Project participants:

In addition to the PI and Co-PI, the research team is formed by our participant organic farmers: Jack Erisman, Adam Butler, and Allen Williams; Gevan Benhke, the Agro-ecology lab technician, who has been instrumental in coordinating and executing the lab and field work for this project, and RachelWelch, a new Masters student, who started on the project in May 2013.

Final Research Report

Objectives

The long-term goal of this project is to develop the knowledge and skills needed to effectively use multifunctional cover crops to alleviate soil compaction, increase nutrient cycling, and suppress weeds in organic grain farms in IL. Our specific objectives for accomplishing this goal are: 1) to identify the best cover cropping practices to alleviate soil compaction, improve nutrient cycling, and suppress weeds on organic grain farms; 2) to partner with organic farmers to conduct on farm research and learn how to effectively use multifunctional cover crops.

Approach

The main approach for our project is to conduct on-farm research to characterize the benefits and limitations of multifunctional cover crops as well as adoption strategies for the farmers.

During 2011, as detailed in our interim report for Year 1, we worked closely with our project partners to clarify the scope and expectations of the project as well as potential outcomes. During a project meeting held in Springfield, IL, project partners selected the cropping sequence for the duration of the experiment, determined a uniform and convenient plot size for all farmers, and decided on cover crop treatments that will take advantage of their knowledge and skills and make good use of field machinery. Our collaborating farmers know their fields very well so we choose the compacted and non-compacted fields for our experiment following their lead. The areas identified as having compaction problems were corroborated with measurements of penetration resistance and supported by a preliminary statistical analysis. Farmers shared their machinery for tillage and soil preparation and were present during field selection, preliminary soil sampling, and cover crop planting in late August and early September, offering their support continuously.

Progress: 10/2012 to 12/2013

Objective 1: Identify the best cover cropping practices to alleviate soil compaction, improve nutrient cycling, and suppress weeds on organic grain farms

a) Location of study areas and soil types:

Mr. Williams farm is located in Cerro Gordo, IL 61818-4321; both fields provided by Mr. Erisman are located in Pana, IL 62557 whereas Mr. Butler field is located in Malta, IL 60150. Soil survey data for the experimental units was obtained from the USDA-NRCS web soil survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) . The dominant soil series at Williams' is Flanagan silt loam (fine, mesic, Aquic Arguidolls), at Erisman's is Virden (fine, smectic, mesic Vertic Arguiaquolls), while Butler's field is on Danabrook series (fine-silty, mixed superactive, mesic Oxyaquic Arguidolls).

b) Experimental design:

The experimental design at each of the four organic farms is a split plot design with two replications. Main plots treatments are compaction levels (compacted, CMP and non-compacted, NCM, fields) and subplot treatments are cover crops levels (control with no cover crop, C, forage radish, FR, forage radish plus buckwheat, FRbw, and the mixture of forage radish plus hairy vetch plus rye, FRhvr). GPS measurements were taken in the corners of the whole experiment. In every farm CMP and NCM areas are located contiguous to the other except for Williams' farm were the two areas are 500 m apart. Each compaction level was split in four, with plot size being 20'x50', and one of the four cover cropping treatments was assigned randomly. Following the recommended seed rate from the literature and adjusting by germination tests, cover crops were planted at seeding rates of:

Treatment	Weight of seeds per plot (g)
FR	115.8
FRhvr	38.6 (FR), 56.8 (hv), 198 (rye)
FRbw	58 (FR), 425 (bw)

for the first time during late September and early October 2012. Williams, Butler and Erisman A/B were planted on 10/1/2012, 9/28/2012, and 10/5/2012, respectively with an Earthway spreader^{TM} that covers a diameter of ~300 cm. A minimum of 2 passes were needed each plot to ensure an even coverage.

c) Field work and measurements:

Soil sampling was conducted within two weeks from seeding times at each field. Three undisturbed soil cores per plot were taken up to 50 cm in depth, cut in 10 cm increments and later used to determine soil physical and chemical properties. During 2012, we used a light weight automated soil sampler (Amity tech, Fargo, ND) that can be easily transported to the farms and mounted on producers' own tractors. Each soil sampling time, a recording cone penetrometer (FieldScout SC 900 Compaction meter, Spectrum technologies, Inc., IL) was used to measure penetration resistance (PR, kPa) in each plot taking 5 soil samples (three sub-subsamples) at incremental depths up to 50 cm using the gravimetric water content from the undisturbed samples as a covariate.

Cover crop stand count was taken before the end of the Fall season in all fields using a pvc square 0.125 m^2 (0.5 x 0.25cm) with 3 subsamples per plot. Forage radish and buckwheat were naturally suppressed during the winter so biomass of overwintering cover crops (vetch and rye) along with the spring weed biomass sampling, identification, and count for all plots were conducted. These spring cover crops counts and biomass were done at all farms (Williams, Butler and Erisman A/B) on 5/21/2013, 5/15/2013, and 5/22/2013 respectively with a 1 ft square quadrat with 3 subsamples per plot.

Spring tillage is a common practice among organic growers. The first spring tillage was carried out on May 14th, May 7th, and May 20th at Williams, Bulter and Erisman A/B, respectively. Williams slightly differed for the others as he initially chisel plowed instead of field cultivated and applied poultry litter with his first spring tillage and incorporated it further on the 15th of May with a Case IH 330 True Tandem. Soil sampling and penetration resistance was conducted on May 21st, May 15th and May 22nd at Williams, Butler, and Erisman A/B, respectively.

Field cultivation followed by the corn planting was conducted on June 5th, May 16th, and June 8th at Williams, Butler and Erisman A/B, respectively. Williams and Butler planted in 30 inch rows and Erisman A/B planted both fields in 36 inch rows. Crop stand counts and yields were taken by hand at the end of the growing season at Williams, Butler, and Erisman A/B on 10/30/2013, 10/16/2013, and 11/15/2013, respectively.

Weed sampling was conducted three times during the summer of 2013. Prior to corn planting, weed identification, counts and biomass were recorded with a 1 foot square quadrat with three subsamples per plot at each farm field. Weed biomass was cut from the quadrat areas, dried in the lab ovens at 140 F (60 C) for 72 hours and then weighed. Corn crop growth stage was recorded at each time of sampling. The weed sampling dates and corn growth stage are shown in the following figure.

Farm	1		2		3	
	Date	**Stage**	**Date**	**Stage**	**Date**	**Stage**
Williams	5/21/2013	NA	6/21/2013	V1	7/6/2013	V7
Butler	5/15/2013	NA	6/4/2013	V1	7/9/2013	V7
Erisman A/B	5/22/2013	NA	6/22/2013	V1	7/1/2013	V7

Crop stand counts and yields were taken by hand at the end of the growing season at Williams, Butler, and Erisman A/B on 10/30/2013, 10/16/2013, and 11/15/2013, respectively. To determine stand, a 17 foot 5 inch transect was laid out in the middle row of the plot and all plants were accounted for. Since the Erisman A/B fields had 36 inch rows, a 14 ft 5 inch transect was used instead for future calculations by acre. This procedure was done twice per each plot. Additionally, five random corn ears were taken out of the transect and used to calculate bushels of grain per acre at 15.5% moisture. The corn harvest concluded the field work for the project.

d) Laboratory determinations:

Soil sampling was conducted as planned before the cover crop or respective grain crop planting in Fall 2011, Spring 2012, Fall 2012 and finished this past Spring 2013. Three samples per subplot were taken with a hand-held split-core sampler up to a depth of 40cm during the Fall 2011, and the rest of the sampling was done with an automated soil core sampler (AMITY Tech, Fargo, ND) to a depth of 50 cm. These cores were taken to the University of Illinois Urbana-Champaign Agro-Ecology lab and cut in 10 cm increments to evidence possible changes in depth of the soil parameters. Before samples were dried, wet soils were extracted and processed for available N by flow injection with LACHAT QuikCHem for NO_3 and NH_4, mg kg^{-1}. Soil samples were then air-dried and sieved to <2 mm before analysis by standard methodology recommended for the North Central Region (NCR, 1998). Soil variables under investigation include soil bulk density (core method, BD, g m^{-3}), water aggregate stability (WAS, %), maximum compactibility (Proctor test ASTM D698, %), soil texture (hydrometer method, %), total carbon (lost on ignition, Hythermco muffle furnace, TC, g kg^{-1}), soil available phosphorus (flow injection with LACHAT QuikChem using Bray1 extraction, P, mg kg^{-1}) and pH with a SevenEasy Mettler Toledo pH meter.

As of today, all laboratory determinations have been completed for all sampling dates with the exception of the Proctor test, water aggregate stability and total carbon. Proctor is currently in progress as is water aggregate stability which has Fall 2012 and Spring 2013 left. Total carbon for the last season of soil sampling will be conducted with SSM-5000 A Shimadzu Solid Sample Module purchased with approved reallocation of CERES funds for this project. All lab determinations are planned to be completed by the end of spring semester.

Narrative of Preliminary Results for Objective 1:

Organic farmers have had some success using cover crops, rotary hoeing, and in-row cultivation during the grain crop growing season to suppress weed populations. But the successful use of tillage is weather dependent necessitating development of alternatives. While important for weed control, the extra time spent tilling can be economically and physically detrimental. Extensive tillage encourages organic matter decomposition, breaks down soil aggregates, weakens soil structure and can eventually lead to compaction. Not only are compacted soils physically difficult and costly to reverse, compaction has a multitude of negative consequences to soil quality and crop productivity. Compaction interferes with water infiltration, nutrient cycling, root development, and aeration which in turn can negatively affect crop growth and yield. Compacted soils in organic grain production present a serious issue to the efficiency and success of the system.

The addition of cover crops has been proposed as a solution to soil compaction, and studies have begun in Illinois to observe the effects of the addition of cover crops on organic grain production systems. Research in other states has suggested that incorporating deep-rooted cover crops minimizes compaction and improves soil quality (Chen and Weil, 2009). Introducing deep rooted cover crops, such as forage radish, into organic grain production systems has the potential to alleviate compaction, improve soil quality, and suppress weed populations. Though the potential benefits from deep rooted cover crops are multiple, the results are highly dependent upon factors such as agronomic management, length of the growing season, plant species, subsequent cash crop, soil type, and weather conditions. The objective of our research was to identify the best cover cropping practices to alleviate soil compaction, improve nutrient cycling and suppress weeds while partnering with organic farmers to develop a deeper knowledge on how to effectively use these multifunctional cover crops.

Led by Dr. Maria Villamil, the Agro-Ecology team at the University of Illinois Urbana-Champaign conducted collaborative research with three farmers who owned certified organic farms located in Malta, Cerro Gordo, and Pana (2 locations), Illinois. When forming the study, the farmers specifically expressed compaction as a concern and identified two areas of their farms as compacted and two areas as non-compacted. Four variations of cover crops: forage radish (FR), forage radish/buckwheat (FRbw), forage radish/hairy vetch/rye (FRhvr), and control that was left fallow were compared on the compacted and non-compacted areas at each of four locations.

This two year study started in fall 2011 and concluded this past fall 2013. Cover crops were planted in early fall and were tilled under at least two weeks before the spring grain crop planting at all sites. The first spring soybeans were planted and the following spring was corn. Soil sampling was conducted four times at each site down to 50 cm of depth, before each respective cover crop or grain crop planting to observe trends in soil physical and chemical properties. Two physical properties are reported here that provide complementary information; soil bulk density, which is the ratio of voids to solids in a given volume of soil and it directly affects aeration and water movement, and penetration resistance, which provides a proxy for the effort that a root tip has to exert to penetrate the soil layers. Additionally, weed and cover crop counts and biomass, and grain crop yields were recorded.

Our results indicate that the compacted areas had higher bulk density **(Figure 1)** and penetration resistance values than the non-compacted areas and that these difference were still present in the following spring after the cover crop season. This trend was witnessed down to 40 cm of depth and it is attributed to the densification of the soil. Compacted areas had significantly higher pH values, and were also richer in nutrients in comparison with the non-compacted counterparts yet there were important seasonal differences. Total mass of phosphorus and nitrates (Mg/ha) were higher in compacted areas in the fall season but not in the spring; an effect that could be attributed to the cover crops improving the nutrient cycling and the efficiency of these systems. During spring time, we observed a higher concentration of nitrates in the surface soil of rotations that included the mixture of forage radish, hairy vetch, and rye, which help support the previous statement.

Our spring weed biomass data shows that in compacted and non-compacted areas the rotation including the mixture of forage radish, hairy vetch, and rye significantly reduces weed pressure **(Figure 2)**. Yet this same mixture resulted in a reduction of soybean yield in non-compacted areas though yield of soybean from compacted areas did not show any effect of cover crop **(Figure 3)**. Our corn yield in 2013 ranged from 151 to 167 bu/acre and did not show any effects from compaction or cover crop treatment. Soybean yields were collected in 2012, an especially dry year, and the observed trend could be due to the cover crops drawing valuable water resources away from the cash crop.

These preliminary findings support the ability of overwintering cover crops to suppress weed populations and retain nutrients in their biomass, and, with more results still coming, the authors hope to have more insight on the effect of these crops on soil properties, and yield.

References

Chen, G., and Weil, R. R. (2009). Penetration of cover crop roots through compacted soils. Plant Soil, 331, 31-43.

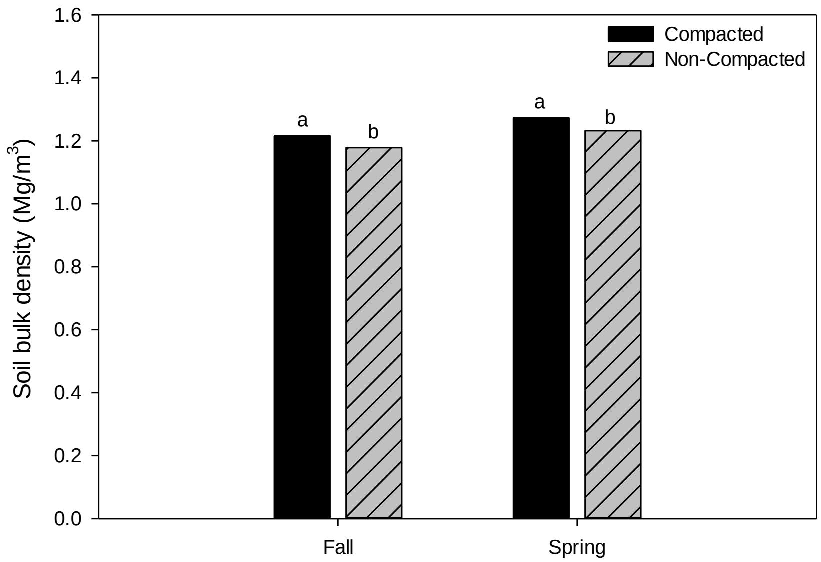

Figure 1 Soil bulk density values during fall (before cover crops) and spring (after cover crops) for compacted and non-compacted areas across all depths considered. Different letters indicate statistically significant differences detected.

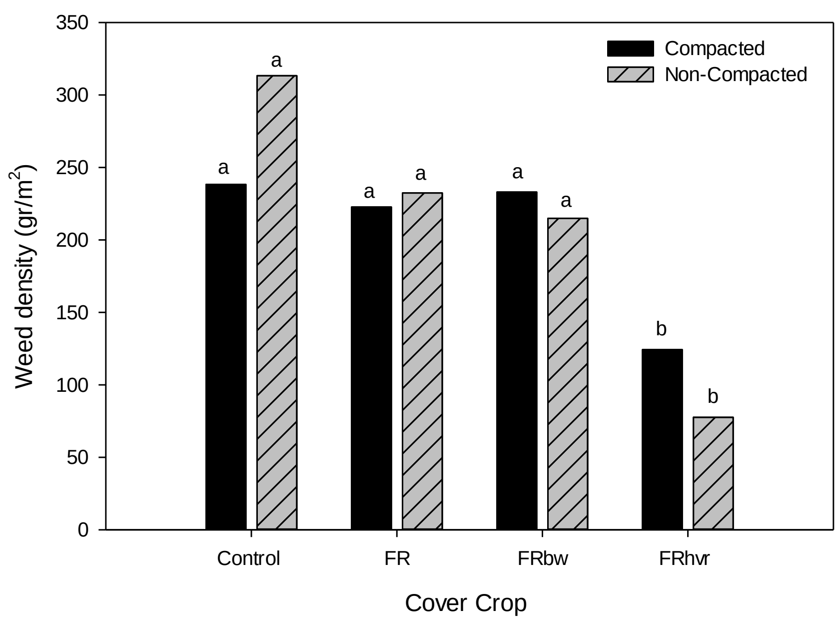

Figure 2. Weed biomass during spring time under each cover crop treatment within compacted and non-compacted areas. The treatments were control fallow; FR forage radish; FRbw, forage radish and buckwheat; and FRhvr, forage radish, hairy vetch, and rye. Different letters indicate statistical differences detected.

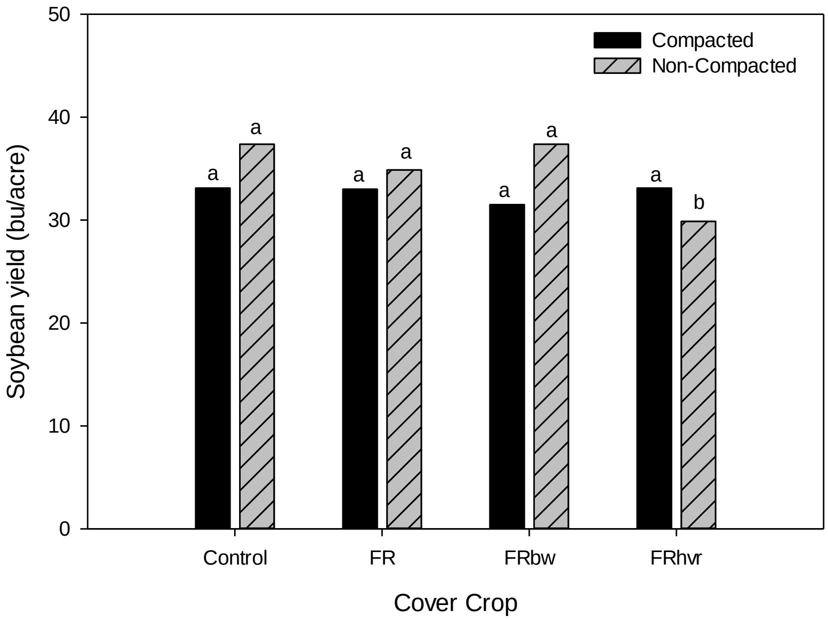

Figure 3. Soybean yields following each cover crop treatment within compacted and non-compacted areas. The treatments were control fallow; FR forage radish; FRbw, forage radish and buckwheat; and FRhvr, forage radish, hairy vetch, and rye. Different letters indicate statistical differences detected.

Objective 2: Partner with organic farmers to develop the knowledge and skills needed to effectively use multifunctional cover crops

Throughout this past year, we have continued to fulfill this second objective in several ways. This past winter 2013, each farmer was visited and interviewed by Masters Student Rachel Welch to compile a detailed land history on the farms in general and the specific plots used in this study. These interviews provided better insight on how past management practices may have caused variation across the different locations in this study, allowed feedback on farmer opinion on the topic studied and encouraged future farmer participation in university research.

In addition to these farmer interviews, Dr. Villamil and Rachel Welch have participated and presented in several conferences to inform others on the results of this study. The following lists the conferences since October 2012.

- American Society of Agronomy International Annual Meeting 2013, Tampa, Florida, November 2013. Rachel Welch, our Masters student, presented a poster from the first year of this study titled “Alleviating Soil Compaction and Suppressing Weed Populations with Multifunctional Cover Crops in Organic Grain Production”

- 2014 Illinois Specialty Crops, Agritourism & Organic Conference, Bloomington, Illinois, January 2014. Rachel Welch and Mr. Allen Williams co-presented a power point presentation at this conference titled “Alleviating Soil Compaction with Cover Crops on Organic Farms: A Participatory Experience”. The presentation highlighted the results from the first three seasons of sampling of the project, outlined the farmers involvement in the project, and expressed the impact of this research on the farmers management plans.
- MOSES Organic Farming Conference, La Crosse, Wisconsin, February 2014. Dr. Maria Villamil and Rachel Welch co-presented a talk titled “Soil Compaction & Cover Crops in Organic Farms”. This presentation discussed the impact of soil compaction, what recent research has been done in conventional and organic systems on this topic and the finds from the CERES project from all sampling seasons.

Plans for future presentations and publications are in process. We hope to publish a brief bulletion in the MOSES Organic Broadcaster this coming spring in addition to at least two scientific publications on the vegetation and the soil properties data by next fall. Dr. Villamil will be presenting this research at two international venues this spring:

- Villamil MB. Cultivos de cubierta invernal para sistemas sustentables: Expectativas y realidades. Invited speaker. XXIV Congreso Argentino de la Ciencia del Suelo y II Reunión Nacional Materia Orgánica y Sustancias Húmicas: Producción sustentable en ambientes frágiles. Bahía Blanca, Argentina, May 5-9, 2014.
- Villamil MB, and ED Nafziger. 2014. Agronomic assessment of cover crops in Illinois. Commissional Symposia. Soil Management Strategy for Enhancing Crop Yields. Invited speaker. 20th World Congress Soil Science. ICC Jeju, Korea. June 8-13.

Additionally, Rachel Welch plans to present the full dataset this fall at the 2014 American Society of Agronomy International Meeting in Long Beach, California.