Cover Crop Strategies to Build Soil Organic Matter, thereby Enhancing Soil Biology, Water Retention and Weed Control in Organic Cropping Systems of the Western Corn Belt

The Ceres Trust Organic Research Initiative
Final Research Report
2015-2017

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Project Abstract

We request funding to expand research initiated in 2009 on organic weed management with support from the Ceres Trust. The experiment was modified in 2012 from a spring terminated cover crop diversity trial in a sunflower–soybean–corn certified organic crop rotation to a winter wheat-corn-soybean rotation with four new cover crop treatments designed to improve soil water and nutrient availability and soil health, and further suppress weed populations. This certified organic field and crop rotation established in 2009 has now become a long-term experiment on organic crop rotations, cover crop strategies, weed suppression, and soil health. The first three years showed that a diverse mixture of spring-sown mustard cover crop species can reduce weed pressure in a subsequent row crops when terminated using a sweep plow undercutter. Research over the last three years showed that some (e. g. sunn hemp) cover crop species successfully improved soil nutrient content and subsequent crop yield. Soil microbial communities responded uniquely to each cover crop treatment – main crop combination, with mycorrhizal fungi showing increased resilience to the drought in 2012 when planted to winter wheat and in the presence of some cover crops. Project results will build on the first 3-year crop cycle by providing data for second complete crop cycle during years 2015-2017 as the system moves towards greater ecosystem stability. Our goal is to provide innovative solutions for organic farmers seeking increased productivity, profitability, and system resilience by increasing biodiversity and reducing off-farm inputs, and these in combination will improve environmental quality.

Description of the Project

The current ongoing field experiment will be continued for the next 3 years at the Agricultural Research and Development Center (ARDC) near Mead, Nebraska. The experiment comprises a 2.8 ha field that is certified for organic production (OCIA). The design of the experiment is a randomized complete block in a 3-year crop rotation with four replications. The field has been used for experiments on the benefits of diverse mixtures of spring seeded cover crops in an organic crop rotations since 2009 and was modified in 2012 based on organic grower feedback and what was learned during the initial three years of research. In fall 2011, the entire field was plowed and fertilized with 25 Mg ha^{-1} composted beef manure. The current experiment, based on a 3-year soybean (*Glycine max*) – winter wheat (*Triticum aestivum*) – corn (*Zea mays*) rotation includes seven management treatments:

1. No cover crop control (NC)
2. Oilseed radish (*Raphanus sativus*) sown with winter wheat (RAD)
3. Sunn hemp (*Crotalaria juncea*) planted as a cover crop following winter wheat harvest (GM)
4. *Nitro radish and turnip (RT) living mulch planted with corn
5. Red clover (*Trifolium pratense*) sown with winter wheat (CLO)
6. Three-species spring-seeded mustard cover crop mixture (yellow mustard [*Brassica hirta*], Idagold mustard (*Sinapis alba*), dwarf essex rape [*B. napus*]) sown prior to soybean (MUS)
7. Treatments 2 through 6 combined is denoted ‘kitchen sink (KS).

*Note: prior treatment of hairy vetch (*Vicia villosa*) and subterranean clover (*Trifolium suberraneum*) living mulch planted with corn did poorly so we substituted nitro radish for the hairy vetch and clover in 2015.

↑ 70 ↓

NC	CLO	MUS	RT	NC	KS	CLO	MUS	CLO	KS	GM	KS	GM	RT	RAD	MUS	GM	RAD	RT	RAD	NC
401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421
WHT	SOY	SOY	CRN	SOY	WHT	CRN	WHT	WHT	SOY	SOY	CRN	WHT	WHT	SOY	CRN	CRN	WHT	SOY	CRN	CRN

←30→

NC	RAD	RT	NC	KS	RT	KS	GM	CLO	CLO	NC	KS	MUS	RAD	RT	RAD	MUS	GM	GM	CLO	MUS
301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321
SOY	SOY	SOY	WHT	WHT	WHT	CRN	CRN	CRN	WHT	CRN	SOY	SOY	WHT	CRN	CRN	CRN	SOY	WHT	SOY	WHT

NC	NC	MUS	RAD	RT	KS	CLO	KS	GM	MUS	RT	MUS	GM	RAD	RAD	KS	CLO	NC	GM	CLO	RT
201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221
WHT	SOY	SOY	WHT	SOY	CRN	SOY	SOY	SOY	WHT	CRN	CRN	CRN	SOY	CRN	WHT	WHT	CRN	WHT	CRN	WHT

↑ 35 ft

KS	RAD	GM	NC	RT	GM	MUS	RT	CLO	NC	KS	GM	NC	CLO	RAD	KS	CLO	MUS	MUS	RAD	RT
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121
SOY	WHT	WHT	WHT	WHT	CRN	SOY	SOY	SOY	CRN	CRN	SOY	SOY	CRN	SOY	WHT	WHT	WHT	CRN	CRN	CRN

Figure 1. Ecological management study near Mead, NE in 2015. There are seven management treatments and three main crops. The management treatments are: **NC**: no cover; **KS**: kitchen sink (all cover crop options); **RAD**: tillage radish interseeded with winter wheat; **GM**: sunn hemp green manure planted after winter wheat; **RT**: nitro radish and turnip planted in corn; **CLO**: red clover frost-seeded in winter wheat; **MUS**: spring-seeded mustard mixture before soybean. The three main crops are corn (CRN), soybean (SOY) and wheat (WHT).

The 21 whole plot experimental units (7 cover crops and 3 main crops) are 9 m wide (12 crop rows) and 24 m long. Cover crops are broadcast or drill seeded using the recommended seeding rate of each species. Legumes are inoculated with recommended *Rhizobium* inoculum to ensure proper nodulation. The spring seeded mustard mix cover crop is planted prior to April 1 and terminated 5 d prior to soybean planting using an undercutter. Soybean and corn are planted in 76 cm rows at seeding rates of 556,000 and 62,000 seeds ha^{-1}, respectively, to allow inter-row cultivation where appropriate. Camelot winter wheat is drilled in 18 cm rows at 120 kg seed ha^{-1} (ca. 3 million seeds ha^{-1}).

Project Objectives

Our overall objective for this granting cycle (2015-2017) is to determine the longer-term impacts (3-6 years) of our cover crop/intercrop treatments modified in 2012 on soil organic matter quantity and quality, soil physical and biological properties, water retention capacity and weed suppression. Our *specific hypothesis* is that "cover crops, particularly those managed as living mulch or intercrops, will increase soil organic matter content over time thereby enhancing soil physical and biological properties leading to improved crop yields through weed suppression, tighter nutrient cycling and greater water retention capacity".

Project Activities from 2015-2017

Water monitoring

Access tubes were installed in wheat plots under the NC, RAD, and KS cover crop treatments. However, several factors rendered this data unreliable. Wildlife animals would remove the plastic cap of the access tubes, and after rain events, the tube would fill up with water. The PR1 Profile Probe (Delta-T Devices Ltd.) cannot be used in such conditions. This occurred during multiple sampling dates of the 2015, 2016, and 2017 wheat growing seasons, and the consequent missing data makes interpreting it unreliable.

Soil Sampling

Our initial sampling design was to include the following soil properties measured at selected time points during the three year study: all soil properties measured in year 1 (i.e. year 4 after initiation of the cover crop treatments) and years 2 and/or 3 as per the following: (1) soil chemical properties (soil organic C (SOC), nitrate, Bray-P, K, pH and EC) in all years; (2) soil microbiological properties (microbial biomass and community composition in years 1 and 2; and (3) soil physical properties (aggregate size distribution and stability) in years 1 and 3.

In 2015, we restricted our soil sampling to the corn phase to allow a more complete sampling of soil microbiological and physical properties across all three years with the goal to input this data into the Soil Management Assessment Framework (SMAF) developed by Andrews et al. (2001). This addition was initiated by Salvador Ramirez II, the graduate student on the project, and will add a new dimension to the project as SMAF has not been used to our knowledge in organic cropping systems.

Soil samples were taken to measure chemical, biological and physical soil quality parameters. For chemical and biological indicators 15 cores (11/16-in diameter) were taken at a depth of 4 inches per plot while the organic rotation was in corn immediately before corn harvest on 10/09/2015, 10/27/2016 and 11/7/2017. Ten of the 15 samples were taken between the rows of corn or in the furrows and five of the 15 cores were taken directly on the row. The 15 samples were mixed to form a composite sample and one subsample was taken for fatty acid methyl ester (FAME) analysis and stored at -20^{o}C while the remaining soil was air-dried for soil chemical analysis.

Soil samples to a depth of 4 inches were taken by the clod method using a spade to determine aggregate size distribution at the same time or close to the dates of sampling for soil biological and chemical parameters (10/9/2015, 10/24/2016, and 10/13/2017 and 10/15/2017). The wet-sieving method separates soil aggregate size classes by using the disruptive force of slaking and wet-sieving. Macroaggregate stability was determined using five sieves to separate stable aggregates into the following size classes: 4 to 8, 2 to 4, 1 to 2, 0.5 to 1 and 0.25 to 0.50 mm (Nimmo et al., 2002).

Soil chemical analysis was conducted following the Recommended Chemical Soil Tests Procedures for the North central Region at Ward Laboratories in Kearney Nebraska. The chemical soil quality indicators measured were Bray-P, nitrate-N, potassium, cation exchange capacity, pH, and total organic carbon. Soil pH was determined in a 1:1 soil:deionized water extract using a Ross Sure-Flow reference electrode standardized with buffer solution. Nitrate-N was extracted using a 500 ppm calcium phosphate solution and determined using a cadmium reduction coupled with sulfanilamide color development measured at 520 nm by a Lachat QuickChem 8500. Exchangeable soil cations potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) were extracted using 1N ammonium acetate (NH4OAc) and analyzed using an Inductively Coupled Argon Cooled Plasma Spectrometer (ICAP). Soil phosphorous (P) was extracted with Mehlich III and determine by ammonium molybdate and L-ascorbic acid color development measured by a Lachat QuickChem 8500 at 800 nm. Soil cation exchange capacity (CEC) is expressed as the sum of cations and was calculated using % base saturation from the exchangeable basic cations from the NH4OAc extraction along with pH when applicable.

Soil microbial biomass and soil microbial community structure was determined by extracting total fatty acid methyl esters (FAME) from soil microorganism in situ through a direct hydrolysis method (Drijber et al., 2000; Grigera et al., 2007). FAMEs were quantified by gas chromatography and their identity confirmed by gas chromatography mass spectrometry. Soil microbial biomass was measured as the sum of 19 fatty acids specific to microbial taxonomic groups.

These soil quality indicators will be integrated into a single soil quality score using the SMAF tool. SMAF is a program that transforms each observed minimum data set indicator value using nonlinear scoring curves (Karlen and Stott, 1994; Andrews et al., 2001). It then integrates all of the indicator scores from the previous interpretation step into a single, additive index value (Figure 1).

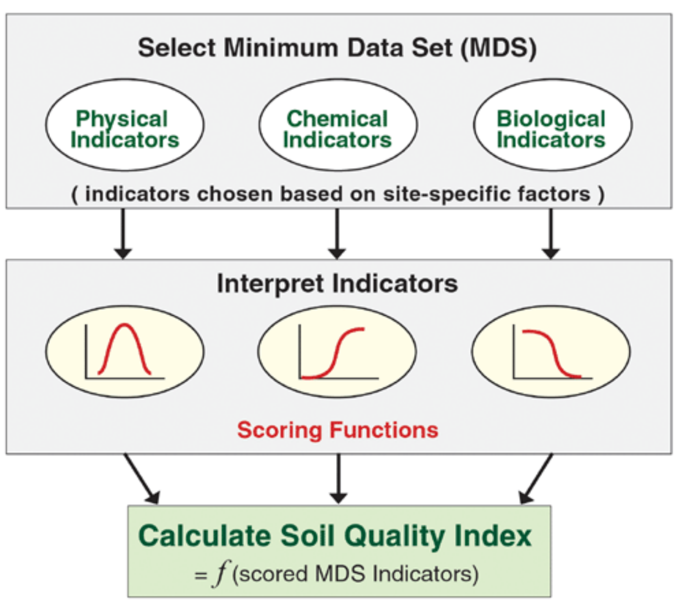

Figure 1. Soil Quality Assessment Framework (Karlen and Stott, 1994)

A Side Project: Impact of Radish and Turnip on Arbuscular Mycorrhizal Biomass in Soil

Radish and turnip are members of the Brassicaceae that do not, or weakly form symbiotic associations with arbuscular mycorrhizal fungi (AMF). Most of the radish varieties currently marketed for cover cropping (e.g., GroundHog radish™, Nitro radish, Sodbuster, and Bio-till radish) are large rooted selections of daikon-type oilseed or forage radishes. (http://articles.extension.org/pages/64400/radishes-a-new-cover-crop-for-organic-farming-systems). Turnips are mainly of the forage variety. This past year we replaced hairy vetch and subterranean clover in our corn-living mulch treatment with a mixture of radish and turnip to evaluate weed suppression potential over the corn-growing season as well as soil quality parameters. Corn is a strongly mycorrhizal crop, so one of our objectives was to evaluate whether radish and turnip, essentially non-mycorrhizal crops, would impact the growth of AMF in the soil and hence ability to access nutrients for the corn plant. We took five 2" diam. by 8" soil cores from each replicate of the corn-living mulch and control treatments and composited cores for each replicate. Cores were taken on two dates: May 28th and July 23rd 2015, representing early (approx. V6) and reproductive (approx. VT) growth stages, respectively. AMF biomass (largely hyphal and not spores) was measured using the fatty acid biomarker C16:1cis11, highly specific to AMF.

Plant Biomass Sampling

Plant sampling was performed yearly on all plots across the 3-yr crop rotation (Table 1). Plant variables measured included weed biomass, a qualitative assessment of weed species composition and crop yield (specifics in results). Within each experimental treatment, aboveground biomass samples were destructively harvested to determine total weed biomass and composition at ~July 1 (~May 1 in winter wheat). Biomass samples were taken from four (0.3 x 0.3 m) randomly placed quadrats. Samples were sorted by weed, crop, and cover crop biomass and dried to constant mass. Around ~August 1 (~June 1 in winter wheat) visual ratings of weed cover and a quality assessment of weed species was determined by surveying three randomly selected crop rows within each experimental unit.

Statistical Analysis

The effect of cover crop treatments (CC) and the organic corn-soybean-wheat crop rotation over time (Yr) on (1) crop, CC, and weed above ground biomass (g plant dry matter m^{-2}), (2) soil microbial biomass (nmol FAME g^{-1} dry soil), (3) soil chemical properties, and (4) wet aggregate stability (mean weight diameter) was assessed using a generalized linear mixed model approach using a randomized complete block design (RCBD) analysis of variance (ANOVA) (PROC GLIMMIX; SAS v9.4) considering CC as a fixed effect and block a random affect by nesting block within Yr. Significant main effects or treatment interactions were assessed using least square means, and differences were reported significant at the 0.05 level. Multiple comparisons were adjusted using Tukey's adjustment.

Results

Soil Quality Indicators

The effect of cover crop treatments within the organic corn-soybean-wheat crop rotation over time (Yr) on soil chemical properties can be found in Table 2. While cover crop treatments influenced soil nitrate N (P_{CC}=0.0467), differences were not statistically different after adjusting for Tukey's multiple comparisons. Cover crop did not influence soil pH, potassium, CEC, or organic C. However, soil pH, nitrate N and CEC changed over time (P_{Yr}=0.0098, P_{Yr}=0.0308, P_{Yr}=0.0.0169, respectively). Soil pH increased over time and was greater 2017 compared to 2015 and 2016, and likely reflects recovery after manure addition which can cause acidification as the ammonium mineralized is converted to nitrates. Soil nitrate N decreased from 2016 and 2017, also indicating a waning of the manure effect. CEC increased slightly over time with CEC in 2016 and 2017 being greater than in 2015. Finally, there was a significant interaction between cover crop treatments and year for BrayP (P_{Yr*CC}=0.0144) and was due to higher BrayP in GM compared to MUS and RAD in 2016.

Soil microbial biomass and soil microbial community structure was determined by extracting total fatty acid methyl esters (FAME) from soil microorganism in situ through a direct hydrolysis method (Drijber et al., 2000; Grigera et al., 2007). The effect of cover crop treatments within the organic corn-soybean-wheat crop rotation on soil microbial biomass over time (Yr) can be found in Table 3. Cover crop influenced total microbial biomass (TMB) and total bacterial biomass (TBB) (P_{CC}=0.0143 and P_{CC}=0.0175, respectively) but not arbuscular mycorrhizal fungal biomass (AMF) or saprophytic fungal biomass (SFB). Radish and turnip cover crops had no effect on AMF biomass in soil at either early (approx. V6) or reproductive (approx. VT) growth stages in 2015 (data not shown). Both TMB and TBB were greatest in GM compared to KS and NC. TMB and AMF changed over time (P_{Yr}=0.0292 and P_{Yr}=0.0032, respectively). TMB was greatest in 2017 compared to 2016. AMF increased over time, being much greater in 2017 compared to earlier years. This may signal soil N limitation whereby AMF are being recruited to scavenge available N resources for the crop and is supported by the poor corn yields in 2017. There were no interactions by Yr with cover crop.

Samples taken for aggregate stability in 2015 and 2016 are complete (data not shown), while 2017 samples are being processed. Once this is complete, selected soil properties will be input to the SMAF model.

Plant Biomass Components: In Corn Plots

Aboveground biomass was destructively sampled 30 days after planting (DAP) corn (Table 1), sorted by crop, cover crop, and weed biomass and dried to constant mass (Tables 4 and 5). The radish/turnip (RT) cover crop treatment was broadcast in corn immediately following corn planting. In 2015 and 2016, the RT cover crop treatment interseeded with corn was out competing the corn 30 DAP, evident in its greater biomass. Consequently, the RT treatment was mechanically terminated and incorporated into the soil using a cultivator. In 2017, the RT treatment did not establish as well compared to 2015 and 2016 (Table 4), rendering mechanical termination unnecessary.

RT cover crop biomass was not different in corn plots under RT compared to those under KS, but yielded differently over time (P_{Yr}<0.0001). RT biomass was the lowest in 2017 compared to 2015 and 2016 (Table 4). Cover crop treatments did not influence weed biomass but RT did impact corn biomass (P_{CC}=0.0038). Corn biomass 30 DAP was greatest in NC compared to KS and RT, suggesting that RT was competing with corn when it established high biomasses.

Plant Biomass Components: In Soybean Plots

There were two above ground biomass sampling events in soybean (Table 1). Aboveground biomass was destructively sampled 30 DAP mustard (MUS) (Table 6) and 30 DAP after planting soybean into the MUS cover crop (Tables 7 and 8).

Cover crop treatments did not influence weed biomass in soybean 30 DAP and weed biomass in soybean plots increased over time (P_{Yr}=0.0273), being the greatest in 2017, followed by 2016, then 2015. Cover crop treatments did not influence soybean biomass 30 days after planting (Table 8). The MUS cover crop treatment influenced weed biomass 30 days after planting MUS (P_{CC}=0.0003) as weed biomass was greatest in NC compared to KS and MUS across sampling years.

Plant Biomass Components: In Wheat Plots

There were two above ground biomass sampling events in wheat (Table 1). Weed biomass was sampled approximately 60 days after frost seeding CLO (Table 9). Wheat, radish (RAD) cover crop, and weed biomass was sampled approximately 30 DAP wheat which was interseeded with RAD (Tables 10 and 11). Due to the rapid canopy closure of wheat, neither weeds nor RAD had any competitive impact, as seen in their respective biomasses (Tables 9 and 10, respectively) and high wheat yields (Table 12).

Establishment of the RAD cover crop treatment differed in wheat plots when seeded alone compared to KS in 2014, 2015, and 2016 (P_{Yr*CC}<0.0001). RAD biomass was the greatest in RAD plots compared to KS plots, but only in 2014 and 2015. Furthermore, KS and RAD biomass were lower in 2016 compared to 2014 and 2015 (Table 10).

Cover crop treatments influenced weed biomass in wheat 90 days after planting and also changed over time (P_{Yr*CC}=0.0030). Cover crop treatments did not influence weed biomass in 2015. However, weed biomass was the lowest under CLO, compared to NC, RAD, and KS in 2016, and lowest in the CLO and KS treatments compared to NC and RAD in 2017 (Table 9).

Weed species were identified but not quantified throughout the 3-yr organic crop rotation. Weed species competing with the main crops within the organic crop rotation included

Abutilon theophrasti, Helianthus annuus, Conyza canadensis, Amaranthus palmeri, A. retroflexus, A. tuberculatus, Chenopodium album, Setaria viridis, and S. pumila.

Crop Yields

Crop yields are presented in Table 12. Corn was harvested differently in 2015 compared to 2016 and 2017. In 2015, the center two rows of corn were harvested at a length of 10 ft. by collecting ears and then threshing them. Corn grain was then weighed and used to estimate corn yield. In 2016 and 2017, corn was harvesting using a combine. Cover crop treatments did not influence corn grain over time but corn yields decreased over time (P_{Yr}=0.0003). Corn yields were the greatest in 2015, followed by 2016, followed by 2017. This likely reflects exhaustion of the manure application that occurred in 2011, with declining yields over time indicating reduced N availability. More frequent manure applications are recommended for future corn productivity in this organic system.

Due to high weed pressure in 2015, 2016, and 2017, soybean was harvested by clipping the center two rows of soybeans at a length of 10 ft, threshing the plants to separate soybeans from plant matter, assessing grain moisture, and correcting soybean mass for grain moisture. Cover crop treatments influenced soybean yield (P_{CC}<0.0001). Because neither Yr or the interaction of cover crop with Yr were significant, soybean yields were averaged across growing seasons. Soybean yields were the greatest under MUS, compared to RAD and GM, and greatest under KS, compared to GM, RAD, and NC. Soybean yields were the lowest GM and RAD.

Due to low weed pressures and excellent wheat stands, wheat was harvested using a combine in 2015, 2016, and 2017. Cover crop treatments did not influence wheat yield. However, wheat yields increased over time (P_{Yr}=0.0180). Because neither cover crop or the interaction of cover crop with Yr was significant, wheat yields were averaged across cover crop treatments. Wheat yields were the greatest in 2017 compared to 2016 and 2016.

Conclusions and Future Plans

Although there were trends in chemical, physical and biological soil parameters with cover crop treatment these differences were not statistically significant. Given the short duration of this study since initiation in 2012, low/variable cover crop biomasses and the three-year crop rotation through a cover crop treatment, a longer time frame may be necessary for trends to become significant. Furthermore, several tillage events were required in all phases of the organic crop rotation to either prepare the seed bed or to mechanically control weed pressure. Numerous tillage events may have disturbed the soil and reduced the effect of cover crop treatments on wet macroaggregate stability. We are currently inputting the data into the SMAF tool, but are cautious regarding significant results. We are also exploring other statistical approaches to address the complexity of the design. Once such approach is a classification and regression tree (CART) analysis, which recursively partitions observations in a matched data set. The response variable within these data sets can be categorical, as is our weed rating data (not shown), or continuous. CART analysis will reveal the most important factors associated with the chosen response variable. How CART analysis is different from traditional regression models is that data space is partitioned in smaller sections where variable interactions may not be as clear (recursive partitioning) as opposed to a single linear or polynomial model, a single equation that represents a biological system. CART analysis is an excellent statistical approach to this project as the cover crop treatments occur at different points in the growing season within a crop rotation, creating confounding interactions that may not be model for in a traditional statistical approach. We hope that implementing a CART analysis to this data set will elucidate interactions and significant cover crop treatment impacts on both ecological and soil quality parameters measured and provide variable importance parameters for cover crop treatments by accounting for the temporal variability of cover crop presence.

When established, some cover crop treatments influenced weed biomass. However, because of the ephemeral presence of the cover crop (which were either mechanically or frost terminated) and the constant pressure of weed competition, it is possible that increasing weed seed banks resulted in increasingly high weed pressures over time. These increasing weed pressures are evident in the corn phase of the organic crop rotation.

Organically sourced manure was applied as a source of fertilizer in 2011. Lack of access to organic manure, the cost of manure, and the lack of equipment to transport manure made it difficult to apply manure since 2011. This decrease in soil fertility is evident in a decrease in chemical soil properties, which, along with increasing weed pressures over time, could have led to the sharp decline in corn yields from 2015/16 to 2017.

Of the three crops in this organic crop rotation, wheat was the most successful, evident in its high yields. Successful organic wheat production with or without cover crops is possible in eastern Nebraska, especially if an appropriate organic source of N fertilization is applied periodically.

Student learning outcomes

The graduate student supported by this project, Salvador (Sal) Ramirez II, gained experience in several field management and sampling techniques through his work on this project. After the abrupt departure in 2015 of the field technician assigned to this project Sal had to take up the reins thereby gaining experience in (1) organic certification through OCIA, (2) finding, selecting, and purchasing organic crops and cover crops, (3) planting corn, soybean, and wheat, including assessment of planting density, planting depth, and row spacing, (4) operation of field equipment including planters, combines, and tillage equipment, (5) identifying common weed species, and (6) coordinating sampling events with fellow graduate students and undergraduate assistants.

Sal had the pleasure of mentoring several undergraduate students who assisted in both the field and lab. These students were (1) Caue Pinheiro, (2) Kellis Fernanda, and (3) Ana Carolina Prestes as Brazilian visiting scholars with the Ciencias sin fronteras program, and (4) Sydney Coran, a University of Nebraska student.

Outputs

2015 results were presented in poster format at the 2016 ASA, CSSA, and SSSA International Annual Meeting:

Ramirez II, S., J.L. Lindquist, R.A. Drijber, V.L. Jin, E.S. Jeske, H. Blanco. The Impact of Organic Crop Rotations and Ecological Weed Management Strategies on Soil Quality. ASA-CSSA-SSSA Annual Meetings, Nov. 6-9, 2016. Phoenix AZ. Poster attached.

2015 and 2016 results were presented as an oral presentation at the 2017 ASA, CSSA, and SSSA International Annual Meeting:

Ramirez II, S., J.L. Lindquist, R.A. Drijber, V.L. Jin, E.S. Jeske, H. Blanco. The Impact of Organic Crop Rotations and Ecological Weed Management Strategies on Soil Quality. ASA-CSSA-SSSA Annual Meetings, Oct. 22-25, 2017. Tampa FL.

2015 and 2016 results were presented at 9th International IPM Symposium:

Ramirez II, S., J.L. Lindquist, R.A. Drijber, V.L. Jin, E.S. Jeske, H. Blanco. The Effect of Ecological Weed Management Strategies on Soil Microbial Communities in Organic Production Systems. 9th International IPM Symposium, March 19-22, 2018. Baltimore, MD.

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Table 1. Above ground biomass and soil sampling events for 2015 to 2017 growing seasons

Date	Event
	Above ground biomass events in corn
5/19/2015	Corn planted; RT cover crop treatment broadcast in planted corn
6/16/2015	Crop, cover crop, and weed aboveground biomass in NC, RT, and KS corn plots
10/26/2015	Corn harvested
5/25/2016	Corn planted; RT cover crop treatment broadcast in planted corn
6/27/2016	Crop, cover crop, and weed aboveground biomass in NC, RT, and KS corn plots
11/17/2016	Corn harvested
6/12/2017	Corn planted; RT cover crop treatment broadcast in planted corn
7/12/2017	Crop, cover crop, and weed aboveground biomass in NC, RT, and KS corn plots
11/29/2017	Corn harvested
	Above ground biomass events in soybean
4/1/2015	MUS cover crop treatment broadcast in plots in which soybean will be planted
5/13/2015	Cover crop and weed aboveground biomass in NC, MUS, and KS in soybean plots
6/24/2015	Soybean planted
7/7/2015	Crop and weed aboveground biomass in NC, MUS, in KS soybean plots
10/7/2015	Soybean harvested
4/19/2016	MUS cover crop treatment broadcast in plots in which soybean will be planted
5/23/2016	Cover crop and weed aboveground biomass in NC, MUS, and KS in soybean plots
6/15/2016	Soybean planted
7/18/2016	Crop and weed aboveground biomass in NC, MUS, in KS soybean plots
10/5/2016	Soybean harvested
4/20/2017	MUS cover crop treatment broadcast in plots in which soybean will be planted
5/24/2017	Cover crop and weed aboveground biomass in NC, MUS, and KS in soybean plots
6/12/2017	Soybean planted
7/13/2017	Crop and weed aboveground biomass in NC, MUS, in KS soybean plots
11/1/2017	Soybean harvested
	Above ground biomass events in wheat
9/29/2014	Wheat planted; RAD cover crop treatment interseeded with wheat
11/3/2014	Crop and cover crop above ground biomass in NC, RAD, and KS wheat plots
2/9/2015	CLO frost seeded in wheat plots
5/1/2015	Crop, cover crop, and weed aboveground biomass in NC, CLO, RAD, and KS wheat plots
7/21/2015	Wheat harvested
9/17/2015	Wheat planted; RAD cover crop treatment interseeded with wheat
11/10/2015	Crop and cover crop above ground biomass in NC, RAD, and KS wheat plots
2/5/2016	CLO frost seeded in wheat plots
5/9/2016	Crop, cover crop, and weed aboveground biomass in NC, CLO, RAD, and KS wheat plots
7/25/2016	Wheat harvested
10/17/2016	Wheat planted; RAD cover crop treatment interseeded with wheat
11/18/2016	Crop and cover crop above ground biomass in NC, RAD, and KS wheat plots
2/8/2017	CLO frost seeded in wheat plots
5/12/2017	Crop, cover crop, and weed aboveground biomass in NC, CLO, RAD, and KS wheat plots
7/26/2017	Wheat harvested
	Soil sampling events at corn harvest in the corn phase of the 3-yr rotation
10/9/2015	Soil sampled for soil microbial biomass, soil chemical properties, and soil wet aggregate stability
10/24/2016	Soil sampled for wet aggregate stability
10/27/2016	Soil sampled for soil microbial biomass and soil chemical properties
11/6/2017	Soil sampled for soil microbial biomass and soil chemical properties in block 1
11/8/2017	Soil sampled for soil microbial biomass and soil chemical properties in blocks 2-4
11/13/2017	Soil sampled for wet aggregate stability in blocks 1 and 2
11/15/2017	Soil sampled for wet aggregate stability in blocks 3 and 4

Table 2. Soil chemical properties under different cover crop strategies at corn harvest within a 3-yr organic corn-soybean-wheat crop rotation.

		Soil pH			Nitrate N			Potassium			BrayP			CEC			Organic C		
		2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017
Cover crop						ppm N			ppm K			ppm P			me 100 g^{-1}			Organic C%	
No cover		5.7	6.0	6.3	7.9	8.5	5.2	382	340	364	42.0	37.0	21.3	15.4	19.2	18.9	2.06	1.87	2.02
Clover		6.0	5.8	6.3	7.4	13.8	3.8	389	392	339	35.5	39.3	16.8	14.3	18.4	18.8	2.12	1.95	1.88
Green manure		6.1	6.1	6.3	7.4	9.2	5.4	373	440	409	27.0	48.5	25.8	13.2	19.8	17.8	2.12	1.93	2.16
Mustard		6.2	5.9	6.2	8.1	11.4	4.9	393	312	353	33.0	25.5	24.0	15.2	17.9	17.6	2.09	1.83	2.04
Radish		6.1	6.0	6.3	9.0	19.9	4.1	389	365	374	30.8	29.3	25.5	15.6	20.1	17.5	2.08	1.76	2.00
Radish/Turnip		6.1	6.0	6.2	12.2	23.2	4.6	405	423	387	27.3	40.5	22.3	16.1	17.5	18.6	2.11	1.96	2.06
Kitchen sink		6.0	5.9	6.3	9.0	9.2	5.9	404	325	417	27.5	33.0	31.0	13.6	17.8	17.9	2.12	1.91	2.12
Source of variation			Pr>F			Pr>F			Pr>F			Pr>F			Pr>F			Pr>F	
Cover Crop (CC)	6		NS			0.0467			NS			NS			NS			NS	
Year (Yr)	2		0.0098			0.0308			NS			0.0584			0.0169			0.0584	
Yr*CC	12		NS			NS			NS			0.0144			NS			NS	

Table 3. Soil microbial biomass under different cover crop strategies at corn harvest within a 3-yr organic corn-soybean-wheat crop rotation.

		Total microbial biomass			Arbuscular mycorrhizal fungal biomass			Saprophytic fungal biomass			Total bacterial biomass		
		2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017
Cover crop			nmol g^{-1}			nmol g^{-1}			nmol g^{-1}			nmol g^{-1}	
No cover		74.4	73.4	101.7	7.3	6.8	12.8	8.5	10.3	9.5	43.0	43.4	47.6
Clover		82.2	83.7	97.2	12.3	8.5	14.8	8.4	14.5	11.0	46.3	57.3	48.8
Green manure		92.5	111.9	103.6	8.6	5.0	15.5	7.6	9.2	10.6	41.0	38.0	48.3
Mustard		88.7	74.3	97.8	7.7	5.3	16.0	9.0	8.5	9.5	47.1	39.9	46.6
Radish		90.5	81.2	102.4	8.2	5.5	17.0	6.4	7.8	10.6	40.3	40.8	46.5
Radish/Turnip		86.7	80.6	97.2	7.8	8.1	15.3	9.0	9.0	13.2	49.0	42.2	46.5
Kitchen sink		79.0	71.3	103.7	9.3	5.8	14.2	8.6	9.9	9.3	45.2	42.0	46.9
Source of variation			Pr>F			Pr>F			Pr>F			Pr>F	
Cover Crop (CC)	6		0.0143			NS			NS			0.0175	
Year (Yr)	2		0.0292			0.0032			NS			NS	
Yr*CC	12		NS			NS			NS			NS	

Table 4. Radish/turnip cover crop biomass 30 DAP corn.

Cover crop		2015	2016	2017
			$g\ m^{-2}$	
Radish/turnip		144.18	142.22	79.16
Kitchen sink		157.07	145.94	61.51
Source of variation			Pr>F	
Cover crop (CC)	1		NS	
Year (Yr)	2		<0.0001	
Yr*CC	2		NS	

Table 5. Weed and corn biomass 30 DAP corn.

		Weed biomass			Corn biomass		
Cover crop		2015	2016	2017	2015	2016	2017
			$g\ m^{-2}$			$g\ m^{-2}$	
No cover		33.42	23.96	25.16	86.73	105.30	111.15
Radish/turnip		25.80	20.64	24.42	65.40	71.83	83.23
Kitchen sink		37.15	30.04	27.75	61.79	64.38	70.57
Source of variation			Pr>F			Pr>F	
Cover crop (CC)	2		NS			0.0038	
Year (Yr)	2		NS			NS	
Yr*CC	4		NS			NS	

Table 6. Weed biomass in soybean plots 30 DAP after planting mustard.

Cover crop		2015	2016	2017
			$g\ m^{-2}$	
No cover		29.52	45.11	51.07
Mustard		23.82	18.46	24.02
Kitchen sink		24.26	25.62	29.35
Source of variation			Pr>F	
Cover crop (CC)	2		0.0003	
Year (Yr)	2		NS	
Yr*CC	4		NS	

Table 7. Mustard biomass 30 DAP soybean in mustard cover crop.

Cover crop		2015	2016	2017
			g m^{-2}	
Radish		75.32	80.71	81.63
Kitchen sink		75.67	87.07	88.28
Source of variation			Pr>F	
Cover crop (CC)	1		NS	
Year (Yr)	2		NS	
Yr*CC	2		NS	

Table 8. Weed and soybean biomass 30 DAP soybean.

		Weed biomass			Soybean		
Cover crop		2015	2016	2017	2015	2016	2017
			g m^{-2}			g m^{-2}	
No cover		26.14	33.76	60.36	203.72	210.83	202.92
Mustard		25.22	27.46	39.04	212.09	213.87	214.56
Kitchen sink		41.73	34.34	40.70	217.60	217.37	220.52
Source of variation			Pr>F			Pr>F	
Cover crop (CC)	2		NS			NS	
Year (Yr)	2		0.0273			NS	
Yr*CC	4		NS			NS	

Table 9. Weed biomass 60 DAP clover in wheat plots.

Cover crop		2014	2015	2016
			g m^{-2}	
No cover		1.22	2.18	2.01
Clover		1.04	0.70	0.45
Radish		1.75	3.52	2.39
Kitchen sink		1.74	2.51	0.29
Source of variation			Pr>F	
Cover crop (CC)	3		<0.0001	
Year (Yr)	2		0.0273	
Yr*CC	6		0.0030	

Table 10. Radish biomass 30 DAP wheat.

		2014	2015	2016
Cover crop			g m^{-2}	
Radish		18.06	19.27	2.35
Kitchen sink		10.20	11.46	2.87
Source of variation			Pr>F	
Cover crop (CC)	1		NS	
Year (Yr)	2		NS	
Yr*CC	2		NS	

Table 11. Wheat biomass 30 DAP.

		2014	2015	2016
Cover crop			g m^{-2}	
No cover		31.13	30.20	29.46
Radish		28.72	26.87	29.52
Kitchen sink		28.66	27.93	31.64
Source of variation			Pr>F	
Cover crop (CC)	2		NS	
Year (Yr)	2		NS	
Yr*CC	4		NS	

Table 12. Corn, soybean, and wheat yields.

		Corn			Soybean			Wheat		
		2015	2016	2017	2015	2016	2017	2015	2016	2017
Cover crop			bu ac^{-1}			bu ac^{-1}			bu ac^{-1}	
No cover		116.72	99.9957	30.6884	22.47	21.31	18.85	73.05	65.78	70.46
Clover		153.28	73.4986	34.2189	24.53	23.59	18.63	57.41	65.68	72.59
Green manure		158.99	71.3899	40.8243	20.22	19.98	17.68	60.40	63.72	74.81
Mustard		149.23	84.413	38.3541	23.47	22.88	23.30	56.30	59.60	72.71
Radish		117.39	65.3071	38.9319	19.12	18.95	17.06	67.51	67.96	71.40
Radish/Turnip		78.3078	78.7937	38.5787	24.32	22.88	22.91	57.52	63.72	74.48
Kitchen sink		91.6096	77.2123	40.9745	24.65	25.45	25.85	61.41	64.31	72.07
Source of variation			Pr>F			Pr>F			Pr>F	
Cover Crop (CC)	6		NS			<0.0001			NS	
Year (Yr)	2		0.0003			NS			0.0180	
Yr*CC	12		NS			NS			NS	