x**		30.8	y		31.4
Wabash	Mix	44.8			43.3			43.8
	One	46.9			43.3			44.7
	Average	45.9	x**		43.3	y		44.7
Wenning	NT	37.0			37.9			37.5
	ST	38.5			37.4			37.9
	Average	37.7			37.7			37.7
Werling	Mix	51.3			49.0			49.2
	One	54.5			48.3			49.7
	NC	52.4			48.3			49.4
	Average	52.7	x***		48.5	y		49.4

Table 19 Notes:
* Indicates a significance level of P < 0.1
** Indicates a significance level of P < 0.05
*** Indicates a significance level of P < 0.01
x and y letters located in the 'Average' rows indicate a significant difference between the soil size fractions at each site in 2017
At Rulon, there was a significant interaction among the treatments and fractions, but mean separations were not attainable. Therefore, a and b in the 'Treatment' rows indicate a significant difference between the soil size fractions and the s and t in the '0-2 mm' and '2-8 mm' columns indicate a significant difference among the treatments within the soil size fraction
Uppercase letters within the '0-2 mm' and '2-8 mm' columns indicate that there was a significant interaction among the treatments and fraction at each site in 2017
Same letters indicate that there was no significant difference
Abbreviations: CC = Cover crop treatment; NC = No cover crop treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; AR = Annual ryegrass cover crop treatment; CR = Cereal rye cover crop treatment; O/R = Oat and radish cover crop treatment; NT = No tillage with cover crop use treatment; ST = Strip tillage with cover crop use treatment

Table 20 Farmer Sites with a Conventional Neighbor soil organic matter g kg^{-1} for the 0-2 mm and 2-8 mm soil size fractions and total soil organic matter (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) g kg^{-1} in 2017 (T-test between the CONV and treatments).

Site	Treatment	0-2 mm		2-8 mm		Weighted Average	
Brocksmith	CONV	40.4		40.7		40.9	
	CC	48.6	***	45.3	**	45.4	**
	NC	44.5	*	42.7	ns	45.0	ns
Desutter	CONV	46.4		44.1		45.2	
	CC	55.9	*	55.2	**	55.4	*
	NC	56.7	*	56.4	**	56.5	*
Scott	CONV	26.3		28.5		27.2	
	CC	32.1	ns	35.7	*	33.2	ns
	Mix	32.3	ns	37.8	*	34.2	ns
	One	31.9	ns	33.5	ns	32.1	ns
	NC	32.4	ns	34.1	ns	33.0	ns
Wenning	CONV	27.0		28.4		27.6	
	NT	37.0	***	37.9	***	37.5	***
	ST	38.5	***	37.4	***	37.9	***
Werling	CONV	36.7		35.1		35.6	
	CC	52.4	***	47.8	***	48.9	***
	Mix	49.5	***	47.2	***	47.9	***
	One	54.5	**	48.3	***	49.7	***
	NC	52.4	***	48.3	***	49.4	***

Table 20 Notes:
— Indicates that there were no samples taken
* Indicates the CONV was significantly different than the treatment, P < 0.1, at each site
** Indicates the CONV was significantly different than the treatment, P < 0.05, at each site
*** Indicates the CONV was significantly different than the treatment, P < 0.01, at each site
ns Indicates the CONV was not significantly different than the treatment at each site
CC at the Scott and Werling sites, combine and test the Mix and One treatments to the CONV
Abbreviations: CONV = Conventional tillage with no cover crop use treatment; CC = Cover crop treatment; NC = No cover crop treatment; ST = Strip tillage with cover crop use treatment; CT = Conventional tillage with cover crop use treatment; Mix = Large cover crop multispecies mixture treatment; One = Small cover crop multispecies mixture or Single species cover crop treatment; NT = No tillage with cover crop use treatment

Correlations

Soil aggregate stability, SAC, TSAC, SOM, and TSOM

Correlations were performed for this study to evaluate 1) the relationship between soil aggregate stability, SAC, TSAC, SOM, and TSOM, 2) the relationship between the soil aggregate stability ratios, SAC ratios, and SOM ratios to the quantity of biomass grown in the current fall and current spring cover crop periods, 3) the relationship between the PAC's soil aggregate stability ratios, SAC ratios, and SOM ratios to the quantity of biomass grown in other combinations of cover crop periods.

All of the correlation positive but weak (very low R^2 values) with each other. Only 14% ($R^2 = 0.14$) and 10% ($R^2 = 0.10$) of the soil aggregate stability was explained by the SAC (Figure 2) and SOM (Figure 3), respectively. About 18% ($R^2 = 0.18$) and 9% ($R^2 = 0.09$) of the soil aggregate stability was explained by the TSAC (Figure 4) and TSOM (Figure 5), respectively. The correlation between the SAC and SOM explained about 50% ($R^2 = 0.50$) of the relationship (Figure 6), which included both 0-2 mm and 2-8 mm soil size fractions (n = 278). The correlation between the TSAC and TSOM (n = 139) explained 53% ($R^2 = 0.53$) of the relationship (Figure 7).

Overall, the correlation between the TSAC and TSOM seemed to have the most percent variation explained ($R^2 = 0.53$). Progressively less variation was explained by correlations of the SAC and SOM ($R^2 = 0.50$), soil aggregate stability and TSAC ($R^2 = 0.18$), soil aggregate stability and SAC ($R^2 = 0.14$), soil aggregate stability and SOM ($R^2 = 0.10$), and soil aggregate stability and TSOM ($R^2 = 0.09$). Therefore, we concluded that the most useful correlations using the raw data involved the soil aggregate stability, TSAC, and TSOM.

Ratios and cover crop biomass

To evaluate the relationship between the quantity of cover crop biomass (grown in the current fall and current spring) and the soil measures, ratios (cover crop soil measurement divided by the no cover crop measurement) were calculated for sites that had cover and no cover treatments for soil aggregate stability, TSAC, and TSOM (considering that they seemed to be the most useful correlations with one another). The soil aggregate stability, TSAC, and TSOM were negatively correlated (negative r value) with the current fall biomass (soil aggregate stability $R^2 = 0.086$; TSAC $R^2 = 0.014$; TSOM $R^2 = 0.067$) timing and positively correlated with the current spring biomass (soil aggregate stability $R^2 = 0.009$; TSAC $R^2 = 0.042$; TSOM $R^2 = 0.034$) timing (Table 21). Overall, these correlations had extremely low R^2 values; the soil aggregate stability and TSOM tended to be explained more in relationship with the fall biomass than the spring; and the TSAC tended to be explained more in relationship with the spring biomass than the spring.

PAC ratios and cover crop biomass

To determine if there was a cash crop effect or cover crop biomass timing influence on the correlations, the PACs soil aggregate stability ratio, TSAC ratio, and TSOM ratio were analyzed independently with more detailed biomass timings: Previous Spring (PS), Current Fall (CF), Current Spring (CS), Net PS, Net CF, Net CS, Sum of PS and CF, and Net Sum of PS and CF. Refer to Chapter 3 or Table 22 for the equations of each of the cover crop biomass periods.

The PACs soil aggregate stability ratio did not have a correlation with the PS biomass timing (Table 22). There was a positive correlation between the soil aggregate stability ratios and CF ($p < 0.05$, n = 68, with a $R^2 = 0.06$) or Net CF biomass ($p < 0.05$, n = 68, with a $R^2 = 0.07$). There was a negative correlation between the soil aggregate stability ratios and CS biomass ($p < 0.1$, n = 68, with a $R^2 = 0.05$ or Net CS biomass ($p < 0.05$, n = 68, with a $R^2 = 0.08$).

The PACs TSAC ratio also did not have a correlation with the PS biomass timing (Table 22). There was a negative correlation between the TSAC and all the biomass timings, but the CF biomass timing had the best percent variation explained by the TSAC ratio ($p = 0.17$, n = 68, with a $R^2 = 0.03$).

The PACs TSOM ratio did have a correlation with the PS biomass timing ($p = 0.26$, n = 24, with a $R^2 = 0.06$), which the soil aggregate stability and TSAC did not show (Table 22). There was a positive correlation between the TSOM and PS ($p = 0.26$, n = 24, with a $R^2 = 0.06$) or Net PS ($p = 0.26$, n = 24, with a $R^2 = 0.06$) biomass timings (Table 22). There was a negative correlation between the TSOM and CS ($p = 0.57$, n = 24, with a $R^2 = 0.02$) or Net CS ($p = 0.42$, n = 24, with a $R^2 = 0.03$) biomass timings (Table 22).

Overall the PS biomass timing had no correlation with the soil aggregate stability ratio and TSAC ratio, but had little correlation to the TSOM. The soil aggregate stability ratio tended to be positively correlated with the CF biomass and negatively correlated with the CS biomass, which was the opposite of what occurred with the correlation that involved all the sites. This could have been due to the wider range of the fall biomass among all the sites (minimum CF biomass = 19 kg ha^{-1}; maximum CF biomass = 17,320 kg ha^{-1}; standard deviation = 3,306 kg ha^{-1}) than the fall biomass among the PACs only (minimum CF biomass = 0 kg ha^{-1}; maximum CF biomass = 707 kg ha^{-1}; standard deviation = 181 kg ha^{-1}). The CF biomass timing seemed to have the best correlation with the soil aggregate stability ratio and TSAC ratio, followed by the CS biomass timing.

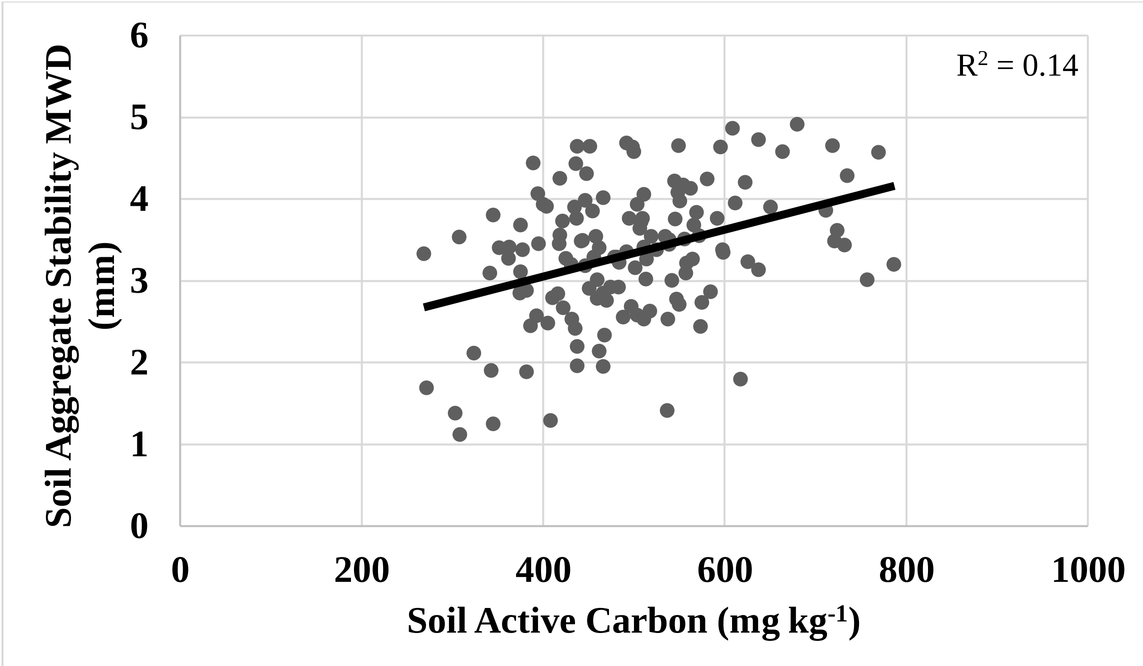

Figure 2 Soil aggregate stability (2-8 mm soil size fraction) and soil active carbon (2-8 mm soil size fraction) correlation.

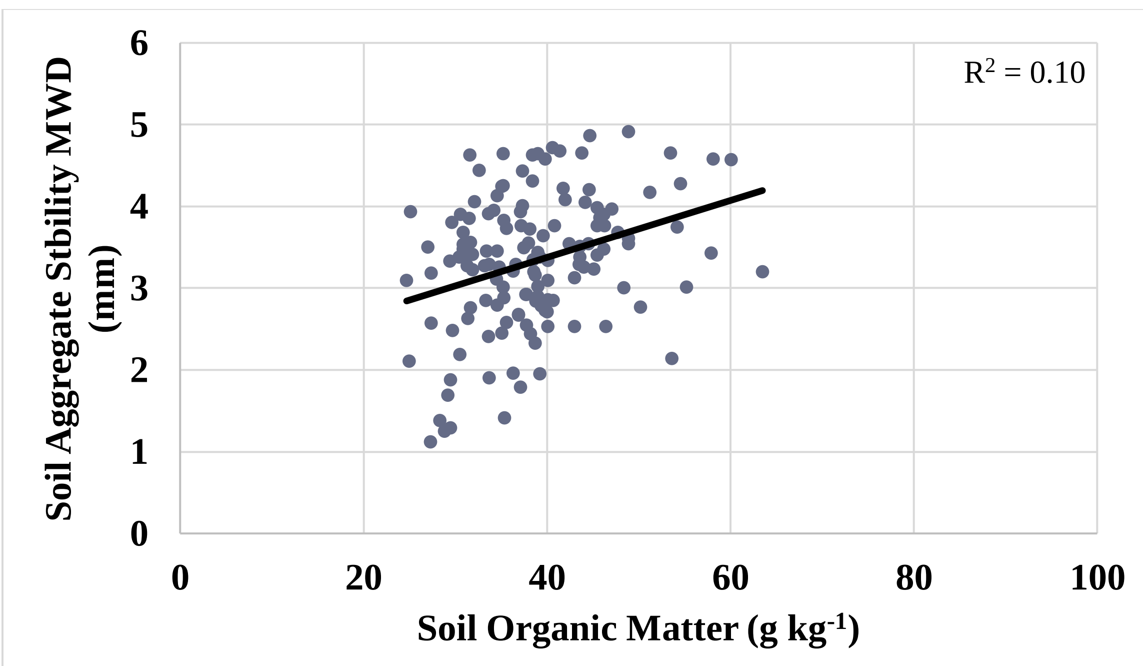

Figure 3 Soil aggregate stability (2-8 mm soil size fraction) and soil organic matter (2-8 mm soil size fraction) correlation.

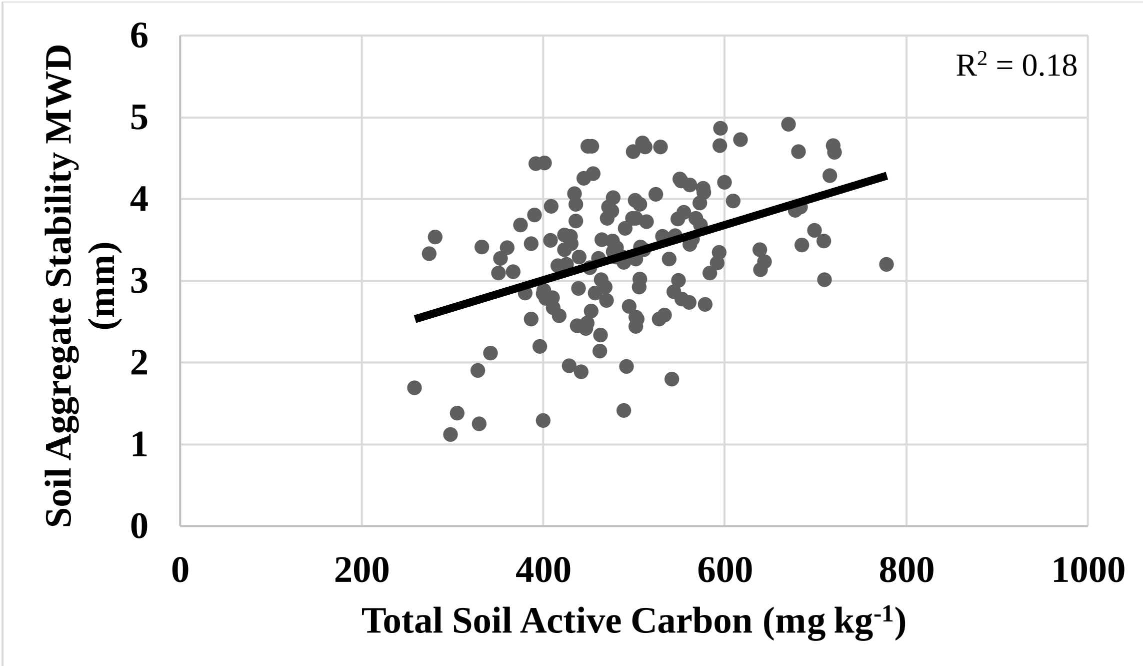

Figure 4 Soil aggregate stability (2-8 mm soil size fraction) and total soil active carbon (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) correlation.

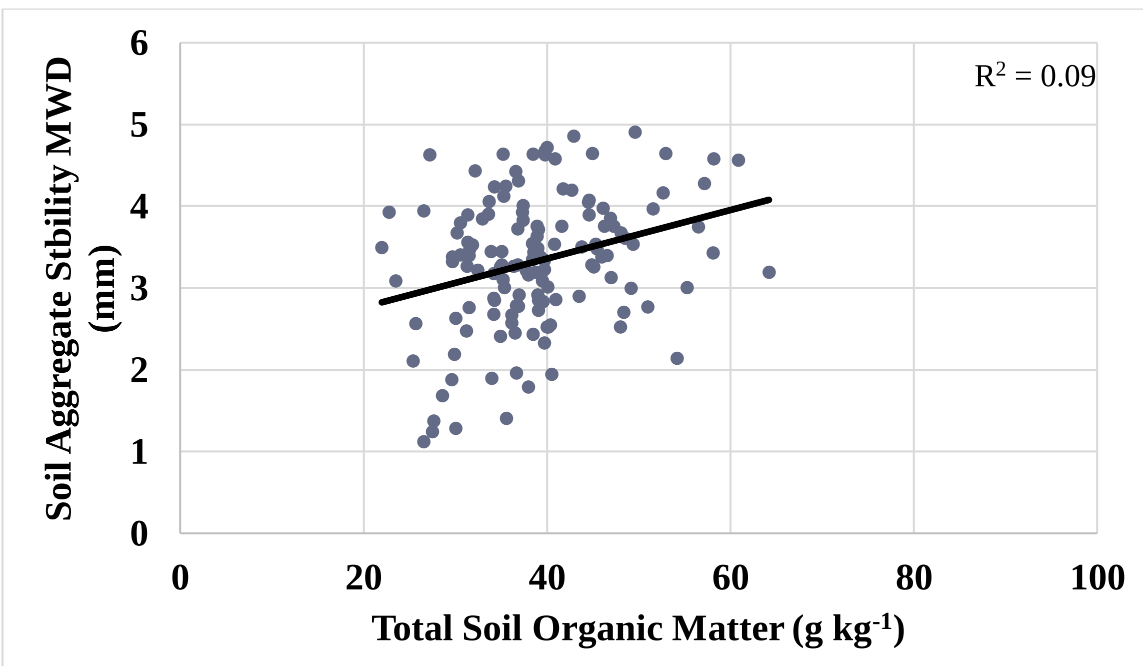

Figure 5 Soil aggregate stability (2-8 mm soil size fraction) and total soil organic matter (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) correlation.

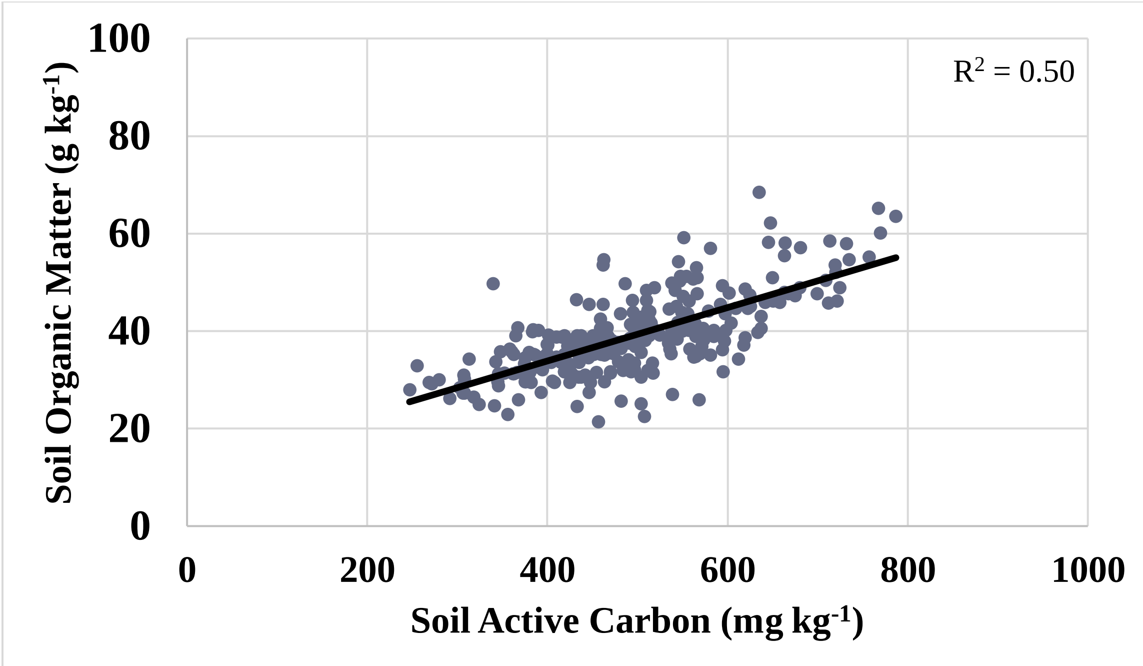

Figure 6 Soil organic matter (0-2 mm and 2-8 mm soil size fractions) and soil active carbon (0-2 mm and 2-8 mm soil size fractions) correlation.

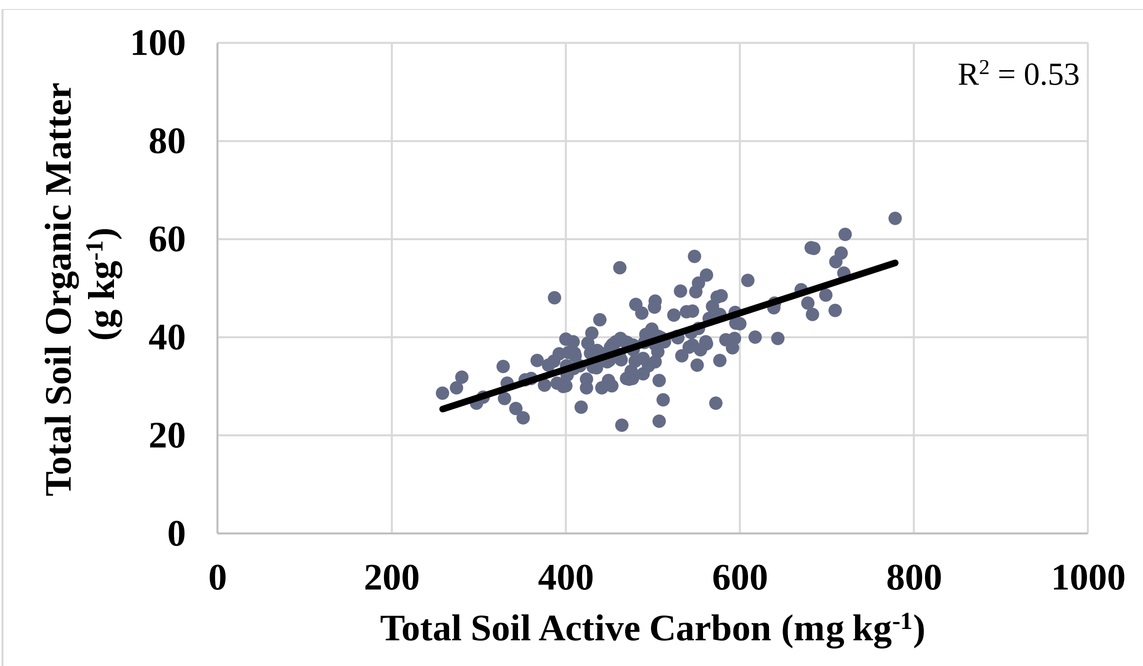

Figure 7 Total soil organic matter (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) and total soil active carbon (weighted average concentration of the 0-2 mm and 2-8 mm soil size fractions) correlation.

Table 21 Correlation results between the cover crop biomass periods and the soil aggregate stability ratio, weighted average concentration (total) soil active carbon ratio, and weighted average concentration (total) soil organic matter ratio for all sites.

Biomass Timing	**Soil Aggregate Stability Ratio**			**Total Soil Active Carbon Ratio**			**Total Soil Organic Matter Ratio**		
	n	**p-value**	**R^2**	**n**	**p-value**	**R^2**	**n**	**p-value**	**R^2**
Current Fall	75	0.01	0.086	75	0.31	0.014	50	0.07	0.067
Current Spring	93	0.37	0.009	93	0.05	0.042	44	0.23	0.034

Table 21 Notes:
n = number of observations between the two variables
p-value = tests the r coefficient is equal to zero or has no effect
R^2 = coefficient of determination which indicates the percent variation that is explained between the two variables i.e. a R^2 of 0.06 indicates 6% of the variation between the two variables is explained.

Table 22 Correlation results between the cover crop biomass periods and the soil aggregate stability ratio, weighted average concentration (total) soil active carbon ratio, and weighted average concentration (total) soil organic matter ratio for the Purdue Agricultural Centers.

Biomass Timing	Soil Aggregate Stability Ratio				Total Soil Active Carbon Ratio				Total Soil Organic Matter Ratio			
	n	**r**	**p-value**	**R^2**	**n**	**r**	**p-value**	**R^2**	**n**	**r**	**p-value**	**R^2**
Previous Spring (PS)	68	-0.0111	0.93	0.000	68	-0.0476	0.70	0.002	24	0.2379	0.26	0.057
Current Fall (CF)	68	0.2369	0.05	0.056	68	-0.1676	0.17	0.028	24	—	—	—
Current Spring (CS)	68	-0.2199	0.07	0.048	68	-0.0929	0.45	0.009	24	-0.1222	0.57	0.015
Net PS	68	-0.0417	0.74	0.002	68	0.0064	0.96	0.000	24	0.2410	0.26	0.058
Net CF	68	0.2546	0.04	0.065	68	-0.1653	0.18	0.027	24	—	—	—
Net CS	68	-0.2767	0.02	0.077	68	-0.0722	0.56	0.005	24	-0.1735	0.42	0.030
Sum of PS and CF	68	0.0365	0.77	0.001	68	-0.0757	0.54	0.006	24	0.2379	0.26	0.057
Net Sum of PF and CF	68	0.0092	0.94	0.000	68	-0.0250	0.84	0.001	24	0.2410	0.26	0.058

Table 22 Notes:
PS = Previous Spring biomass collected for 2016 sampling (spring 2015) or for 2017 sampling (spring 2016)
CF = Current Fall biomass collected for 2016 sampling (fall 2015) or for 2017 sampling (fall 2016)
CS = Current Spring biomass collected for the 2016 sampling (spring 2016) or for 2017 sampling (spring 2017)
Net PS = PS cover crop biomass – PS no cover crop biomass
Net CF = CF cover crop biomass – CF no cover crop biomass
Net CS = CS cover crop biomass – CS no cover crop biomass
Sum of PS and CF = PS cover crop biomass + CF cover crop biomass
Net Sum of PS and CF = (Net PS) + (Net CF)
n = number of observations between the two variables
r = coefficient of correlations which indicated the degree of relationship between the two variables (a negative r indicated a negative correlation and a positive r indicates a positive correlation)
p-value = tests the r coefficient is equal to zero or has no effect
R^2 = coefficient of determination which indicates the percent variation that is explained between the two variables i.e. a R^2 of 0.06 indicates 6% of the variation between the two variables is explained.

Discussion

The most significant differences found in this study were the sites that had a conventional neighbor comparison. The soil aggregate stability, SAC, and SOM were greater in the CC treatments than the CONV treatments. The formation and stability of soil aggregates is often related to the amount of soil organic carbon. During our study we also found a positive correlation between the soil aggregate stability, SAC, and SOM with our sites that had cover crop and no cover crop treatments. This is similar to the findings of (Villamil et al., 2015), who reported that soil organic carbon was positively correlated with soil aggregate stability ($r = 0.38$, $P = < 0.0001$). The soil aggregate stability tended to relate to the amount of cover crop biomass grown prior to sampling, which could be linked to the presence of plant and residue on the soil surface and increased organic matter levels and microorganism activity (Jacobs et al., 2009; Alhameid et al., 2017; Celik et al., 2017; Kinoshita et al., 2017) as well as the absence of mechanical disturbance (Kumar et al., 2012; Zuber et al., 2015) of soil under no-till.

Woodyard (2018), whose thesis is on the cover crop biomass collected at the sites in this study, concluded that the addition of cover crop biomass stimulated the soil microbial community earlier in the season in the cover crop treatments than the no cover crop treatments, due to ample growth. Woodyard (2018) also determined that if the goal is to detect differences between cover crop treatments, it would be ideal to sample (soil health) around V3-V6 growth stages in corn, which is approximately during the month of June in Indiana and after the cover crops have been terminated. Soil sampling during the fall after the cash crop harvest is best to track changes in soil health over years. It is also recommended to compare soil health tests data across years if they are sampled at a consistent and similar time as soil fertility testing (Woodyard, 2018).

Kibet et al. (2016a) found that no-till management increased soil aggregate stability and concentrations of soil organic matter and soil active carbon at the 0-10 cm depth. Other research indicates that the soil aggregate stability was impacted more by tillage than by cover crop management (Patton, 2016; Jacobs, 2018). However, Villamil et al. (2006) concluded that the use of winter cover crops (i.e. hairy vetch and cereal rye) in no-till systems proved to be important in soil chemical and physical characteristics such as water stable aggregates and soil organic matter, in Illinois. In Southeast Indiana, Rorick and Kladivko (2017) found that after 4 years of cereal rye soil aggregate stability increased by 55% when compared to the no cover control in the 0-10 cm depth and 29% in the 10-20 cm depth. Appelgate et al. (2017) investigated cover crop options/mixtures and found that the winter rye and rye mixtures produced the greatest spring aboveground biomass (758 kg ha^{-1}) and rye accounted for more than 79% of the biomass in the mixtures. Appelgate et al. (2017) concluded that cover crop mixtures increased the biomass grown in the fall, but had no advantages when they measured spring biomass, nitrogen, carbon, weed density, corn leaf chlorophyll, and yield over single species cover crops. For our study, the cover crop biomass seemed to link to greater soil aggregate stability and soil active carbon content if the CC treatments had at least 50% more cover crop biomass than the NC treatments including an accumulated growth of the fall and spring.

Different crops are known to affect soil aggregation due to a variety of physical, biological, and chemical interactions (Harris et al., 1966). In our study, the sites that had wheat planted as the cash crop during the cover crop season tended to have no significant differences among the cover crop and no cover crop treatments. The same was true for the sites that had a large presence of weeds in the control/fallow treatments. This is similar to the research done by Kabir and Koide (2000) in Pennsylvania who found that soil aggregate stability was statistically similar among the winter wheat cover crop and native winter weeds. Monroe and Kladivko (1987) found in a greenhouse study that the presence of corn, soybean, and wheat crops and their roots planted in soils versus a fallow control was associated with increased aggregate stability, but no differences were found with aggregate stability among the different crops or root densities.

We did see similar relationships to Angers (1992), who concluded that the improvements in aggregation were comparatively larger and took place more rapidly than those in soil organic carbon, and Moore et al. (2014) who stated that increasing soil organic matter is a slow process. Villamil et al. (2015) suggested that there may be impacts on crop rotation especially when corn-soybean rotations are being compared to monocropping on their soil water aggregate stability, total carbon stocks, bulk density, and penetration resistance. In California, it took about 5 years to measure distinct differences in organic matter among cover crop treatments within a vineyard (Steenwerth and Belina, 2008). Similar to our study, cereal rye treatments tended to have greater soil organic matter content than the NC treatments (Villamil et al., 2006; Steenwerth and Belina, 2008). In Canada, Campbell and Zentner (1993) found that soil organic matter increased in the 0-15 cm depth with wheat, cereal rye, flax, or grain lentil (a constant root growing year-round similar to a cover crop practice) compared to fallow treatments. Similar to our study, Moore et al. (2014) found differences in soil organic matter among the treatments at a 0-5 cm depth, however they did not find any significant differences at a 5-10 cm depth.

The sites in our study that either transitioned to a new field, changed treatments, or used cover crops for the first time may not have had statistical differences among the soil aggregate stability, soil active carbon, or soil organic matter due to not having enough time for the cover crops to impact the soil (Jacobs, 2018). In our study, there was also no clear pattern or any statistical significance with aggregate stability and soil active carbon among the treatments that had cover crop use and different N rates. This is similar to other research (Rasmussen et al., 1998; Russell et al., 2009) and could be due to the offset of cover crop biomass increasing the soil organic carbon decay rates with the nitrogen available (Neff et al., 2002; Kirkby et al., 2013).

Based on observations, it has been identified that soil carbon increases with increasing aggregate size classes from micro to macroaggregates. Soil aggregates considered to be 'macroaggregates' are typically 0.25 to 5 mm in diameter and 'microaggregates' are 0.002 to 0.25 mm in diameter (Brady and Weil, 2010). However, in our study and others who analyze different soil aggregate fractions or sizes, the aggregates are defined differently. Most of the soil samples in our study had 40-60% of their soil mass in the 2-8 mm soil size fraction after initial moist sieving through an 8 mm screen, except for Villwock which had a high sand content with approximately 22-28% of soil mass in the 2-8 mm size fraction.

Soil aggregate stability controls the sequestration of plant-derived organic matter by occlusion into macro and microaggregates (Lagomarsino et al., 2012; Tian et al., 2015). Angers (1992) performed a study to determine the soil aggregation and soil organic carbon under corn and alfalfa at a 0-15 cm depth. Overall, the alfalfa had better aggregation improvements than the corn and fallow treatments and the study found that the increase in

MWD was largely attributed to an increase in aggregates > 2 mm at the expense of the aggregates 0.25 to 1.0 mm diameter. Tisdall and Oades (1982) showed that the effects of cropping treatments on soil aggregation were mostly apparent in the > 2 mm soil size fraction. This was also confirmed by Angers et al. (2008) who found that the stability index for the 1-2 mm soil size fraction was not as sensitive as the MWD of the 2-6 mm soil size fraction in determining the effects of the different cropping treatments. Angers (1992) also found that the cropping treatments' of at least 3 years of forages reflected in the increase of water stable aggregates and total soil organic matter, which likely indicates a buildup of humified binding agents.

It is clear that tillage affects soil microbial habitats because it changes the distribution of the aggregates sizes and pore structure (Gupta and Germida, 2015). A major outcome of this disruption is that previously protected soil organic matter becomes available for soil microbes (Culman et al., 2012). Six et al. (2004) suggests that the microaggregates are made up of relatively old carbon compared to macroaggregate. The quality of carbon within the aggregates regulates the structure and activity of the microbial community in the soil (Hattori, 1988; Bach and Hofmockel, 2014). Tisdall and Oades (1982) suggested that the large aggregates > 2 mm are formed by smaller aggregates, which serve as building blocks. Tisdall and Oades (1982) also suggest that early changes in water stable aggregation under annual ryegrass were caused by the fine roots and fungal hyphae. In contrast, it is suggested that carbon stabilization within microaggregates may be a factor determining increase in soil organic matter under reduced till systems (Angers et al., 1997; Culman et al., 2012) and the loss of carbon sequestration is linked to an increase of macroaggregates formation and reduction of microaggregate formation (Gupta and Germida, 2015).

We hypothesized that the SAC and SOM would be greater in the 2-8 mm size fraction and be closely correlated with the soil aggregate stability, however it was not certain in our study. It is also important to note that microbial communities and their activities differ between aggregate size classes, which affects soil organic matter decomposition which is important for nutrient cycling (Caravaca et al., 2005; Gupta and Germida, 2015).

CHAPTER 4. CONCLUSIONS AND FUTURE WORK

Overall, we found that tillage appears to be significant when we compared the farmer sites with conservation cropping systems to conventional tillage comparison sites. For this study the conventional comparison sites were similar soil types to conservation cropping system fields, however there could be historic management practices that could have also made a difference. In general, the farmer sites with conservation cropping systems had greater soil aggregation, SAC, and SOM when compared to conventional comparison sites. Within conservation cropping system fields, cover crops tended to improve soil aggregation, while the SAC and SOM were relatively unaffected. Therefore, taking a soil physical property measurement such as soil aggregate stability when comparing different treatment managements may be ideal for showing more significant changes or differences between treatments. However, more research should be continued on how soil active carbon and organic matter respond with different treatments over time to better understand the extent and behavior of the soil active carbon and organic matter measurements in relation to soil health.

Soil aggregate stability seemed to be linked with the amount of cover crop biomass grown in the previous fall and spring before sampling in early/late summer. However, there were some exceptions such as the sites that had a wheat/oat cash crop, different tillage treatments, different N rate treatments, or using cover crops for the first time where the treatments did not differ. Therefore, more detailed notes or observations on the cover crop biomass growth and residue may be key for understanding the impacts of cover crops on soil aggregate stability over time. Cover crop biomass was collected at most of the sites involved in our study but due to lack of communication and the large-scale project, it was unclear if the times it wasn’t sampled were because growth did not meet height requirements and did not get sampled, or if there was no time available to sample for cover crop biomass, or if the cover crop(s) did not get proper establishment.

In our study we did not find a consistent pattern of the SAC across the sites within the treatments and/or soil size fractions (0-2 mm and 2-8mm in diameter). We also found no treatment effects of SOM among the treatments, however the 0-2 mm soil size fraction had significantly more SOM than the 2-8 mm size fraction at majority of the sites. Yet the SOM in the 0-2 mm soil size fraction was only slightly greater (1-4 g kg^{-1}) than the 2-8 mm size fraction. This implies that there should continue to be more research on the SAC and SOM content within different soil size fractions to better understand the relationship across soils and treatments. Also, more time of cover crop use may be needed to detect a difference with cover crop use and possibly observe a pattern in the SAC and SOM in general.

Participation from farmers in research, especially on fairly new practices such as cover crops, is hard to assemble and accommodate. Yet it is a strong approach to involve and teach farmers about current or upcoming conservation practices and research methods. Working with farmers, also helps researchers gather data and understand the limitations or concerns of conservation practices and approaches in the real world. However, there are still some improvements that can be made when doing research on farms, such as knowing the type of statistical analysis prior to the project so the fields and treatments can be designed properly. During our study, it was challenging to compare the treatments because it varied depending on the farmer site and the project was still developing over the years. Establishing similar treatments and having a good statistical approach prior to the project could have helped make better and stronger conclusions.

Another challenge during this study involve the timing of sampling. The timing of sampling the sites in this study was mostly done in June, but it was dependent on the weather, labor, and travel availability. Having help from farmers or other volunteers with proper training could possibly save traveling time and help take soil samples within similar days rather than within a similar month. So, weather is not a determining factor or more observations on the soil conditions at the time of sampling could help explain the sample conditions. However, the issue with having more people take samples may induce more human error and take inconsistent samples across the sites. Therefore, it is also important to state that the sampling method, using a golf cup cutter, in our study helped take uniform and consistent samples across the sites involved in our study.

If money, supplies, and time were not limiting, it could have been possible to analyze the 2016 samples for SOM. This could have been helpful at determining if the SOM remained in the 0-2 mm soil size fraction and/or other patterns. Money could also be a limiting factor for farmers, therefore programs or research projects should continue to exist until a firm conclusion is made for soil active carbon as a soil health indicator.

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