

# ORG Project Details

Award Year 2015

7 Research Projects

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# Tradeoffs Between Soil Carbon Sequestration and Greenhouse Gas Emissions in Organic Pastures Under Management Intensive Grazing

Accession No.	1006993
Project No.	NH.W-2015-06273
Agency	NIFA NH.WI
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2015-51106-23967
Proposal No.	2015-06273
Start Date	01 SEP 2015
Term Date	31 AUG 2018
Grant Amount	\$498,384
Grant Year	2015
Investigator(s)	Contosta, A.
Performing Institution	UNIVERSITY SYSTEM OF NEW HAMPSHIRE, 51 COLLEGE RD SERVICE BLDG 107, DURHAM, NEW HAMPSHIRE 03824

## NON-TECHNICAL SUMMARY

Management intensive grazing (MIG)--the most popular approach to pasturing on \*\*organic\*\* dairy farms in the northeastern U.S. --can potentially remove carbon (C) from the atmosphere and store it in soil. However, increased soil C storage may cause higher soil nitrous oxide (N<sub>2</sub>O) emissions, offsetting any gains in climate mitigation achieved with MIG. The goal of our project is to provide \*\*organic\*\* dairy farmers and industry partners with science-based information and decision support systems on grazing practices that maximize soil C \*\*sequestration\*\* and minimize soil GHG losses. Specific objectives include: 1) quantifying SOC stocks at three \*\*organic\*\* dairy farms in the Northeast under MIG; 2) investigating drivers of soil C stabilization with MIG; 3) measuring soil N<sub>2</sub>O emissions in grazed and ungrazed pastures and comparing them to C stocks; 4) developing a grazing-specific version of the biogeochemical model Manure-DNDC; 5) refining the Northeast Dairy Emissions Estimator (NDEE) decision support system using the updated model; 6) hosting workshops that train stakeholders to use the NDEE; 7) broadly disseminating research results and products through eOrganic and the USDA Northeast Climate Hub; and 8) using feedback from workshops to define future research questions. These activities are highly relevant to \*\*Organic\*\* Transitions program by documenting the effects of \*\*organic\*\* practices on greenhouse gas mitigation and improving a model for estimating soil C and greenhouse gas dynamics (Priorities 1 and 2). They are also critical for improving the sustainability of \*\*organic\*\* dairy production in the northeastern U.S., which comprises 20% of national \*\*organic\*\* milk sales.

## OBJECTIVES

The goal of our project is to provide stakeholders--\*\*organic\*\* dairy farmers and \*\*organic\*\* dairy industry--with science-based information and decision support systems on grazing practices that maximize soil carbon (C) \*\*sequestration\*\* and minimize soil greenhouse gas (GHG) losses, particularly during the transitional period from conventional to intensively managed, \*\*organic\*\* systems. We will accomplish our goal through a combination of 1) measurements of soil \*\*organic\*\* carbon (SOC) stabilization and GHG emissions at three \*\*organic\*\* dairy farms located throughout the Northeast; 2) modeling that simulates soil C storage and GHG losses in intensively

grazed pastures; 3) refinement of the Northeast Dairy Emissions Estimator (NDEE) to reflect soil C and GHG dynamics with intensive grazing; and 4) dissemination of our research products, both through direct extension and via eOrganic and the USDA Northeast Climate Hub. We define our measurements and modeling as research, our dissemination of research products as extension, and our work refining and training stakeholders to use the NDEE as the integration across our efforts. Our specific objectives include: 1. Quantifying SOC stocks with MIG at three organic dairy farms throughout the Northeast at different stages of transition to intensive, organic pasture management; 2. Investigating drivers of soil carbon stabilization with grazing, i.e., biomass production and allocation, N inputs, soil organic matter decomposition, bulk density, and time; 3. Measuring soil N<sub>2</sub>O emissions in grazed and ungrazed pastures and comparing them, in net global warming potential (GWP) equivalents, to changes in SOC stocks; 4. Developing a grazing-specific version of the biogeochemical model Manure-DeNitrification-DeComposition (DNDC) using data collected in objectives 1, 2, and 3; 5. Refining the NDEE using the updated Manure-DNDC model generated in objective 4; 6. Hosting workshops at regional gatherings that train stakeholders to use the refined NDEE developed in objective 5 to understand how they might build soil C stocks and minimize soil greenhouse gas losses; 7. Developing webinars on the NDEE, writing extension bulletins on soil C and GHG losses with pasture management, publishing research papers describing our results, and broadly disseminating these products through eOrganic and the USDA Northeast Climate Hub; and 8. Using feedback from producers, industry, and other stakeholders to define future research questions.

## APPROACH

This study will promote fundamental scientific understanding of relationships among management intensive grazing, soil organic carbon (SOC), and nitrous oxide emissions using field measurements, lab analyses, and process-based modeling. We will then translate this fundamental understanding into a user-friendly decision support system to assist organic dairy farmers in making pasture management decisions that enhance soil carbon sequestration and reduce soil greenhouse gas emissions. Our research activities include: 1. Quantifying SOC stocks at three organic dairy farms throughout the Northeast at different stages of transition to intensive, organic pasture management. These farms represent a range of climatic, soils, and management conditions that likely affect soil organic carbon stabilization in different ways. 2. Investigating drivers of soil carbon stabilization with grazing, i.e., biomass production and allocation, N inputs, soil organic matter decomposition, bulk density, and time. A unique aspect of this work will be applying both physical and chemical fractionation techniques to determine how MIG influences SOC by altering its chemical structure, occlusion in aggregates, and interactions with minerals. 3. Measuring soil N<sub>2</sub>O emissions in grazed and ungrazed pastures and comparing them, in net global warming potential (GWP) equivalents, to changes in SOC stocks. Spatially and temporally intensive sampling of soil N<sub>2</sub>O fluxes will allow us to capture "hot spots" and "hot moments" of N<sub>2</sub>O fluxes across the landscape. 4. Developing a grazing-specific version of the biogeochemical model Manure-DeNitrification-DeComposition (DNDC) using data collected in activities 1, 2, and 3. Currently, the ability of DNDC to simulate soil C stabilization and N<sub>2</sub>O emissions (and the variables that drive them) from grazing systems is not well-documented. As a result, this model upgrade will be a significant improvement over previous versions of DNDC. Our extension efforts include: 5. Refining the NDEE using the updated Manure-DNDC model generated in activity 4. Decision support systems such as the NDEE are critical tools for farmers to use in making management choices based on quantitative data. They also provide a vehicle through which we can integrate our research and extension efforts. 6. Hosting workshops at regional gatherings that train stakeholders to use the refined NDEE developed in activity 5 to understand how they might build soil C stocks and minimize soil greenhouse gas losses. Direct interaction with the organic dairy community (farmers and industry) at regional meetings is one of the most effective ways to disseminate research findings, resulting in a change in knowledge and / or actions. 7. Developing webinars on the NDEE, writing extension bulletins on soil C and GHG losses with pasture management, publishing research papers describing our results, and broadly disseminating these products through eOrganic and the USDA Northeast Climate Hub. 8. Using feedback from producers, industry, and other stakeholders to define future research questions.

**Evaluation Plan:** The success of the project will be determined in several ways. First, we anticipate that our research will result in both informal and formal review from other scientists. Informal review will be garnered at national scientific meetings where we present our research to our peers. More formal feedback will occur when papers are submitted for publication in peer-reviewed journals. Other metrics of our research impact will be in the number of times our papers are cited and in the application of our new version of Manure-DNDC to additional science, policy, and land management concerns. Finally, we will receive direct feedback on our research and outreach activities from farmers, extension specialists, industry leaders, and other stakeholders who attend our workshops at regional meetings or who attend our webinar. This feedback will allow us to determine our effectiveness at translating our research findings into management recommendations and will enable us to identify future, stakeholder-driven research questions.

## PROGRESS

2015/09 TO 2020/08 Target Audience:undergraduate and graduate students, technical service providers, farmers and producers, industry Changes/Problems:The research scientist conducting the modeling on our project left for a new position in the fall of 2019. We experienced significant delays in recruiting a new researcher to take her place, and then have been grappling with the disruption of the COVID pandemic. Both of these issues have slowed our progress toward publication. We should have our final two papers submitted in the first quarter of 2021 What opportunities for training and professional development has the project provided?Training Over the life of the project, we have afforded training opportunities to over ~12 undergraduate students who assisted with field sampling and lab analysis. Many of these undergraduate students conducted independent research associated with the project, which they presented at the annual UNH Undergraduate Research Conference. Three of these former undergraduate students are currently enrolled in graduate programs in environmental science and another currently works with the Nature Conservancy. Professional Development Early in the project, we met at the UNH Organic Dairy Research Farm with a group of high school Earth science teachers describing the project and discussing ways in which teachers can use project goals and activities as context for developing novel and hands-on Earth science curricula in their classrooms How have the results been disseminated to communities of interest?We disseminated results to communities of interest through both formal and informal activities, reaching a broad array of stakeholders. Informal activities: June 2016: research demonstration at one of our study sites, Wolfe's Neck Farm, for NRCS soil conservationists, directors of the USDA Northeast Climate Hub, American Farmland Trust, and farm staff showing our soil and trace gas monitoring protocols and brainstorming synergies between our research and other initiatives. July 2016: A pasture walk sponsored by NOFA Vermont and Organic Valley at another farm within our study, Franklin Farm, that featured informal discussions of pasture improvement, herd health, and agroecosystem management for building soil organic matter while reducing greenhouse gas emissions. September 2016: A formal presentation plus informal discussion at the Harvard Forest Grazing and Conservation seminar describing project goals and objectives to a group of regional dairy farmers, land trust representatives, farm advocacy groups, and scientists. May 2017: Participation in a short film for international distribution as part of the G8 Global Open Data for Agriculture and Nutrition(GODAN) initiative. Our role in the film was to show how our ongoing measurements of soil biogeochemical processes and real-time monitoring of soil microclimate can contribute to an emerging movement among citizens, farmers, and scientists to promote sustainable agriculture through open source and transparent data collection, modeling, and decision support tools:<http://www.godan.info/news/open-farms-godan-documentary-web-series-episode-3>. Formal Research Presentations American Geophysical Union Annual Meeting (fall 2017, 2018, 2019) Natural Capital Project Symposium (spring 2018) Slow Living Summit (summer 2018) Massachusetts Institute of Technology (spring 2018, 2019) University of Massachusetts (spring 2019) Tufts University (fall 2019) Antioch University New England (fall 2020) University of New Hampshire (fall 2020) Maine Organic Farmers and Growers Association (fall 2020) What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

2015/09 TO 2016/08 Target Audience:Target audiences included leaders in climate, natural resource, and agroecosystem fields, farmers, K-12 teachers, and the general public. Changes/Problems:Since receiving the award from the USDA ORG program, one of the lead PIs, Changsheng Li, unfortunately passed away. Dr. Li possessed considerable modeling expertise which we planned to use in supporting a graduate student on this project. Due to his unforeseen passing, we have had to re-organize project personnel to both meet our modeling needs as well as our other goals. To that end, we hired a research scientist to assume responsibilities for the modeling aspects of the work. We alerted the USDA in the spring of 2016 about Dr. Li's death and our plans for fulfilling his role in the project. What opportunities for training and professional development has the project provided?In Y1, the primary avenue for training and professional development was an informal discussion we held at the UNH Organic Dairy Research Farm with a group of high school Earth science teachers describing the project and discussing ways in which teachers can use project goals and activities as context for developing novel and hands-on Earth science curricula in their classrooms. How have the results been disseminated to communities of interest?In addition to the training and professional development activities outlined above, we have disseminated results to communities of interest through both formal and informal activities, reaching a broad array of stakeholders. These include: A research demonstration at one of our study sites, Wolfe's Neck Farm, for NRCS soil conservationists, directors of the USDA Northeast Climate Hub, American Farmland Trust, and farm staff showing our soil and trace gas monitoring protocols and brainstorming synergies between our research and 1) baseline soil sample collection for the National Soil Health Assessment effort of which Wolfe's Neck is a member; 2) a USDA Climate Hub virtual farm tour featuring our ongoing research and education initiatives; and 3) open source platforms for collecting and disseminating our agroecological data and management information for decision support. A pasture walk sponsored by NOFA Vermont and Organic Valley at another farm within our study, Franklin Farm, that featured informal discussions of pasture improvement, herd health, and agroecosystem

management for building soil organic matter while reducing greenhouse gas emissions. A formal presentation plus informal discussion at the Harvard Forest Grazing and Conservation seminar describing project goals and objectives to a group of regional dairy farmers, land trust representatives, farm advocacy groups, and scientists. Participation in a short film for international distribution as part of the by the G8 Global Open Data for Agriculture and Nutrition (GODAN) initiative. Our role in the film was to show how our ongoing measurements of soil biogeochemical processes and real-time monitoring of soil microclimate can contribute to an emerging movement among citizens, farmers, and scientists to promote sustainable agriculture through open source and transparent data collection, modeling, and decision support tools. What do you plan to do during the next reporting period to accomplish the goals? During the second year of the project, we will conduct our second year of soil greenhouse gas emissions measurements and will complete physiochemical analysis of soil samples. We will also begin development of a grazing specific version of Manure-DNDC (Objective 4) and use model results to begin refining the NDEE (Objective 5). We will continue to engage stakeholders in a variety of informal and formal settings (Objective 6), and will also increase our visibility to the broader public through the eOrganic and the USDA Climate Hub (Objective 7). Already we are collaborating with eOrganic to build a project website and coordinating with the Climate Hub to be featured in their virtual farm tour of Wolfe's Neck Farm. What do you plan to do during the next reporting period to accomplish the goals? During the second year of the project, we will conduct an additional year of soil greenhouse gas emissions measurements and will complete physiochemical analysis of soil samples. We will also begin development of a grazing specific version of Manure-DNDC (Objective 4) and use model results to begin refining the NDEE (Objective 5). We will continue to engage stakeholders in a variety of informal and formal settings (Objective 6), and will also increase our visibility to the broader public through the eOrganic and the USDA Climate Hub (Objective 7). Already we are collaborating with eOrganic to build a project website and coordinating with the Climate Hub to be featured in their virtual farm tour of Wolfe's Neck Farm. We will also prepare publications for both extension and peer-reviewed journals.

## IMPACT

2015/09 TO 2020/08 What was accomplished under these goals? To meet Objective 1, we conducted a spatially intensive soil sampling effort at all of our study sites and analyzed our soil samples for total SOC stocks as well as physiochemical fractions to determine mechanisms of C stabilization (Objective 2). We also conducted a spatially and temporally intensive measurement campaign of greenhouse gas emissions at our study sites (Objective 3), which span a range of management, edaphic, and climatic conditions. The data we collected as part of Objectives 1 through 3 are featured in a manuscript currently in review in the journal *Agriculture, Ecosystems & Environment*. All of the underlying data and code that generated the results in the paper are on a publicly available github repository: <<https://github.com/Contosta/Organic-Dairy>>. To address Objective 4, we developed new parameters for simulating management intensive grazing in the DeNitrification-DeComposition model, which we used to simulate grazing practices at both the farm and regional scales. All of the code, input files, and underlying data needed to run the model are hosted on a web repository for sharing and dissemination with the research community: <<https://github.com/eecampbell/DNDCDairy>>. We are currently preparing a manuscript for submission that highlights different approaches to simulating management intensive grazing and explores mechanisms by which this management practice might increase soil C storage and minimize GHG emissions. Both staffing changes and the COVID situation slowed our progress on this effort, but our target submission date is February of 2021. The results from the regional model runs formed the database underlying the Northeast Dairy Emissions Estimator (NDEE), which we refined based on our updates to the DNDC model (Objective 5). We are drafting a third manuscript that describes our methodology and results. As above, personnel changes and the pandemic have slowed our progress. We aim to have this paper submitted in spring of 2021. We have broadly shared our results with farmers, technical service providers, industry partners, students, researchers, and the general public (Objectives 6 and 7), and have incorporated feedback from the community in defining future research questions (Objective 8), most recently in proposals to the New Hampshire Innovation Research Center (funded) and the NASA Early Career Investigator program (pending).

**\*\*PUBLICATIONS (not previously reported):\*\*** 2015/09 TO 2020/08 1. Type: Journal Articles Status: Under Review Year Published: 2020 Citation: Contosta, A.R., Arndt, K.A., Campbell, E.A., Grandy, A.S., Perry, A., and Varner, R.K., in review, Management intensive grazing on New England dairy farms enhances soil nitrogen stocks and nitrous oxide emissions while having little effect on soil carbon, *Agriculture, Ecosystems & Environment*. 2. Type: Journal Articles Status: Other Year Published: 2020 Citation: Arndt, K.A., E.E. Campbell, A.R., Contosta, C. D. Dorich, P. Ingraham, A.S. Grandy, T. Griffin, A. Perry, and R. K. Varner. Managing intensive rotational grazing systems for soil health and sustainability. in prep. 3. Type: Journal Articles Status: Other Year Published: 2020 Citation: Arndt, K.A., EE Campbell, A Contosta, P. Ingraham, J. Deng, W. Salas, C.

Dorich, S. Grandy, and R. Varner. Impacts of management intensive grazing on the greenhouse gas budget of New England dairy farms. in prep.

2015/09 TO 2016/08 What was accomplished under these goals? During the first year of the project, we primarily focused on Objectives 1 through 3 in accordance with our proposed timeline. To meet Objective 1, we conducted a spatially intensive soil sampling effort at all of our study sites and are currently in the process of analyzing soil samples for total SOC stocks as well as physiochemical fractions to determine mechanisms of C stabilization (Objective 2). We also conducted a spatially and temporally intensive measurement campaign of greenhouse gas emissions at our study sites (Objective 3), which span a range of management, edaphic, and climatic conditions. In preparation of addressing Objective 4, we have begun compiling management data required for modeling and have also developed modeling architecture for simultaneously running different versions of the DNDC model as well as other biogeochemical models such as DayCent. Regarding Objective 7, we have disseminated initial project findings and described overall project goals in both formal and informal venues involving a variety of stakeholders. **\*\*PUBLICATIONS (not previously reported):\*\*** 2015/09 TO 2016/08 No publications reported this period.

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# Unraveling the Interactive Effects of Tillage, Residue, and Manure Additions on Nitrous Oxide Emissions in Grain and Silage Systems

Accession No.	1007100
Project No.	PENW-2015-06276
Agency	NIFA PENW\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2015-51106-24237
Proposal No.	2015-06276
Start Date	01 SEP 2015
Term Date	31 AUG 2017
Grant Amount	\$375,243
Grant Year	2015
Investigator(s)	Kemanian, A. R.
Performing Institution	PENNSYLVANIA STATE UNIVERSITY, 408 Old Main, UNIVERSITY PARK, PENNSYLVANIA 16802-1505

## NON-TECHNICAL SUMMARY

"Sustainable agriculture" is increasingly demanded by consumers that expect food to be produced with environmentally friendly practices. It is as well an explicit goal of **organic** producers, who pride themselves in producing food while preserving the integrity of the soil, air, and water resources. In this context, the greenhouse gas emission associated with **organic** agriculture is largely unknown. The greenhouse gas emission in **organic** grain and silage systems with high input of **manure** is, most likely, associated to the emission of nitrous oxide - the laughing gas. But this is no laughing matter. This gas is emitted in low amounts and in episodic events during the cycling of nutrients in the soil. So low are these emissions that it is challenging to measure them. But, unfortunately, this gas has an outsized impact on the greenhouse gas emission of agriculture worldwide. This project seeks to measure the emission of this gas from experimental fields that represent realistic **organic** grain and silage production systems in the northeastern United States. We have the technical expertise to measure the emissions of nitrous oxide and the knowledge to interpret the results and extrapolate them to other **organic** systems. In fact, we plan to project our results to a broader range of management systems by enhancing the software Cycles-OT (**organic** tool), a decision support system that will help producers manage better their production cycle. Because our team works closely with **organic** producer's networks, our results will flow seamlessly into their information stream and help provide measurable benchmarks of the sustainability of **organic** systems.

## OBJECTIVES

The goal of this project is to measure the N<sub>2</sub>O emission and their control in grain and silage production systems typical of the northeastern United States. We do so in an existing tillage, rotation, and **manure** management **organic** experiment (ROSE). In addition, we propose to use the simulation model Cycles (Kemanian and Stöckle, 2010) to do both, test hypotheses in silico before launching the field measuring campaign, and to design a decision support tool that can help **organic** producers assess the component of the carbon footprint of their system that is attributable to N<sub>2</sub>O emissions. The ROSE team has in place an extension and educational

infrastructure that will be expanded and enriched by including a comprehensive assessment of the N<sub>2</sub>O emission, and as a byproduct, the soil C storage in these **organic** systems.

## APPROACH

Our approach has three components: (1) measuring N<sub>2</sub>O emissions in the four ROSE management system treatments (N<sub>2</sub>O flux - and soil respiration - will be measured by in situ non-steady state, static, chambers); (2) using micro-plots (0.25 m<sup>2</sup>) within the main plots to increase **manure** application by budgeting **manure** additions to meet the N demand of the crops (currently the supply meets the phosphorus demand of the crop) and expand the domain of the experiment without changing any field operations; and (3) testing the skill of the Cycles model to simulate the measured emission, and evaluate using it to create a N<sub>2</sub>O emission database or **organic**-specific emission factors based on a combination of field data and simulations. The use of microplots to increase **manure** rates is a unique aspect of the project, and so is the application of a simulation model. The cropping systems represent four approaches for reducing tillage in a crop rotation that uses cover crops. A traditional **organic** full-tillage 3-yr annual grain rotation using cover crops will typically use 5 primary tillage events (moldboard or chisel plow) and 8 or more supplemental tillage events (disking, cultivating) for weed control and incorporation of fertility inputs. Our proposed cropping system treatments in ROSE use no-till planting of cover- or cash-crops (1 to 3 events per rotation) to reduce the frequency of primary tillage events and will evaluate minimum tillage practices (chisel plow) to reduce the intensity of primary tillage within a 3-yr rotation in comparison to a full tillage system. No-till planting and primary tillage treatments are a function of the different cover crop management strategies chosen for the proposed cropping systems, which are summarized below. We will synthesize and analyze the N<sub>2</sub>O emissions data from different **organically** managed systems with two types of data analysis: classical parametric statistic (ANOVA) and non-parametric statistics (Random Forest).

## PROGRESS

2015/09 TO 2019/08 Target Audience: Nothing Reported Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided?"The Cropping System Model Cycles: Digital Ag, and the Future of Agronomic, Biogeochemical and Hydrology Models plus Remote Sensing and Artificial Intelligence; Invited Talk in the Penn State Extension Annual Conference. Champion, PA. 2 April 2019 "Cycles Agroecosystems Model Workshop". This workshop trained extension professionals on the use of the Cycles model webservice. The workshop was attended by 11 Extension Experts. 004 Life Science Building, University Park, PA. 22 August 2019 How have the results been disseminated to communities of interest?A paper with the major findings is under review. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

2015/09 TO 2016/08 Target Audience: The target audience are organic producers, and scientists and practitioners working on life cycle assessment of organic products. We reached both audiences through a February meeting with the Advisory Board of the broader project - ROSE - which provides our stakeholder engagement platform. In addition, a Penn State led symposium on cropping systems, and a field day hosting scientist from Argentina, gave the postdoc working in this project the opportunity to show and discuss our first results with scientists from the Rodale Institute, Penn State, and Argentina. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided?Dr. Debasish Saha, a postdoctoral researcher now working in this project, is in charge of the field campaign and works closely with the PI to run the simulations. Dr. Saha is an expert on measuring, modeling and interpreting soil carbon and nitrogen fluxes, in particular nitrous oxide. An undergraduate student, Jonathan Stephens, has been working with the team during the summer and learned not only about the lively agronomy that goes on in managing organic systems, but also the techniques to measure nitrous oxide emission which requires both careful field and laboratory work. How have the results been disseminated to communities of interest?The first measurements obtained before June 2016 were shown in a field day that included scientist from Argentina, the Rodale Institute and Penn State. What do you plan to do during the next reporting period to accomplish the goals?The project is moving along as planned, so we will continue: - monitoring nitrous oxide - analyse data as it is produced - proceed with the analysis of the simulated output and the production of a decision support tool

## IMPACT

2015/09 TO 2019/08 What was accomplished under these goals? Since soil fertility in organic agriculture typically relies on microbial cycling of nutrient inputs from legume cover crops and animal manure, the risk of nitrous oxide (N<sub>2</sub>O), a powerful greenhouse gas, from soils was dimmed high. Indeed, one of the impacts of our project is that we measured substantial emissions of N<sub>2</sub>O in the corn phase of the rotation, after both cover crops and manure are incorporated in the soil, and therefore discovered the valve to manipulate to reduce these emissions. A follow up project is testing "smart tillage" as a way of driving down these emissions, retain nitrogen in the system, and therefore improve the overall efficiency and environmental footprint of not only organic but all systems managing manure and cover crops. Details follow. We measured soil N<sub>2</sub>O emission for two growing seasons in four corn-soybean-winter grain organic rotations with tillage, cover crop and manure management variations typical of organic agriculture in temperate and humid North America. To identify biogenic pathways of N<sub>2</sub>O production, we also measured N<sub>2</sub>O emission in microplots with and without cover crop and manure additions and measured the N<sub>2</sub>O isotopomer composition and microbiological genomic DNA abundances. The N input from legume-rich cover crops and manure prior to corn planting made the corn phase the main source of N<sub>2</sub>O emissions, averaging 9.8 kg ha<sup>-1</sup> of N<sub>2</sub>O-N and representing 80% of the three-year rotations' total emissions. A key finding was that N<sub>2</sub>O emissions increased sharply when legume residue and manure inputs exceeded 1.8 and 4 Mg ha<sup>-1</sup> respectively. Removing the legume aboveground biomass before corn planting decreased N<sub>2</sub>O emissions by 60% during the corn phase. Denitrification was the main N<sub>2</sub>O source, contributing ≈ 90% of the N<sub>2</sub>O emissions. High N<sub>2</sub>O emission coincided with high carbon dioxide emission, from which we inferred that microbial oxygen (O<sub>2</sub>) consumption promoted soil hypoxia. Limited N<sub>2</sub>O reduction was revealed by both the and of the N<sub>2</sub>O molecules and the significant reduction in nosZ activity following incorporation of cover crops and manure. Thus, rather than limitations to O<sub>2</sub> diffusion in wet soils, accelerated O<sub>2</sub> consumption seems to be a critical control of N<sub>2</sub>O emissions in systems with large additions of decomposable C and N substrates. Since many sustainable agricultural approaches rely on combined fertility inputs from legumes and manures, our research suggests that spatially and temporally decoupling these inputs could provide a tool for managers to reduce N<sub>2</sub>O emissions. **\*\*PUBLICATIONS (not previously reported):\*\*** 2015/09 TO 2019/08 Type: Journal Articles Status: Submitted Year Published: 2019 Citation: Saha, D. O., Kaye, J. P., Bhowmik, A., Bruns, M. V., Wallace, J., & Kemanian, A. R. (Primary Author) Organic fertility inputs synergistically increase denitrification-derived nitrous oxide emissions in agroecosystems. Ecological Applications. \Submitted October 21, 2019\.

2015/09 TO 2016/08 What was accomplished under these goals? We measured nitrous oxide emissions in the ROSE experiment from March 2016 to date (August 2016) and plan to continue doing so. The field campaign so far has been a complete success. We measured nitrous oxide emissions about 25 times in the 48 plots of the experiments, plus some additional measurement in manured microplots. Simulation outputs from the model Cycles for a cropping system used by one of the organic producers collaborating in the project (Mr. Esbenshade) were compiled to go through the process of assimilating data and producing a decision support tool. Because this is a major task with many moving parts, we decided to do a full path or test focusing only on nitrogen management for corn that follows a cover crop or alfalfa (the producer uses a 9-year rotation with two corn crops). Thirty years of simulations with 9 entry points (i.e. 270 years of simulations) were simulated for this purpose. Regarding extension, our efforts have been limited because the project is in the first year. Nonetheless, we already introduced the project to the Advisory Board of ROSE. **\*\*PUBLICATIONS (not previously reported):\*\*** 2015/09 TO 2016/08 No publications reported this period.

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# Fishing for a Novel Source of Methionine in Organic Poultry Feed: Exploring the Potential of Invasive Asian Carp as Sustainable Fish Meal

Accession No.	1007117
Project No.	ARK02483
Agency	NIFA ARK\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2015-51106-23966
Proposal No.	2015-06280
Start Date	01 SEP 2015
Term Date	31 AUG 2018
Grant Amount	\$499,984
Grant Year	2015
Investigator(s)	Donoghue, D. J.

## NON-TECHNICAL SUMMARY

Synthetic methionine is the only synthetic amino acid allowed in organic poultry feed and it has been a challenge to find a natural, cost effective source for producers (ORG FY2013 Priority 3). Fish meal is an excellent source of methionine and an allowable natural substance under the NOP livestock rule. However, there are critical issues regarding cost, sustainable acquisition without depleting ocean stocks, and the use of synthetic ethoxyquin as a preservative. Our project will take a holistic approach evaluating a unique source of fish meal and evaluating its efficacy and potential utilization for organic poultry production. **Asian carp** are invasive species imported to improve water quality for aquaculture ponds. Through escape and deliberate release they have had a devastating impact in U.S. waterways with no known predators (> \$200 million/annually). These fish are boney, not normally eaten in the U.S. and have little market value. The potential for **Asian carp** is tremendous as a low cost, wild caught resource to our farmers. Their use would reduce the impact of this invasive species on our waterways and eliminate the need to capture natural stocks of ocean fish. We will evaluate organically suitable preservatives for **Asian carp** derived fish meal; develop diets that optimize methionine levels; evaluate growth parameters, feed efficiency and meat and egg quality and test optimal doses on working organic farms. Educational and extension activities to disseminate results and strategies for organic producers will be conducted through train the trainer programs, electronic and printed material, and workshops.

## OBJECTIVES

A major goal of organic poultry farming is to ensure high quality protein source for consumers. Our overall goal is to evaluate the potential source of a natural source of methionine, while assisting organic poultry producers to comply with the requirements of the National Organic Program (NOP, 2012). Our specific research objectives are: 1) evaluate organically suitable preservatives for **Asian carp** derived fish meal utilizing tocopherol compounds and development of broiler ration formulations that optimize methionine levels; 2) evaluate growth parameters, feed efficiency and meat quality using an **Asian carp** derived fish meal compared to the synthetic methionine product fed to meat birds; 3) evaluate egg quality and production parameters using an **Asian carp** derived fish meal compared to the synthetic methionine product fed layer birds; and 4) On-farm testing of effectiveness of treatments in organic poultry broiler and layer production systems. The results of the project and information on organic poultry production in general, will be disseminated to the organic and sustainable

agriculture communities by an extension team comprised of experienced poultry specialists and stakeholders who have been involved in organic poultry production. The outreach/extension objectives of this proposal are to: 1) disseminate results of the project to the organic poultry community, through numerous delivery methods including conferences, electronic and printed materials, and training activities in a research and teaching oriented organic poultry facility; and 2) conduct train the trainer programs for extension specialists and other interested stakeholders regarding the objectives and results of this project.

## APPROACH

The first objective of this project is to evaluate organically suitable preservatives for \*\*Asian carp\*\* derived fish meal utilizing tocopherol compounds and development of broiler ration formulations that optimize methionine levels. As part of this objective, we will test the oxidative stability of a natural, alternate preservative and conduct studies to determine how the \*\*Asian carp\*\* fish meal can deliver methionine needs while providing the protein and energy requirements in the diets. We will evaluate the digestibility of nutrients in \*\*Asian carp\*\* meal and conduct the digestibility studies in broiler chickens. We will also develop rations with nutrient profiles suitable for organic poultry production and diets will be analyzed for ash, dry matter, crude protein, amino acids (specifically methionine), crude fat, minerals and gross energy at the University of Arkansas Central Analytical Laboratory. As part of our second objective, we will conduct studies to evaluate the growth parameters and feed efficiency of \*\*Asian carp\*\* derived fish meal as a source of methionine in comparison to birds supplemented with synthetic methionine in their feed. We will also determine the post-harvest meat quality and conduct sensory studies to evaluate the consumer acceptability of meat from broilers fed with natural and sustainable source of methionine in comparison to broiler chickens fed with conventional diets. We will extend these studies to layer birds and evaluate egg quality and production parameters using an \*\*Asian carp\*\* derived fish meal compared to the synthetic methionine product fed layer birds. Sensory studies will also be conducted to evaluate the taste and consumer acceptability of eggs from birds supplemented with the \*\*Asian carp\*\* derived source of methionine in comparison to layers supplemented with synthetic methionine. We will utilize the data from the aforementioned studies to determine the most effective treatments and we will conduct on farm testing of effectiveness of treatments in organic poultry broiler and layer production systems at our working organic farms. We will disseminate the results of the project to the organic poultry community, through numerous delivery methods including conferences, electronic and printed materials, and training activities in a research and teaching oriented organic poultry facility. Educational and extension activities will be continued through our train the trainer programs for extension specialists and other interested stakeholders.

## PROGRESS

2015/09 TO 2019/08 Target Audience: Our main target is small, medium and large-scale organic poultry producers, but we will also focus our efforts to reach educators such as extension poultry specialists, extension agents, federal and state personnel, and nonprofit organizations that assist organic poultry producers and processors. Changes/Problems: We had to alter the way we prepared the Carp Fishmeal as the rendering process is odorous and has caused many of the small business producers to shut down or move. To honor the commitments of our grant we used extrusion technology which showed promising results. What opportunities for training and professional development has the project provided? This project has provided training for postdoctoral fellows and graduate students associated with project. Our Co-PI Dr. Anne Fanatico from Appalachian State University, gave a talk at "Innovaciones sobre Educación en Agricultura Sustentable en los Estados Unidos." Oct 13, 2016, COLPOS Campeche Campus, Campeche, Mexico. Our Co-PI Dr. Ondieki Gekara presented a part of our research at "Backyard Poultry Production" an urban agricultural workshop held in Los Angeles County California, Aug 11, 2017. Co-PI, Dr. Fanatico gave a guest lecture on Sustainable Livestock Production, Mar. 22, 2018 Dr. Anne Fanatico gave a talk on "Free-Range Poultry Production in Mexico" at the Appalachian Global Symposium, Nov 15, 2017. Dr. Annie Donoghue gave a talk on "The triathlon for success: Integrating research, outreach, and stakeholders to support poultry producers" at the National Outreach Workshop: The Future of Agriculture-Serving Audiences of all sizes through Integration of Research and Outreach, Poultry Science Association Conference San Antonio, Texas (July 2018). Dr. Anne Fanatico participated in the Panel, National Outreach Workshop at the Annual Poultry Science Association Conference San Antonio, Texas (July, 2018). Dr. Fanatico gave a presentation with two colleagues on "Community Garden Development for Research, Teaching and Outreach". This campus-wide talk was given on April 17, 2019 and it was attended by 21 students. We conducted annual review meetings (during the PSA annual conference) involving the Co-PIs and collaborators to review the project productivity, update findings and discussed the plan for outreach activities for the next reporting period. We have participated in the Joint Annual Meeting of American & Canadian Societies of Animal Science held in Austin, Texas (2019) and Poultry Science Association (PSA)

annual conference (2015-2019) and few other national and international conferences. These meetings provided an excellent educational and networking opportunities. How have the results been disseminated to communities of interest? During this project we have participated at multiple meetings to present our project to producers and interested stakeholders. A review article has been published in the Journal of Applied Poultry Research, disseminating the potential of using fishmeal in organic poultry production to reach the scientific community. (Fanatico et al., 2018) Information about sustainable sources of methionine including the potential use of Asian carp meal and other possible alternatives were disseminated to poultry producers through direct email contacts and at regional meetings where organic poultry producers and leaders gather. Our collaborator at University of Kentucky, Dr. Jacqueline Jacob participated in various webinars discussing our project: Raising ducks for egg production (September 15, 2016) Safe handling of eggs from small and backyard flocks (October 11, 2016) Understanding and meeting your market: Conducting a local customer survey (November 3, 2016) Poultry medications - new rules affecting small and backyard flocks (December 12, 2016) Setting culling standards for small and backyard flocks (December 13, 2016) Avian genetics: Introduction to poultry breeding (January 12, 2017) Predator control for small and backyard poultry flocks (February 7, 2017) Animal welfare considerations for backyard poultry flocks (March 30, 2017) Dr. Fanatico integrated work on the Organic Transition grant with the Appalachian State research on Black Soldier Fly (BSF) production, another potential natural source of methionine in poultry diets. She gave a webinar on 'Black Soldier Fly Larvae for Ecological Poultry Feed: On-Farm Production' on March 22, 2019, hosted by the Small and Backyard Flock Community of Practice on eXtension. Co-PI, Margo Hale created a blog post with information and recorded a podcast with Dr. Fanatico about the results of the project. This page (<https://www.ncat.org/alternative-poultry-feeds/>) received 111 Unique Views since 7/3/19 and the podcast received 1894 listens/downloads. The details of the podcast can be found at <https://attra.ncat.org/alternative-feed-for-poultry/>. The NCAT Southeast Facebook page had a post promoting this blog and podcast. That post reached 767 people and had 214 engagements. Outreach articles for eXtension and eOrganic on this project are under internal review. Both have a very high readership in the agricultural community especially among organic farmers. What do you plan to do during the next reporting period to accomplish the goals? Our work associated with this award is complete. We will finalize manuscripts and utilize these findings to enhance and continue our efforts to address the issues concerning organic poultry producers. We will continue our outreach efforts by sharing the educational materials produced during the period of this grant with other research and extension groups at the scientific meetings to expand the outreach effort of this project. We continue to develop eOrganic webinars and articles. After the life of this award we will continue to use the research results to conduct farmer workshops and provide educational information to organic poultry producers. There is the potential for a small business to utilize the results of this work to develop a Big headed carp meal product as a source of methionine for organic poultry producers.

2016/09 TO 2017/08 Target Audience: Organic poultry farmers and poultry producers interested in transitioning to organic production. Extension and research scientists working on strategies to improve nutrition in organic poultry. Changes/Problems: See comments under Accomplishments section. We had to alter the way we prepared the Asian Carp Fishmeal as the rendering process is odorous and has caused many of the small business producers to shut down or move. To honor the commitments of our grant we are utilizing extrusion technology which appears promising. What opportunities for training and professional development has the project provided? This project has provided training for postdoctoral fellows (3) and graduate students (4) associated with project. Members of the project are experimenting with new technology associated with dry extrusion processes. How have the results been disseminated to communities of interest? We are preparing outreach articles for eXtension and eOrganic on this project. Both have a very high readership in the agricultural community especially among organic farmers. Information about sustainable sources of methionine including the potential use of Asian carp meal and other possible alternatives were disseminated to poultry producers through direct email contacts and at regional meetings where organic poultry producers and leaders gather. Our Co-PI Dr. Anne Fanatico from Appalachian State University, gave a talk on using organic waste management as protein supplement in poultry production at "Innovaciones sobre Educación en Agricultura Sustentable en los Estados Unidos." Oct 13, 2016, COLPOS Campeche Campus, Campeche, Mexico. Our Co-PI Dr. Ondieki Gekara presented a part of our research at "Backyard Poultry Production" an urban agricultural workshop held in Los Angeles County California, Aug 11, 2017. Our collaborator at University of Kentucky, Dr. Jacqueline Jacob participated in various webinars discussing our project: · Animal welfare considerations for backyard poultry flocks (March 30, 2017) · Predator control for small and backyard poultry flocks (February 7, 2017) · Avian genetics: Introduction to poultry breeding (January 12, 2017) · Setting culling standards for small and backyard flocks (December 13, 2016) · Poultry medications - new rules affecting small and backyard flocks (December 12, 2016) · Understanding and meeting your market: Conducting a local customer survey (November 3, 2016) · Safe handling of eggs from small and backyard flocks (October 11, 2016) · Raising ducks for egg production (September 15, 2016) What do you plan to do during the next reporting period to accomplish the goals? Complete studies evaluating the growth parameters, feed efficiency and meat quality using an Asian carp derived

fish meal compared to the synthetic methionine product fed to meat birds. Present findings at scientific meetings. On farm testing of effectiveness of treatments in organic poultry production systems. Prepare manuscripts and present findings at scientific meetings. The results of the project and information on organic poultry production in general, will be disseminated to the organic and sustainable agriculture communities by an extension team comprised of experienced poultry specialists and stakeholders who have been involved in organic poultry production. Disseminate results of the project to the organic poultry community, through different methods.

## IMPACT

2015/09 TO 2019/08 What was accomplished under these goals? Study 1: Bigheaded carp-based meal as a sustainable and natural source of methionine in feed for ecological and organic poultry production Our initial strategy was to use rendered fish meal from Bigheaded Carp for our studies. However, since initiation of our project the sources of this product has been delayed. As a rendered product causes noxious odors, we rethought the use of this method of fishmeal production and devised a novel dry extrusion method instead. Although this is a completely new process for producing fishmeal, small extruders are becoming affordable and will limit the odor/short shelf life associated with rendering. Small batches of Bigheaded Carp fishmeal were made using Insta Pro Jr. (600) with new collaborators at the Texas A&M University. Dry extrusion of Bigheaded carp was carried out by mixing the fish with soybean meal (SBM) in a 1:1 proportion to reduce high moisture in the starting material. A natural stabilizer, Naturox, was added to help preserve the meal and extend shelf life to approx. 6 months. Proximate analysis, amino acid composition, digestible amino acids and true metabolizable energy (TME<sub>n</sub>) for the extruded carp-based meal (CBM) were determined. To study the digestible amino acids and TME<sub>n</sub> of the extruded product, a colony of adult roosters were fasted and tube fed AC fish meal. The gross energy and protein content of the feces from CBM were determined to calculate the digestibility of amino acids and TME<sub>n</sub> for feed formulation. Diets with CBM were formulated and fed to broilers (two treatments, CBM or Control diet with synthetic methionine; 8 replicates/treatment; n=30 birds/replicate) from day 1 to 42 days of age. The starter and grower diets formulated with CBM showed the potential to supplement the required methionine content for organic poultry production. When tested in broiler production, the carpmeal diets were very effective in maintaining the body weight, feed intake and feed conversion ratio comparable to commercial starter and grower diets. Results revealed that carpmeal is an efficient source of protein and amino acids, especially methionine, that can potentially supplement natural methionine to eliminate the use of synthetic form in organic poultry production. These studies were completed and the manuscript was published in the Journal of Applied Poultry Research. Study 2: Supplementing Bigheaded Carp-based fishmeal as a natural methionine source and its effect on broiler meat quality characteristics. In this study, we compared the meat and carcass qualities of control birds with commercial diet and birds fed on extruded carp meal. Carcass analysis revealed that birds maintained on carp meal diet did not differ in live weight, carcass weight, breast weight, ready-to-cook yield, wing yield, tenders and thigh yields. No significant difference in meat color, cook loss and texture were observed between treatments. Sensory analysis of breast and thigh meat revealed no differences in overall impression and purchase intent between thigh meat treatments. However, a lower purchase intent for the breast from birds fed with carp meal was observed. The results suggest that carp meal has the potential of replacing synthetic methionine in commercial poultry diet with limited impact on post-harvest meat quality. These studies were completed and a manuscript will be submitted to the Journal of Applied Poultry Research after internal review. Study 3: Investigating the effect of Asian carp meal on gut health of poultry via comprehensive microbiome and metaproteomic profiling of poultry gut contents In this study, we investigated the effect of incorporation of fish meal in broiler diet on gut microbiome and metaproteome. In addition, we hope to identify major bacterial species dominating in the cecal microbiota based on total spectra counts and to correlate it with the relative abundance of bacterial species observed with 16s rRNA sequencing from Illumina Mi-seq. We have completed processing the samples and we are analyzing the data using Scaffold software version 4.2. The cecal contents were also collected from the birds fed with or without fish meal and the samples were used for protein extraction followed by gel electrophoresis. The protein samples were processed further for in-gel tryptic digestion followed by determination of protein sequences using liquid chromatography with tandem mass spectrometry. We expected to identify the pool of major proteins in the gut microbial community and expected to determine a deviation in the functional gut community when birds were fed with fish meal. We have completed processing the samples and the raw data is available. Currently we are analyzing the microbiome and metaproteomics data and the obtained data will be incorporated in a manuscript for submission to the journal Poultry Science. Study 4: An on-farm study to evaluate the egg quality and production parameters using the Bigheaded carp based meal compared to a synthetic methionine product fed layer birds. An on-farm study was conducted where Rhode Island Red birds aged between 60-65 weeks were divided into two treatment groups, control layers fed with commercial ration and treatment group fed with fishmeal ration. Eggs were collected for 3 weeks from the two groups and evaluated for

egg quality parameters including egg weight, shell thickness, yolk color and fatty acid analysis. Furthermore, the eggs were also subjected to sensory analysis. These studies have been completed and the manuscript is under preparation for submission to Journal of Applied Poultry Research. \*\*PUBLICATIONS (not previously reported):\*\*

2015/09 TO 2019/08 1. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Upadhyaya, I., K. Arsi, A. M. Donoghue, C. N. Coon, M. Schlumbohm, M. N. Riaz, M. B. Farnell, A. Upadhyay, A. J. Davis, D. J. Donoghue. Dry-extrusion of Asian Carp to Supplement Natural Methionine for Organic Poultry Production. TICEAS 2018, The International Conference on Engineering and Applied Sciences. Bangkok, Thailand. February 22-24, 2018. 2. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Upadhyaya, I., K. Arsi, A. M. Donoghue, C. N. Coon, M. Schlumbohm, M. N. Riaz, M. B. Farnell, A. Upadhyay, A. J. Davis, D. J. Donoghue. Dry-extrusion of Asian Carp, a Sustainable Source of Natural Methionine for Organic Poultry Production. 20th International Conference on Sustainable Livestock Production Systems. (ICSLPS 2018). Phuket, Thailand. March 22- 23, 2018. 3. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Upadhyaya, I., K. Arsi, B. R. Wagle, S. Shrestha, A. Upadhyay, A. M. Donoghue, C. N. Coon, M. Schlumbohm, J. Trushenski, C. M. Hanning, M. N. Riaz, M. B. Farnell, A. J. Davis, A. C. Fanatico and D. J. Donoghue. Dry-extrusion of Asian Carp to Supplement Natural Methionine in Organic Poultry Production. Poult. Sci. 97(E-Suppl. 1). San Antonio, Texas. July 23-26, 2018. 4. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Donoghue, A. M., The triathlon for success: Integrating research, outreach, and stakeholders to support poultry producers. PSA 2018. Poult. Sci. 97(E-Suppl. 1). San Antonio, Texas. July 23-26, 2018. 5. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Upadhyaya, I., K. Arsi, A. M. Donoghue, C. N. Coon, A. Upadhyay and D. J. Donoghue. 2018. Evaluating the Potential of Dry Extruded Meal from Asian Carp, an Invasive Fish species, as a Natural and Sustainable Source of Methionine for Organic Poultry Production. 6th International Conference on Sustainable Development. Rome, Italy. September 12-13, 2018. 6. Type: Journal Articles Status: Published Year Published: 2018 Citation: Fanatico, A. C., K. Arsi, I. Upadhyaya, J. Morales Ramos, D. Donoghue, and A. M. Donoghue. 2018. Sustainable Fish and Invertebrate Meals for Methionine and Protein Feeds in Organic Poultry Production, The Journal of Applied Poultry Research. 27(4):437-448. 7. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Arsi, K., A. M. Donoghue and D. J. Donoghue. 2019. Invasive Asian Carp Fish species, a Natural and Sustainable Source of Methionine for Organic Poultry Production. 21st International Conference on Poultry Diseases and Nutritional Strategies (ICPDNS 2019). January 17-18, Bangkok, Thailand. 8. Type: Other Status: Published Year Published: 2019 Citation: Fanatico, A.C. 2019. Black Soldier Fly Production for Ecological Poultry Feed: On-Farm Production. eXtension <https://learn.extension.org/events/3629>. Mar. 22, 2019. 9. Type: Other Status: Other Year Published: 2019 Citation: Fanatico, A.C., J. Ferrell, and S. Blume. 2019. Community Garden Development for Teaching, Research, and Outreach. Apr. 17, 2019. Appalachian State University, Boone, NC. 10. Type: Other Status: Other Year Published: 2019 Citation: Fanatico, A.C. Alternative Feeds for Poultry. Podcast for National Center for Appropriate Technology. <https://attra.ncat.org/alternative-feed-for-poultry/> Jun 26, 2019. 11. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Fanatico, A.C. 2019. Black Soldier Fly Larvae for Ecological Poultry Feed: On-Farm Production. July 15-18, Montréal, Canada, Poult. Sci. 98(E-Suppl. 1). 12. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Upadhyaya, I., K. Arsi, B. Wagle, S. Shrestha, A. Upadhyay, D. J. Donoghue, C. N. Coon, C. Owens-Hanning, B. Mallman, J. Caldas-Cueva, A. Fanatico, and A. M. Donoghue. 2019. Bigheaded Carp-based fishmeal as a potential methionine source for organic poultry: Effect on meat quality characteristics in market age broilers. July 15-18, Montréal, Canada, Poult. Sci. 98(E-Suppl. 1). 13. Type: Journal Articles Status: Published Year Published: 2019 Citation: Upadhyaya, I., K. Arsi, A. Fanatico, B. R. Wagle, S. Shrestha, A. Upadhyay, C. N. Coon, M. Schlumbohm, J. Trushenski, C. Owens-Hanning, M. N. Riaz, M. B. Farnell, D. J. Donoghue and A. M. Donoghue. 2019. Bigheaded Carp-based Meal as a Protein Feed in Ecological and Organic Poultry Production. The Journal of Applied Poultry Research. 28(4)1131-1142. <<https://doi.org/10.3382/japr/pfz077>>. 14. Type: Journal Articles Status: Other Year Published: 2019 Citation: Upadhyaya, I., K. Arsi, B. Wagle, S. Shrestha, A. Upadhyay, C. N. Coon, M. Schlumbohm, C. Owens-Hanning, B. Mallman, J. Caldas-Cueva, J. Trushenski, M. N. Riaz, M. B. Farnell, A. J. Davis, A. Fanatico, D. J. Donoghue, A. M. Donoghue. Effect of Bigheaded Carp-based meal as a natural methionine source on broiler meat quality characteristics. Under internal review for submission to Journal of Applied Poultry Research. 15. Type: Journal Articles Status: Other Year Published: 2019 Citation: Upadhyaya, I., B. Wagle, S. Shrestha, K. Arsi, A. Upadhyay, D. J. Donoghue, C. N. Coon, M. Schlumbohm, T. Spencer, C. Owens-Hanning, M. Acharya, B. Mallman, J. Trushenski, M. N. Riaz, M. B. Farnell, A. M. Donoghue. Bigheaded Carp-based fishmeal to Supplement Natural Methionine in Organic Layer Production. Manuscript under preparation for submission to Journal of Applied Poultry research. # Impact of feeding bigheaded carp fish meal on meat quality and sensory attributes in organic broiler chickens Author links open overlay panel , , , , , , , , , , <<https://doi.org/10.1016/j.japr.2021.100224>>Get rights and content{.underline} Under a Creative Commons license{.underline}(<http://creativecommons.org/licenses/by-nc-nd/4.0/>) open access ## SUMMARY Novel protein feeds are needed in ecological and organic poultry production to supply natural sources of amino acids,

particularly methionine. Synthetic amino acids are increasingly banned in certified organic production. Carp is an invasive fish in the United States and its harvest can help provide natural source of methionine, while reducing an undesirable population. In our previous study, we formulated a diet using extruded carp-based meal (\*\*CBM\*\*) to replace synthetic methionine in broiler diets and conducted a feeding trial to test its effect on broiler performance. For this study, birds were processed at the end of the feeding trial and evaluated for quality and sensory attributes of meat from birds fed with CBM diet. Controls were normal diet that contained methionine and the carp meal was used to replace methionine and a portion of soybean meal. Results suggest that birds fed with CBM diet did not differ from the Control in live weight, carcass weight, breast weight, ready-to-cook yield, wing yield, tenders, and thigh yields (\*P\* > 0.05). Breast meat was more light (L<sup>\*</sup>) for birds from the CBM treatment compared to the Control and the pH was lower (\*P\* < 0.05). For the thigh meat, birds fed CBM diets resulted in higher protein and less fat compared to the Control (\*P\* < 0.05). In the consumer analysis, overall impression, flavor, and mouthfeel were lower for the CBM breast meat than the Control and scored lower in terms of tenderness and juiciness (\*P\* < 0.05). Interestingly, thigh meat from CBM had more omega-3 fatty acids, which has a human health benefit. The results indicate that carp-based meal hold potential as a novel protein to replace synthetic methionine in organic broiler diets.

2016/09 TO 2017/08 What was accomplished under these goals? Our initial strategy was to use rendered fish meal from Asian Carp for our studies. However, since initiation of our project the sources of this product has been delayed. As a rendered product causes noxious odors, we rethought the use of this method of fishmeal production and devised a novel dry extrusion method instead. Although this is a completely new process for producing fishmeal, small extruders are becoming affordable and will limit the odor/short shelf life associated with rendering. Small batches of Asian Carp fishmeal were made using Insta Pro Jr. (600) with new collaborators at the Texas A&M University. Since the carp is a large fish, it was ground to a small size for dry extrusion. The extruder used friction and pressure to reach a high temperature (100 C) for cooking. Carp is high in moisture (70%) and was therefore mixed 50:50 with a dry ingredient (soybean meal) in order to reduce moisture content to 35%. The Asian Carp fishmeal was further dried to 10% moisture to reduce microbial growth and form a product to replace soybean meal. This change in strategy has delayed our live bird feeding trials, however if successful we believe this will be an efficient and practical application for fishmeal production and will increase the potential for utilization of the fishmeal product. Objective 1: Evaluate organically suitable preservatives for Asian Carp derived fishmeal utilizing tocopherol compounds and development of broiler ration formulations that optimize methionine levels: Study 1: Test the oxidative stability of a natural, alternate preservative: Naturox, an antioxidant blend of natural ingredients including vegetable oil, tocopherols, lecithin, and rosemary extract was tested with the Asian Carp fishmeal. It was added at 2% during manufacture of Asian Carp fishmeal for preservation and to extend shelf life to 6 months. Tests were conducted for moisture, protein, ash and lipid content. In addition, oxidative stability was tested for 6 months of storage. Results of the shelf life experiment indicated that the antioxidant stabilizer was effective in protecting significant oxidative damage for up to four months when Asian carp meal was stored at room temperature. A manuscript discussing this study is currently under preparation. Study 2: Determine the digestible amino acids and total metabolizable energy (TMEn) for Asian Carp Fishmeal: The Asian Carp fishmeal was analyzed for its digestible amino acid content and TMEn. Briefly, a colony of cecectomized Bovans White Roosters was used. Adult roosters (48 weeks of age) were fasted for 30 h and tube fed 35 grams of 3 treatments: (1) extruded Asian Carp fishmeal, (2) soybean meal and (3) corn. Excreta from each individual bird was collected for the next 48 h. An additional 10 un-fed roosters served as endogenous controls. The gross energy and protein content of the feces from the treatments were determined to calculate the TMEn. Fecal samples and treatment feeds were analyzed for amino acid content and percent digestible amino acid. Results from the analysis suggested that addition of Asian carp increased the methionine content of SBM from 0.63 to 0.83%. Also, the digestibility of amino acid and the TMEn values were greater for the AC meal with SBM than SBM alone. A manuscript discussing this study is currently under preparation. An abstract was submitted to present this study at the 20th International Conference on Sustainable Livestock Production Systems; Phuket, Thailand. Study 3: Develop rations with nutrient profiles suitable for organic poultry production: We developed 24 starter and grower diets using Asian Carp fishmeal using BRILL 2.0 Software for optimum nutritional formulation. A series of diets were formulated using Cobb 500 nutritional specifications with acceptable protein and energy requirements and minimum concentrations of essential amino acids per 1000 kcal AMEn. We were able to develop a balanced Starter and Grower diet for the birds using Asian Carp fishmeal. Currently a study evaluating the growth parameters, feed efficiency and meat quality of birds fed with a diet containing Asian Carp fishmeal is in progress. \*\*PUBLICATIONS (not previously reported):\*\* 2016/09 TO 2017/08 1. Type: Websites Status: Awaiting Publication Year Published: 2017 Citation: Fanatico et al., 2017, Potential protein/methionine sources for ecological organic poultry production: Exploring sustainable fishmeal and invertebrate protein feeds as future resources. eOrganic. 2. Type: Conference Papers and Presentations Status: Accepted Year Published: 2017 Citation: Upadhyaya et al., 2018. Dry extrusion of Asian Carp to supplement

natural methionine in organic poultry production. Accepted for presentation in ICSLPS 2018, 20TH International Conference on Sustainable Livestock production Systems.

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# Assessing the Resiliency of Integrated Crop-livestock Organic Systems Under Current and Predicted Climate

Accession No.	1007105
Project No.	MONB00128
Agency	NIFA MONB\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2015-51106-23970
Proposal No.	2015-06281
Start Date	01 SEP 2015
Term Date	31 AUG 2018
Grant Amount	\$499,990
Grant Year	2015
Investigator(s)	Menalled, F.

## NON-TECHNICAL SUMMARY

**Organic** production has become a major agricultural, economic, and cultural force. However, in the face of unprecedented climate change and market demand, **organic** producers in water-limited environments need to increase the resiliency of their enterprise to secure their long-term environmental and economic sustainability. Based on inputs from stakeholders, we developed **organic** systems that replace tillage with targeted sheep grazing. While successful to terminate cover crops, manage pests, and improve nutrient cycling; can this integration enhance the long-term resiliency of the **organic** enterprise while mitigating the emission of anthropogenic greenhouse gases? This research/education/extension project combines experimental plot studies with on-farm research to increase our knowledge-base on the biophysical and economic short- and long-term challenges facing integrated **crop-livestock organic** systems in water-limited environments. We will 1) compare agronomic performance, greenhouse gas emissions, and weed-pathogen interactions between **organic**-tilled and **organic**-grazed systems, 2) model the long-term consequences of these interactions under current and predicted climate scenarios, and 3) evaluate approaches to improve perennial weed management, a major concern expressed by our advisory group. We will develop educational resources on **organic** practices to engage students in system thinking and critical evaluation. Our transformative extension activities will enhance producers' ability to make informed management decisions about integrated **crop-livestock organic** systems. An external evaluator will assess our research, education, and outreach achievements. By addressing two general NIFA-ORG priorities and three Specific Priority Areas for FY 2015, this project will help new and existing **organic** growers in water-limited regions balance short-term economic and environmental constraints with long-term challenges.

## OBJECTIVES

This research/education/extension project combines experimental plot studies with on-farm research to increase our knowledge-base on the biophysical and economic short- and long-term challenges facing integrated **crop-livestock organic** systems in water-limited environments. We will 1) compare agronomic performance, greenhouse gas emissions, and weed-pathogen interactions between **organic**-tilled and **organic**-grazed systems, 2) model the long-term consequences of these interactions under current and predicted climate scenarios, and 3) evaluate approaches to improve perennial weed management, a major concern expressed by our advisory group. Our specific objectives include Research objectives Address the potential for integration of

**livestock** into diversified **organic crop** production systems to reduce tillage intensity and mitigate GHG emissions. 2i. Evaluate how critical ecological interactions between pathogens and weeds that increase the vulnerability of **organic** production are modified by management systems and environmental variables; and 2ii. Model how, under different climate scenarios, critical ecological interactions impact the long-term sustainability of **organic** systems. 3i. Assess the long-term effects of livestock integration on agricultural production, and 3ii. Develop enterprise budgets to assess economic trade-offs and impacts of integrating sheep and crop production in water-limited environments. Evaluate approaches to manage perennial weeds in **organic** small-grain production. Education and extension objectives Develop training opportunities and educational resources on sustainable **organic** practices to engage undergraduate and graduate students in system thinking and critical evaluation. Design and disseminate transformative extension activities to enhance **organic** producers' ability to make informed decisions on integrated **crop-livestock** production systems. Evaluation objective Adopt a systematic approach to evaluate the success and adjust protocol of research, educational, and outreach activities. By addressing two general NIFA-ORG priorities and three Specific Priority Areas for FY 2015, this project will help new and existing **organic** growers in water-limited regions balance short-term economic and environmental constraints with long-term challenges.

## APPROACH

This research, education, and extension project will be conducted at two research farms (Ft. Ellis, Corvallis), one horticultural farm (Townes Harvest), and on eight certified-**organic** farms. Collectively, these sites provide a range of environments, management practices, and socio-economic contexts. Specific research approaches are as follows: 1) To address the potential for integration of **livestock** into diversified **organic crop** production systems to reduce tillage intensity and mitigate GHG emissions we will measure soil emissions of N<sub>2</sub>O, CO<sub>2</sub>, and CH<sub>4</sub> following USDA-ARS GRACEnet protocols using vented chambers (0.50-m long, 0.20-m wide, 0.15-m high). Greenhouse gas concentrations will be determined using a gas chromatograph equipped with 63Ni electron capture, flame-ionization, and thermal conductivity detectors. Soil moisture content (0-10 cm depth) and soil (5 cm depth) and air temperature will be monitored continuously site using soil dielectric constant probes ECHO NRC weather stations. 2) We will evaluate the interactions occurring among three species that, while occurring at different trophic levels, are major threats to the sustainability of small grain systems: Wheat streak mosaic virus (WSMV), its vector (the wheat curl mite, WCM, *Aceria tosichella*), and a preferred host (cheatgrass, *Bromus tectorum*). To do this, we will use 1.4 m bottom diameter open-top chambers (OTC) which raise yearly mean temperature by 1.6 C and rain out shelters which reduce precipitation by 50%. Temperature will be recorded continuously using i-button data loggers (Maxim Integrated). Soil moisture will be recorded twice weekly via Delmhorst GB-1 gypsum sensor blocks and a KS-D1 digital soil moisture tester (Delmhorst Instrument Co). Soil N samples will be obtained in all plots prior to seeding. We will measure yield, *B. tectorum* biomass and seed production, and WCM population growth. WSMV infection will be evaluated in the laboratory through enzyme-linked immunosorbent assay (ELISA). Disease severity will be evaluated based on wheat yield losses. Yield and biomass data will be compared across treatments and systems with non-linear mixed effects models. WSMV incidence will be compared with a GLM model for binomial data. The information gathered in this field study will be used to 3) Model how, under different climate scenarios, critical ecological interactions impact the long-term sustainability of **organic** systems. 4) As part of our long-term assessment of the impact of **livestock-crop** integration, we will continue assessing weed pressure and sample crop production. Weeds and cover crops production will be determined by clipping biomass at two 0.5-m<sup>2</sup> areas within each plot, separating by species, and weighing. Samples will be oven-dried at 55°C and ground to 1 mm for determination of C and N concentrations by a high induction furnace C and N analyzer. Carbon and N removal in crops and C and N in crop residue returned to the soil in each year will be determined by multiplying crop or biomass yields by their respective C and N concentrations. Visual appraisals of species regrowth and mean plant counts will be conducted after each grazing event. By combining data obtained since 2013 with the information gathered in this research, we will produce 5) long-term enterprise budgets, a straightforward and intuitive interpretation of economic costs and benefits. The analysis will include input costs and revenues associated with current **organic** production of crops, evaluated in the short- and long-run. We will consider both observed (e.g., total price paid for an input and outputs) and unobserved factors affecting costs and revenues (e.g., foregone marketing opportunities due to a particular production choice). 6) To address specific concerns expressed by our stakeholders on the spread and impact of *Convolvulus arvensis* (field bindweed), one of the biggest threats to the production of **organic** small-grains we will evaluate approaches to manage perennial weeds in **organic** small-grain production. The study will combine manipulative experiments conducted at an MSU research farm with on-farm studies. At the MSU research farms, treatments to manage field bindweed will include a combination of a biocontrol agent (*Aceria malherbae*, bindweed gall mite), crops (spring wheat, kamut -khorasan wheat, pea, flax (*Linum usitatissimum*), safflower, and oat (*Avena sativa*), and seeding density (recommended, 1.5 recommended) treatments, plus a no-crop control. The following year, this field will be seeded with winter wheat

at 430 plants m<sup>-2</sup> in all plots (except control). On-Farm Sites: in collaboration our stakeholders, we will establish experiments on eight commercial **organic** farms located to measure *C. arvensis* - crop competition. Farmers will select areas of fields, with different crops when possible, which are infested with *C. arvensis*, will establish the bio-control agent in half of the infested patches and monitor their development.7) Our education objectives will develop training opportunities and educational resources on sustainable **organic** practices to engage undergraduate and graduate students in system thinking and critical evaluation. We will incorporate results of our research into classrooms at various levels to provide experimental learning and critical thinking that combines systemic and systematic reasoning, an essential strategy to develop educational curricula in sustainable agriculture.8) We will Design and disseminate transformative extension activities to enhance **organic** producers' ability make informed management decisions on integrated **crop-livestock** production systems. Extension activities will be conducted during years two and three of this project in collaborations with the Montana **Organic** Association, the Montana Farmers Union, the Montana Woolgrowers Association, and NRCS (see Letters of Support). We expect to directly reach an audience of approximately 4,000 growers and agricultural professionals through our local and regional outreach meetings.9) Finally, an external evaluator will assess the achievement of the research, educational, and outreach objectives. Adjust research, education and extension methods as needed. The evaluation will adopt a systematic approach to assess the achievement of our objectives. Data collected from monitoring and evaluation activities will be analyzed using qualitative and quantitative methods and findings will be communicated to the leadership of the project in a timely and frequent manner (formative) and at the end of each year/cycle (summative). Formative assessments will allow a permanent revision and enhancement of the project activities to effectively reach the project's objectives. Evaluation activities will be framed by two models: one focusing on the multidisciplinary nature of the project, and the other focusing on its outreach component. The first model is based on organizational theory, while the second addresses outcomes of agricultural extension programs including: 1) dissemination of technology focused on the production of staple food crops; 2) development of human capital in relation to technical and management skills needed to increase farm income; 3) building social capital; and 4) education about sustainable systemic management of natural resources.

## PROGRESS

2015/09 TO 2019/08 Target Audience: Our targeted audience included organic farmers and ranchers as well as agricultural professionals, researchers, and extension agents interested in organic dryland agriculture. Our educational activities targeted farmers and extension agents, undergraduate and graduate students, and research associates with interest in sustainable and organic agriculture, with a special emphasis on the integration of crop and livestock operations. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Over the course of this research, the outcomes were presented in the following courses: ENSC410/LRES 510. Biodiversity Survey and Monitoring. MSU AGSC 428/LRES 529 Sustainable Cropping Systems. ANRN 222. Livestock in Sustainable Systems. MSU LRES 110. Introduction to Land Resources and Environmental Sciences. MSU AG SC 342- Forages Undergraduate students. The following undergraduate students were directly trained during the course of this project: Claire Dittmore, Meagan Key, Toby Leppicello, Mellissa Marlen, Uriel Menalled, Jeanna Ratcliff, and Brody Wallace Graduated students: Romero, C. 2018. Cycling and storage of reactive soil carbon and nitrogen pools: management implications for semiarid crop production. Ph.D. dissertation. Montana State University Adhikari, S. 2018. Impacts of dryland farming systems on biodiversity, plant-insect interactions, and ecosystem services. Ph.D. dissertation. Montana State University Nixon, M. In Preparation (targeted defense: December 2018). Effects of *Bromus tectorum* on wheat growth and yield under contrasting climate scenarios. MS thesis. Montana State University Research technicians: Devon Ragen, Jeff Holmes, Rosie Wallander Post-doctoral associate: Bree Cummings, Timothy Seipel, and Suzanne Ishaq. How have the results been disseminated to communities of interest? During the length of this project, we offered a total of 58 extension presentations, directly reaching close to 3400 participants. These presentations were offered in the context of field days, producers meetings, and extension/outreach workshops in Montana and Wyoming. In these talks, we discussed the potential advantages and shortcomings of using livestock in an organic cropping system. Topics discussed included agronomic and soil challenges of organic production, weed management, and impact and mitigation of climate change, among other topics. At the international level, results were presented at the 2016 Aapresid Meeting in Rosario, Argentina (400 attendants). Partial results were showcased in the eOrganic Webinar Targeted Sheep Grazing in Organic Systems on October 11, 2016 (<https://www.youtube.com/watch?v=5OssfAuwWhyA>) and the video MSU organic farming study finds diverse benefits (<https://www.youtube.com/watch?v=Y5w25UgWMTs>). As on August 13, 2019 these videos were viewed 450 times and 2,212 times, respectively. As part of our program to train teacher in organic and sustainable agriculture, we produced the article Science in action: Biological and ecological principles of urban agriculture to be published in Designing urban agriculture programs to improve STEM learning and teaching. Patchen et al. eds. Springer and gave an invited presentation on this topic at the 2016 National

Association Research in Science Teaching meeting. We published the Extension Bulletin: Bauer, B., S.C. McKenzie, F. Menalled, J. Mangold, G. Pederson, and N. Silverman. 2016. Climate Science 101 for Montana. Montguide. Montana State University Extension MT201614AG. Nov. 2016 (available on line at <http://msuextension.org/publications/AgandNaturalResources/mt201614AG.pdf>) Between 2016 and 2019, results of our research were disseminated via the following mass-media channels: Belgrade News new article "Organic agriculture topic of field day discussion" <http://www.belgrade-news.com/news/agriculture/organic-agriculture-topic-of-field-day-discussion/article/83c9302c-4555-11e7-ab84-8348e45ae5d4.html> MSU New release "MSU Extension offers new MontGuide on climate science in Montana" (<http://www.montana.edu/news/16559/msu-extension-offers-new-montguide-on-climate-science-in-montana>) Bozeman Chronicle news article "Tester says climate change impacting farmers and ranchers" <http://www.bozemandailychronicle.com/news/environment/tester-says-climate-change-impacting-farmers-and-ranchers/article/f948abf2-fcb1-5aa8-a446-3c9655cb2190.html> Pivot news article "Fort Ellis Field Day" <http://www.pivotandgrow.com/blog/event/fort-ellis-farm-field-day/> An alternative view to weeds (In Spanish). Agro TV, Argentina. <https://www.youtube.com/watch?v=1dePr2UbMfg> An alternative view to weed management (In Spanish). Aapresid. <https://www.youtube.com/watch?v=-RyuWGStQv8> Western Farmer Stockman news article "Montana guide offers climate insight" <http://www.westernfarmerstockman.com/weather/montana-guide-offers-climate-insight> Montana Farmer Union news release "Montana Farmers Union & Montana State University to hold climate change event in Lewistown" <https://montanafarmersunion.com/montana-farmers-union-montana-state-university-to-hold-climate-change-event-in-lewistown/> Great Falls Tribune news article "Ag leaders discuss climate change in Great Falls" <http://www.greatfallstribune.com/story/news/local/2015/06/19/ag-leaders-discuss-climate-change-great-falls/29016161/> The Furrow news article "Who's warming up?" <https://www.johndeerefurrow.com/2016/03/27/whos-warming-up/> What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

2016/09 TO 2017/08 Target Audience: The targeted audience of our research, extension activities includes farmers, ranchers, agricultural professionals, and extension agents with interest in dryland sustainable organic agriculture. Our education activities targeted undergraduate and graduate students, and research associates interested in sustainable agriculture, animal production, and organic cropping systems. Changes/Problems: To minimize the risk of wheat streak mosaic virus (WSMV) infection in the whole experimental site, we performed a mechanical inoculation instead of a biological one. Greenhouse trials were conducted to evaluate the rate of plant WSMV transmission via the Wheat Curl Mite. What opportunities for training and professional development has the project provided? Several undergraduate and graduate students, research technicians and post-doctoral associates collaborated in this project. Undergraduate students: Ali Thornton, Marco Huot, Laura Ippolito, Genna Shaia, Nathan Kerzner, Karl Owen, Clare Dittermore. Michaela O'Donohue, Emma Bode, and Melissa Marlen. Graduated students: Adhikari, S. In Preparation (targeted defense: October 2017). Impacts of dryland farming systems on biodiversity, plant-insect interactions, and ecosystem services. Ph.D. dissertation. Montana State University Nixon, M. In Preparation (targeted defense: December 2017). Effects of *Bromus tectorum* on wheat growth and yield under contrasting climate scenarios. MS thesis. Montana State University Research technicians: Devon Ragen, Jeff Holmes, Rosie Wallander Post-doctoral associate: Bree Cummings, Timothy Seipel, and Suzanne Ishaq. How have the results been disseminated to communities of interest? Delivery to community of interests. Between 2016 and 2017, Drs. Menalled, Miller, Carr, and Glunk offered a total of 33 extension presentations, directly reaching 1859 participants. These presentations were offered in the context of field days, producers meetings, and extension/outreach workshops in Montana and Wyoming. In these talks, data was presented which showed the potential of using livestock in an organic cropping system, agronomic and soil challenges of organic production, weed management, and impact and mitigation of climate change, among other topics. At the international level, results were presented at the 2016 Aapresid Meeting in Rosario, Argentina (400 attendants). Results were showcased in the eOrganic Webinar Targeted Sheep Grazing in Organic Systems on October 11, 2016 (<https://www.youtube.com/watch?v=5OssfAuwHyA>). As on August 23, 2017 these webinars were viewed 820 and 264 times, respectively. We produced the video MSU organic farming study finds diverse benefits (<https://www.youtube.com/watch?v=Y5w25UgWMTs>), with 1,751 views as August 23, 2017. As part of our program to train teacher in organic and sustainable agriculture, we produced the article Science in action: Biological and ecological principles of urban agriculture to be published in Designing urban agriculture programs to improve STEM learning and teaching. Patchen et al. eds. Springer and gave an invited presentation on this topic at the 2016 National Association Research in Science Teaching meeting. We published the Extension Bulletin: Between 2016 and 2017, results of our research were disseminated via the following mass-media channels: Belgrade News new article "Organic agriculture topic of field day discussion" <http://www.belgrade-news.com/news/agriculture/organic-agriculture-topic-of-field-day-discussion/article/83c9302c-4555-11e7-ab84-8348e45ae5d4.html> MSU New release "MSU Extension offers new MontGuide on climate science in Montana" (<http://www.montana.edu/news/16559/msu-extension-offers-new-montguide-on-climate-science-in-montana>) Bozeman Chronicle news article "Tester says climate change impacting farmers and ranchers"

<http://www.bozemandailychronicle.com/news/environment/tester-says-climate-change-impacting-farmers-and-ranchers/article-f948abf2-fcb1-5aa8-a446-3c9655cb2190.html> Pivot news article "Fort Ellis Field Day"  
<http://www.pivotandgrow.com/blog/event/fort-ellis-farm-field-day/> An alternative view to weeds (In Spanish). Agro TV, Argentina. <https://www.youtube.com/watch?v=1dePr2UbMfg>. An alternative view to weed management (In Spanish). Aapresid. <https://www.youtube.com/watch?v=-RyuWGStQv8> Western Farmer Stockman news article "Montana guide offers climate insight" <http://www.westernfarmerstockman.com/weather/montana-guide-offers-climate-insight> Montana Farmer Union news release "Montana Farmers Union & Montana State University to hold climate change event in Lewistown" <https://montanafarmersunion.com/montana-farmers-union-montana-state-university-to-hold-climate-change-event-in-lewistown/> Great Falls Tribune news article "Ag leaders discuss climate change in Great Falls" <http://www.greatfallstribune.com/story/news/local/2015/06/19/ag-leaders-discuss-climate-change-great-falls/29016161/> The Furrow news article "Who's warming up?" <https://www.johndeerefurrow.com/2016/03/27/whos-warming-up/> What do you plan to do during the next reporting period to accomplish the goals? Our goal is to complete the data analysis and finish the development of the model to assess the vulnerability of organic crop production under contrasting management and climate scenarios

2015/09 TO 2016/08 Target Audience: Our targeted audience includes farmers, ranchers, agricultural professionals, and extension agents with interest in dryland sustainable organic agriculture. We also target undergraduate and graduate students, research professionals, and elementary and secondary rural schoolteachers interested in sustainable agriculture, animal production, and organic cropping systems. Changes/Problems: To minimize the chances of Wheat Curl Mite and Wheat Streak Mosaic Virus spread in our research plots, we conducted a mechanical inoculation. All other proposed activities were conducted as planned and we foresee no major changes during the next reporting period. What opportunities for training and professional development has the project provided? Several undergraduate and graduate students, research technicians and post-doctoral associates collaborated in this project. Undergraduate students: Ali Thornton, Rachel Sullivan, Kyla Crisp, Lazaro Vinola <!-- --> Master level students: Madison Nixon, Tessa Scott Research technicians: Devon Ragen, Jeff Holmes Post-doctoral associates: Timothy Seipel, and Suzanne Ishaq How have the results been disseminated to communities of interest? Farmers/ranchers: Between October 2015 and August 2016, we presented our research in nine extension/outreach talks, for a total of 370 participants. We plan to present our results at two eOrganic webinars and we are preparing one outreach publication (see item 6. Design and disseminate transformative..., above) Students / Research Associates: Our research has been used in several undergraduate and graduate courses and our research framework has been to train four undergraduate students, two MS students, two Research technicians, and two Post-doctoral associates (see item 5. Develop training opportunities and educational resources..., above) What do you plan to do during the next reporting period to accomplish the goals? We plan to continue our field and greenhouse studies on 1) the impact of predicted climate scenarios in tilled and grazed organic systems and 2) approaches to manage perennial weeds in organic cropping systems. We will analyze the data and present results among communities of interests by presenting our results in professional and growers meetings and by developing and delivering education and outreach opportunities on organic agriculture and re-integration of sheep grazing into dryland farming systems.

## IMPACT

2015/09 TO 2019/08 What was accomplished under these goals? The main goal of this study was to determine solutions to the short- and long-term biophysical and economic challenges facing integrated crop-livestock organic systems in water-limited environments. To achieve this goal, we compared three management systems: 1) conventionally tilled organic (O-CT), 2) reduced tillage/grazed organic (O-RTG), and conventionally managed chemical no-till (NT). All systems followed the same rotation: safflower - sweet clover - winter wheat - lentil - winter wheat. Agronomic integration of crop and livestock production Tillage reduction was accomplished by using sheep to graze the cover crop and for weed control after cover crop termination and post-harvest. A continuous 36-month period of no-tillage management occurred in O-RTG, from the planting of safflower to spring tillage preparation for lentil. Weed management became a key challenge, with the following observations: a) Weed density increased in the O-RTG system, with Canada thistle particularly problematic b) The lentil phase resulted in the greatest proliferation of Canada thistle c) Harvest chaff rows became particularly weedy in all systems, but especially organic From 2015-17, lentil yields for the O-CT were equal or greater than the NT system, but were reduced in the O-RTG system. During the last three years of the study, lentil yields 37% less in the O-RTG system, compared with the O-CT system. Over the same three year-period, winter wheat yields averaged 90 bu/ac in the NT system, 81 bu/ac in the O-CT system, and 54 bu/ac in the in the O-RTG system. Winter wheat protein content generally did not differ between the organic systems, but levels were low (10.5%)

compared with the NT system (12.2%). Safflower yields and wheat grain protein levels did not differ between organic systems, but were reduced compared with the NT system. Sweet clover cover crop biomass was greatest in the O-CT system, due in part to overwinter and early spring rodent damage in the O-RT and NT systems. Organic production and climate variability Winter wheat yields and weed communities were compared across organic systems and climate conditions (ambient, increased temperature, and increased temperature and reduced moisture). In ambient conditions, wheat yields was higher in the O-CT (5.1 t/ha) than the O-RTG system (3.1 t/ha;  $P < 0.001$ ). Wheat yield was negatively impacted by hotter and drier climate condition ( $P = 0.02$ ). Weed biomass and number of weed species was highest in the O-RTG (14.4 g and 4.4 species per plot). Climate did not influence the number of weed species ( $P = 0.96$ ), but impacted seed production. Weed communities varied with farming system ( $P = 0.001$ ,  $R^2 = 0.28$ ), but not in response to climate conditions ( $P = 0.77$ ,  $R^2 = 0.02$ ).

Greenhouse Gas (GHG) emissions in organic management systems Soil emissions of  $N_2O$ ,  $CO_2$ , and  $CH_4$  were measured using vented chambers between early spring and fall, with sampling intensity varying in response to soil wetness. Sampling occurred by filling channel anchors with water and covering them with lids. Aliquots of air were collected 0, 20, and 40 min following placement of the lid and transferred to pre-evacuated 13-mL septum-capped Exetainers. Concentrations of GHG were determined using a gas chromatograph equipped with  $63Ni$  electron capture, flame-ionization, and thermal conductivity detectors. Periods of elevated GHG emissions were linked to precipitation events and soil moisture, tillage, and fertilizer applications (including sheep feces and urine). The intensity of soil  $N_2O$  emissions was modest ( $< 1$  g  $N_2O-N$  ha $^{-2}$  d $^{-1}$ ) and cumulative  $N_2O$  production levels under the three cropping systems did not exceed 1.0 kg  $N_2O-N$  ha $^{-1}$  in any one season. Cropping systems had a nominal effect on  $N_2O$  production during brief periods of the year when soils were wet from rains, and following fertilizer N application events in the NT systems or tillage. Soil emissions of  $CO_2$  were strongly related to soil moisture content. During wet periods or following precipitation,  $CO_2$  emission by soil microbes elevated (5 to 10 kg  $CO_2-C$  ha $^{-1}$  d $^{-1}$ ). Cumulative  $CO_2$  emissions was greater ( $P < 0.05$ ) for the O-RTG (759 g  $CO_2-C$  m $^{-2}$  y $^{-1}$ ) than the O-CT (479 g  $CO_2-C$  m $^{-2}$  y $^{-1}$ ) and NT systems (521 g  $CO_2-C$  m $^{-2}$  y $^{-1}$ ). Soils behaved as modest sinks for  $CH_4$  under all three cropping systems averaging 0 to 1.2 g  $CH_4$  d $^{-1}$  and system did not affect cumulative  $CH_4$  consumption. Overall, the global warming potential (in  $CO_2$  equivalents) of the O-RTG (988 g  $CO_2e$  m $^{-2}$  y $^{-1}$ ) was slightly greater ( $P < 0.06$  level) than the O-CT system (629 g  $CO_2e$  m $^{-2}$  y $^{-1}$ ), but similar to NT system (767 g  $CO_2e$  m $^{-2}$  y $^{-1}$ ). Introduction of sheep for targeted grazing of organic systems may result in brief episodes of elevated  $N_2O$  and  $CO_2$ , but has a nominal effect on cumulative production of GHG. Long-term impact of climate conditions on weed pathogen Interactions. We developed a susceptible-infected compartmental model of wheat streak mosaic virus (WSMV) disease spread in winter wheat. The model incorporates competition of *Bromus tectorum* (cheatgrass) with winter wheat as well as the impact of climate change. Field data were used to empirically model the impact of *B. tectorum* populations under the three climate scenarios described above. Hot conditions were favorable for increased winter wheat yield but hot/dry conditions were predicted to be detrimental when *B. tectorum* populations were less than 100 plants m $^{-2}$ . The impact of the *B. tectorum* population was predicted to be the dominating factor in wheat yield loss at or above 100 *B. tectorum* plants m $^{-2}$ . In Montana, disease loss is estimated to be 30% per plant infected in the fall and 15% per plant infected in the spring. With this disease loss parameter, climate and *B. tectorum* competition almost entirely determined wheat yield, with WSMV contributing comparatively little to yield loss. In a field with a population of 10 *B. tectorum* plants m $^{-2}$  and 100 volunteer wheat plants m $^{-2}$  (i.e., a large disease reservoir), the yield loss was comparable to climate change with a disease loss parameter of 55% for fall infection. Overall, results indicate that as long as farmers practice weed control and if biomass loss due to WSMV infection is below 50% per infected plant in heavy volunteer wheat years, climate change is predicted to be the dominating factor in wheat yield. Perennial weeds management We conducted meta-analyses of the existing literature to identify management approaches for field bindweed and Canada thistle in organic systems. Mechanical control accounted for 40% of data extracted, but did not outperform most of the other management actions. Integrated management emerged as the management technique that caused the greatest decrease in abundance and survival for field bindweed. Additional management techniques that decreased field bindweed and/or Canada thistle included biocontrol, mowing, grazing, crop diversification, solarization, shading, flaming, and crop competition. However, most of the studies reported impacts over short time spans and only 16% of field bindweed and 26% of *C. thistle* studies reported measures of variability. Integrating poultry into organic vegetable rotations Poultry plus cover crop was compared to a cover crop treatment. The poultry system (stocking rate of 30 birds in a 10 ft $^2$ ) was efficient to manage cover crops and weeds with chickens removing most vegetation, but allowing the cover to regrow. By the time the pens returned in 14 days, the cover crop had regrown to a height of  $\sim 20$ -30 cm. Very little weed seed production was observed in the poultry treatments, while it was common in the control. The cover crop + poultry treatment had higher subsequent fertility. In the following spring, total fall planted cover crop biomass in the cover crop + poultry system averaged 7400 kg/ha, over twice that seen in the cover crop alone (3500 kg/ha). Weed biomass was similar among treatments. \*\*PUBLICATIONS (not previously reported):\*\* 2015/09 TO 2019/08 1. Type: Journal Articles Status: Published Year Published: 2019 Citation: Adhikari, S., A. Adhikari, D. K. Weaver, A. Bekkerman, F. Menalled. 2019. Impacts agricultural management systems on biodiversity and ecosystem services in highly

simplified landscapes. *Sustainability* 11, 3223; DOI 10.3390/su11113223. 2. Type: Journal Articles Status: Published Year Published: 2019 Citation: Seipel, T., S. Ishaq, and F. Menalled. 2019. Agroecosystem resilience is modified by management system and climate conditions via plant soil feedbacks. *Basic and Applied Ecology* 39:1-9. 3. Type: Book Chapters Status: Published Year Published: 2019 Citation: Briar, S.S., P.M. Carr, G.G. Gramig, F.D. Menalled, and P.R. Miller. 2019. Current status and soil biology impacts of organic conservation tillage in the U.S. Great Plains. p. 11-23. In C. Sarath Chandran, S. Thomas, and M.R. Unni (ed.) *Organic Farming: New Advances Towards Sustainable Agricultural Systems*, Springer International Publishing AG. ISBN 978-3-030-04656-9. 4. Type: Journal Articles Status: Published Year Published: 2018 Citation: Adhikari, S and F. Menalled. 2018. Impacts of dryland farm management systems on weed and ground beetle (*Carabidae*) communities in the Northern Great Plains. *Sustainability* 2018, 10, 2146; doi:10.3390/su10072146. 5. Type: Journal Articles Status: Published Year Published: 2018 Citation: Davis, S. J. Mangold, F. Menalled, N. Orloff, and E. Lehnhoff. 2018. A Meta-Analysis of *Convolvulus arvensis* (field bindweed) management in annual and perennial systems. *Weed Science* 66:540-547 6. Type: Journal Articles Status: Published Year Published: 2018 Citation: Davis, S., J. Mangold, F. Menalled, N. Orloff, and Z. Miller, and Erik Lehnhoff. 2018. A meta-analysis of Canada thistle (*Cirsium arvense*) management. *Weed Science* 548-557. 7. Type: Journal Articles Status: Submitted Year Published: 2019 Citation: Ishaq, S., T. Seipel, C. Yeoman, and F. Menalled. Submitted. Rhizosphere bacterial communities of wheat vary across the growing season and among dryland farming systems. *Geoderma*. 8. Type: Journal Articles Status: Submitted Year Published: 2019 Citation: Menalled, U., T. Seipel, and F. Menalled. Submitted. Farming system and crop rotation effects on biologically mediated plant-soil feedbacks. *Renewable Agriculture and Food Systems* 9. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Larson, C., Menalled, F., Seipel, T. F. 2019. The effect of management system on weed communities during a transition to organic farming. 72nd Meeting of the Western Society of Weed Science. Denver CO. March 12, 2019. 10. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Menalled, U., T. Seipel, and F. Menalled. 2019. Understanding the interaction of crop management system and crop Identity on biologically-mediated plant-soil feedbacks. The Northeastern Plant, Pest, and Soil Conference. January 8-10, 2019. Huntley Valley, MD. 11. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Engel, R. and R. Wallander. 2018. Soil emission of N<sub>2</sub>O under organic tilled, organic grazed reduced-till and chemical no-till cropping systems. *Proc. Great Plains Soil Fertility Conference*. Denver, CO March 6-7, 2018. 17:235-241. 12. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Seipel, T., S. Ishaq, and F. Menalled. 2018. The effect of climate conditions on weed competition and wheat yields in the Northern Great Plains. 2018 Western Society of Weed Science Annual Meeting. March 12-15, 2018. Garden Grove, CA. 13. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Miller, P.R., A. Bekkerman, P. Hatfield, F. Menalled, R. Walker, L. Ward, C. Zabinski, E.C. Glunk, and S. Tallman. Integrated crop livestock research in Montana: Challenges and challenges. \abstract\ ASA-CSSA-SSSA Annual Meeting, Oct 22-25, 2017, Tampa, FL (Invited) PROGRESS: 2017/09 TO 2018/08 Target Audience: Our targeted audience included organic farmers and ranchers as well as agricultural professionals, researchers, and extension agents interested in organic dryland agriculture. Our educational activities targeted undergraduate and graduate students and research associated interested in sustainable and organic agriculture with a special emphasis on the integration of crop and livestock operations. Changes/Problems:As explained in a previous report, to minimize the risk of wheat streak mosaic virus (WSMV) infection in the whole experimental site, we performed a mechanical inoculation instead of a biological one. Greenhouse trails were conducted to evaluate the rate of plant-plant WSMV infection via the Wheat Curl Mite. To increase our inferential space, we supplemented the field data with observations obtained at an additional site located 15 km from the original site What opportunities for training and professional development has the project provided?The research outcomes were presented in the following courses: ENSC410/LRES 510. Biodiversity Survey and Monitoring. MSU AGSC 428/ LRES 529 Sustainable Cropping Systems. ANRN 222. Livestock in Sustainable Systems. MSU LRES 110. Introduction to Land Resources and Environmental Sciences. MSU AG SC 342- Forage Undergraduate students: Mellissa Marlen, Uriel Menalled, Jeanna Ratcliff, Claire Dittmore Graduated students: Adhikari, S. 2018. Impacts of dryland farming systems on biodiversity, plant-insect interactions, and ecosystem services. Ph.D. dissertation. Montana State University Nixon, M. In Preparation (targeted defense: December 2018). Effects of *Bromus tectorum* on wheat growth and yield under contrasting climate scenarios. MS thesis. Montana State University Research technicians: Devon Ragen, Jeff Holmes, Rosie Wallander Post-doctoral associate: Bree Cummings, Timothy Seipel, and Suzanne Ishaq How have the results been disseminated to communities of interest?During this reporting period, Drs. F. Menalled, Z. Miller, P. Carr, R. Engel, and P. Miller offered a total of 16 extension presentations, directly reaching 1020. Since the initiation of this project, we offered a total of 49 extension presentations, directly reaching 2879 participants. These presentations were offered in the context of field days, producers meetings, and extension/outreach workshops in Montana and Wyoming. In these talks, we discussed the potential advantages and shortcomings of using livestock in an organic cropping system. Topics discussed included agronomic and soil challenges of organic production, weed management, and impact and mitigation of climate change, among

other topics. What do you plan to do during the next reporting period to accomplish the goals? Our goal is to finalize the predictive model of winter wheat yield under stresses due to climate, weeds, and wheat streak mosaic virus. We expect to submit two to three peer-reviewed publications within the next reporting period and prepare the final report. IMPACT: 2017/09 TO 2018/08 What was accomplished under these goals? In water-limited environments, organic crop production is highly challenged by environmental, biological, and economic stressors. Recently, there has been increased interest in the integrating crop and livestock operations to reduce tillage intensity and increase system diversification. We compared greenhouse gas emissions, agronomic performance, weed and disease challenges between organic-tilled and organic-grazed systems. We are using data gathered in field conditions to model the long-term consequences of these management systems under current and predicted climate scenarios. Greenhouse Gas (GHG) emissions We evaluated the impact of integrating sheep grazing into organic cropping systems on GHG (N<sub>2</sub>O, CH<sub>4</sub>, and CO<sub>2</sub>) soil emissions. Soil emissions were measured between early spring and fall over three seasons (2016, 2017, and 2018) utilizing vented chambers. Aliquots of air inside the chamber were collected and concentrations of GHG were determined using a gas chromatograph equipped with <sup>63</sup>Ni electron capture, flame-ionization, and thermal conductivity detectors. Soil emissions of GHG were episodic and variable across the site. Periods of elevated GHG emissions were linked to precipitation events and soil moisture, tillage, and fertilizer (including sheep feces and urine). In general, the intensity of soil N<sub>2</sub>O emissions was modest (< 10 g N<sub>2</sub>O-N ha<sup>-2</sup> d<sup>-1</sup>) and cumulative N<sub>2</sub>O production levels did not exceed 0.9 kg N<sub>2</sub>O-N ha<sup>-1</sup> in any one season. Cropping systems had only a nominal effect on N<sub>2</sub>O production during brief periods of the year when soils were wet, and following tillage events (organic till system). CO<sub>2</sub> emissions were strongly related to soil moisture content. During wet periods, CO<sub>2</sub> emission activity by soil microbes becomes elevated (5 to 15 kg CO<sub>2</sub> ha<sup>-1</sup> d<sup>-1</sup>) but was not affected by cropping system practice. Overall, soils behaved as modest sinks for CH<sub>4</sub> under all cropping systems averaging 0 to 1.2 g CH<sub>4</sub> d<sup>-1</sup> over much of the three growing seasons. Cropping system did not significantly affect cumulative CH<sub>4</sub> consumption. In summary, introduction of sheep for targeted grazing of organic systems may result in brief episodes of elevated N<sub>2</sub>O production, but generally has a nominal effect on cumulative N<sub>2</sub>O production as well as CH<sub>4</sub> and CO<sub>2</sub>. Organic production and climate variability Winter wheat yields and weed communities were compared across organic systems and climate conditions (ambient, increased temperature, and increased temperature and reduced moisture). Under ambient conditions, winter wheat yields was higher in the tilled systems (5.1 t/ha) than the grazed system (3.1 t/ha; P<0.001). Also, wheat yield was negatively impacted by hotter and drier climate condition (P=0.02). Weed biomass and number of weed species was highest in the grazed-organic system (14.4 g and 4.4 species per plot) than the tilled-organic system (3.8 g and 1.5 species per plot). Climate did not influence the number of weed species (P=0.96) or biomass (P=0.87) but impacted seed production. Weed communities varied with farming system (P=0.001, R<sup>2</sup>=0.28), but not in response to climate conditions (P=0.77, R<sup>2</sup>=0.02). Using field data, we are constructing a predictive model of winter wheat yield under stresses due to climate, weeds, and wheat streak mosaic virus (WSMV). The model is based on a system of ordinary differential equations that describe the yearly spread of WSMV, winter wheat density, volunteer wheat density, and *Bromus tectorum* density. Multi-year simulations and sensitivity analysis are underway. Preliminary results indicate that winter wheat yield is dominated by combined climate and weed effects, and is much less impacted by WSMV which will either remain endemic over a multi-year period or will naturally extinguish. The primary parameter dominating this process is the wheat-wheat transmission, indicating that control of volunteer wheat and mite movement are promising strategies for controlling the disease., whereas *B. tectorum* control has little effect on disease spread. Agronomic integration of crop and livestock production The chief result of the first 5-yr rotational cycle shows a significant yield gap between organic grazed and tilled organic systems. In 2017, winter wheat yielded 15-23% (8-15 bu/ac) less in the reduced tillage system, and lentil yielded 33% less (460 lb/ac). Winter wheat protein content did not differ between the organic systems, but levels were low (10-11%). Safflower yields, nor sweet clover biomass, differed between these systems. Most worrisome is the rapid advancement of *Cirsium arvense*, Canada thistle, a game-stopper for organic producers in Montana, often requiring conversion of annually cropped systems to perennial forage to achieve control. Disease pressure Wheat and lentil whole plant samples were collected to assess disease pressure across systems. Wheat was sampled at tiller, flag, and maturity. Lentil was sampled when the sixth multifoliate leaf had unfolded, at the sixth node, and at full bloom. Foliar diseases were scored and diseased samples were placed into a humid chamber. Hyphal growth was transferred to potato dextrose agar, and to selective media if required, for morphological and molecular identification. Disease scores were converted to whole plant disease incidence and disease severity. For wheat, foliar diseases included tan spot, powdery mildew, and stripe rust. Root rots included rhizoctonia, pythium, common root rot, and fusarium. Disease incidence was low in all lentil plots at both sampling times. Perennial weeds management This study was done with funds in part provided by our OREI grant 2012-02244. Field bindweed rhizomes were planted in 1m<sup>2</sup> plots at 0, 4, 12, and 32 fragments plot<sup>-1</sup> and ten cropping treatments were imposed. In the fall of 2016, plots were planted to winter wheat. In spring 2017, bindweed abundance and spread was measured. Winter wheat and safflower halted increases in bindweed patch growth and fruit production. Tilled fallow management led to a 10x increase in the number of bindweed shoots. We conducted meta-analyses of the existing literature to identify

promising management approaches for field bindweed and Canada thistle in organic systems. Mechanical control accounted for 40% of data extracted, but did not outperform most of the other management actions. Integrated management emerged as the management technique that caused the greatest decrease in abundance and survival for field bindweed. Additional management techniques that decreased field bindweed and/or Canada thistle included biocontrol, mowing, grazing, crop diversification, solarization, shading, flaming, and crop competition. However, most of the studies reported impacts over short time spans and only 16% of field bindweed and 26% of Canada thistle studies reported measures of variability. Integrating poultry into organic vegetable rotations In this study, poultry plus cover crop was compared to a cover crop treatment. Our preliminary results indicate that the poultry system (stocking rate of 30 birds in a 10 x 10 ft. chicken tractor) is efficient to manage cover crops and weeds. In one day, chickens grazed the plants, removing most vegetation, but allowed the cover to regrow. By the time the pens returned in 14 days, the cover had regrown to a height of ~20-30 cm. As a result of grazing, very little weed seed production was observed in the poultry treatments, while it was common in the control. The cover crop + poultry treatment had higher subsequent fertility. In the following spring, total fall planted cover crop biomass in the cover crop + poultry system averaged 7400 kg/ha, over twice that seen in the cover crop alone (mean=3500 kg/ha). Weed biomass was similar among treatments. Effects of vegetable production were measured in the treatments for two years (year1=winter squash, year2= corn). Yields were higher following poultry, but analysis is ongoing. PUBLICATIONS (not previously reported): 2017/09 TO 2018/08 1\ Type: Book Chapters Status: Awaiting Publication Year Published: 2018 Citation: Menalled, F. In Press. Sustainable agriculture and integrated weed management. In Weed Control. Sustainability, Hazards and Risks in Cropping Systems Worldwide. N. E. Korres, N. R Burgos, and S. O. Duke, eds. Science Publishers 2\ Type: Journal Articles Status: Published Year Published: 2018 Citation: Grimberg, B.I., S. Ahmed , C. Elis, Z. Miller, and F. Menalled. 2018. Climate change perceptions and observations of agricultural stakeholders in the Northern Great Plains. Sustainability 2018, 10, 1687; doi:10.3390/su10051687 3\ Type: Journal Articles Status: Published Year Published: 2018 Citation: Ranabhat, N., T. Seipel, E. Lenhoff, Z. Miller, K. Owen, F. Menalled and M. Burrows. 2018. Temperature and alternative hosts influence *Aceria tosichella* infestation and Wheat streak mosaic virus infection. Plant Disease 102:546-551. <https://doi.org/10.1094/PDIS-06-17-0782-RE> 4\ Type: Journal Articles Status: Published Year Published: 2018 Citation: Adhikari, S., T. Seipel,, F. Menalled, and D. Weaver. 2018. Farming system and wheat cultivar affect infestation of and parasitism on *Cephus cinctus* in the Northern Great Plains. Pest Management Science DOI 10.1002/ps.4925 5\ Type: Journal Articles Status: Published Year Published: 2018 Citation: Grimberg, B.I., Burrows, M. and Menalled, F.D. 2018. Plant Virus Classification. Plant Health Instructor. DOI: 10.1094/PHI-K-2017-1129-01 6\ Type: Journal Articles Status: Published Year Published: 2018 Citation: Orloff, N., J. Mangold, Z. Miller, and F. Menalled. 2018. A meta-analysis of field bindweed (*Convolvulus arvensis* L.) and Canada thistle (*Cirsium arvense* L.) management in organic agricultural systems. Agriculture, Ecosystems and Environment 254: 264-272. 7\ Type: Journal Articles Status: Published Year Published: 2017 Citation: Ishaq, S., S. Johnson, Z. Miller, E. Lehnhoff, S. Olivo, C. Yeoman, and F. Menalled. 2017. Impact of cropping systems, soil inoculum, and plant species identity on soil bacterial community structure. Microbial Ecology 73:417-434. 8\ Type: Journal Articles Status: Published Year Published: 2017 Citation: Lehnhoff, E., Z. Miller, P. Miller, S. Johnson, T. Scott, P. Hatfield, and F. Menalled. 2017. Organic agriculture and the quest for the holy grail in water-limited ecosystems: Managing weeds and reducing tillage intensity. Agriculture 7, 33; doi:10.3390/agriculture7040033. 9\ Type: Journal Articles Status: Submitted Year Published: 2018 Citation: Adhikari, S., L. Burkle, K. O'Neill, D. Weaver, C. Delphia, and F. Menalled. Impacts of simplified dryland farming systems on forbs, bees, and bee-flower networks. Submitted to Agriculture, Ecosystems, and the Environment. 10\ Type: Journal Articles Status: Submitted Year Published: 2018 Citation: Adhikari, S., L. Burkle, K. O'Neill, D. Weaver, C. Delphia, and F. Menalled. Dryland organic farming increases floral resources and bumble bee colony success in agriculturally intensive and highly simplified landscapes. Submitted to Agriculture, Ecosystems, and the Environment. 11\ Type: Journal Articles Status: Submitted Year Published: 2018 Citation: S.L. Ishaq, T. Seipel, C.J. Yeoman, F. Menalled. A longitudinal look at wheat-rhizosphere soil bacterial communities in three dryland cropping systems over the course of a season. Submitted to Soil Biology and Biochemistry 12\ Type: Journal Articles Status: Submitted Year Published: 2018 Citation: Cummins, B., T. Seipel, T. Gedeon, M. Burrows, and F. Menalled. In preparation. A predictive model of winter wheat yield under stresses due to climate change, weed competition, and wheat streak mosaic virus. Bulletin of Mathematical Biology 13\ Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Seipel, T., S. Ishaq, and F. Menalled. 2018. The effect of climate conditions on weed competition and wheat yields in the Northern Great Plains. 2018 Western Society of Weed Science Annual Meeting. March 12-15, 2018. Garden Grove, CA. 14\ Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Engel, R. and R. Wallander. 2018. Soil emission of N2O under organic tilled, organic grazed reduced-till and chemical no-till cropping systems. Proc. Great Plains Soil Fertility Conference. Denver, CO March 6-7, 2018. 17:235-241. 15\ Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Menalled U., Seipel T., & Menalled F. (2018) Crop management system and crop identity effects on biologically mediated plant-soil feedbacks. LRES Colloquium Montana State University. April 11th, 2018 16\ Type:

Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Menalled U., Seipel T., & Menalled F. (2018) Crop management system and crop identity effects on biologically mediated plant-soil feedbacks. Undergraduate Scholar Program Research Symposium Montana State University. April 20th, 2018

2016/09 TO 2017/08 What was accomplished under these goals? 1. Organic production and GHG emissions Evaluation of trace soil gas emissions begun in April of the 2016 using a vented, static chamber sampling system. Aliquots of gas from the headspace were collected at 0, 20, and 40 min following placement of the lid onto the chamber anchor. Samples were transferred to pre-evacuated 13-mL septum-capped Exetainers and gas concentrations were determined via a gas chromatograph. Gas fluxes were calculated from the change in concentration within the vented chamber headspace. In 2016, spring N<sub>2</sub>O emission activity from the no-till chemical system was greater than for the organic tilled and organic grazed systems, likely due to the urea fertilizer application to the no-till system. This elevated production was observed within a week following application of the urea-N and persisted for approximately 7 weeks. N<sub>2</sub>O emission activity during the summer was modest for all systems, a common observation in semiarid climates and reflects the drought induced reduction in microbial activity. Finally, N<sub>2</sub>O emission activity in the fall increased in the grazed system, probably because of fecal. 2 Vulnerability of organic production to climate variability We compared winter wheat yields and weed communities across contrasting climate conditions and the three farming systems described above. Climate treatments included ambient, hotter conditions created using open-top chambers that increased temperatures ~2C, and hotter and drier conditions achieved using open-top chambers and rain-out shelters that block ~50% of precipitation. Under ambient conditions, winter wheat yields were similar between the conventional (5.7 t/ha) and tilled-organic systems (5.1 t/ha; P=0.37), and lowest in the grazed system (3.1 t/ha; P<0.001). Wheat yield in the hotter and drier climate condition declined 46% (P=0.02) when compared to the ambient conditions in the conventional system. Wheat yield in the tilled- and the grazed-organic systems remained similar between ambient and hotter and drier conditions (P=0.17 and P=0.14, respectively). Weed biomass and number of weed species was highest in the grazed-organic system (14.4 g and 4.4 species per plot; P=0.08 and P=0.03, respectively), and lowest in the conventional farming system (0.60 g and 0.4 species per plot) and the tilled-organic system (3.8 g and 1.5 species per plot). Climate did not influence the number of weed species (P=0.96) or biomass (P=0.87) but impacted seed production. Weed communities varied with farming system (P=0.001, R<sup>2</sup>=0.28), but not in response to climate conditions (P=0.77, R<sup>2</sup>=0.02). We are modeling the long-term impact of climate change on wheat yield due to the transmission of wheat streak mosaic virus (WSMV) in a mixed population of wheat and cheatgrass. The model incorporates the interactions between the primary host (wheat), the reservoir hosts (cheatgrass, *Bromus tectorum*, and volunteer wheat), WSMV, the timing of the transmissions between hosts, and the effects of climate on the length and/or intensity of these transmission effects. The algorithms have been coded and are awaiting parameter estimates. The model is a set of ordinary differential equations that arise from a compartmental model in epidemiology. Each population (wheat, cheatgrass, and volunteer wheat) is divided into infected and susceptible populations. WSMV is transmitted from an infected individual to a susceptible individual with a probability that is dependent on which populations the individuals come from. In this model, the wheat yield depends on climate conditions, competition with cheatgrass, and the proportion of wheat infected at various times of the year. We are working on the parameterization of the model using field data, lab data, and data from previously published studies. 3. Agronomic and economic integration of crop and livestock production The 2017 harvest of winter wheat and lentil is complete; safflower harvest will occur in October. Yield results from the reduced tillage Organic -Grazed system lagged the conventionally tilled Organic - Till system by 20% in both winter wheat and spring lentil. Grazing value may offset crop yield losses. While it appears that it is not agronomically or economically feasible to attempt a completely no-till organic system with current knowledge and technology, we have achieved a net reduction in the number of tillage events of approximately 50-60%. Economic assessment will be made in fall 2017 now that one full rotational cycle is complete. Grain protein data will be obtained a few weeks from now but it was visually obvious that wheat protein concentration was lower in the organic than in the conventional chemical no-till system. Discounts for low protein in winter wheat are not particularly severe in conventional markets in Montana in August 2017, but wheat grain protein content can be a much more vital valuation factor in organic markets. 4. Perennial weeds management This study was done with funds in part provided by our OREI grant 2012-02244. Our field study evaluated crops, crop sequences, and cultural methods to suppress field bindweed. In 2015, rhizomes were planted in 1m<sup>2</sup> plots at 0, 4, 12, and 32 fragments plot<sup>-1</sup> and ten cropping treatments were imposed. In the fall of 2016, plots were planted to winter wheat. In spring 2017, bindweed abundance and spread was measured. Winter wheat and safflower halted increases in bindweed patch growth and fruit production. Tilled fallow management led to a 10x increase in the number of bindweed shoots. We conducted meta-analyses of the existing literature to identify promising management approaches for field bindweed and Canada thistle in the absence of synthetic herbicides and determine aspects of management warrant further study. Mechanical control was the most studied management technique, accounting for 40% of data extracted, but did not outperform most of the other management actions. Integrated management emerged as the management technique that caused the greatest

decrease in abundance and survival for field bindweed. Additional management techniques that decreased field bindweed and/or Canada thistle included biocontrol, mowing, grazing, crop diversification, solarization, shading, flaming, and crop competition. However, most of the studies reported impacts over short time spans, with 53% being conducted for one to two years, and only 9% conducted for five or more years. Further, only 16% of field bindweed and 26% of Canada thistle studies reported measures of variability.

6. Training opportunities and educational resources on sustainable organic practices The research outcomes were presented in the following courses: ENSC410/LRES 510. Biodiversity Survey and Monitoring. MSU AGSC 428/ LRES 529 Sustainable Cropping Systems. T ANRN 222. Livestock in Sustainable Systems. MSU LRES 110. Introduction to Land Resources and Environmental Sciences. MSU AG SC 342- Forages Ten undergraduate students, two graduate students, and three post-doctoral research associates participated in different components of this project.

5. Evaluation A survey was conducted at the end of the field day at our study site focused on: 1) integration of crop-livestock, 2) weed management, 3) beneficial insects, 4) soil quality and greenhouse emissions, 5) climate change impact on agricultural production, and 6) economic overview of integrated systems. The field day was attended by about 60 people including producers, extension agents, students, and researchers, and 29 completed the survey. Results showed that participants increased the understanding by 3.44/4.00 for beneficial insects, and 3.15/4.00 for assessing climate change impact and soil quality. 79% of attendees strongly agreed or agree to apply the information obtained in the field day, 96% find the information of the field day relevant and will recommend it to their colleagues. Weed management and crop rotation were the most relevant topics, and greenhouse gases the least useful.

**\*\*PUBLICATIONS (not previously reported):\*\***

- 2016/09 TO 2017/08 1. Type: Journal Articles Status: Published Year Published: 2017 Citation: Menalled, F., R. K. Peterson, R. G. Smith, W. S. Curran, D. J. Perez, Menalled, F., R. K. Peterson, R. G. Smith, W. S. Curran, D. J. Perez, and B. D. Maxwell. 2016. The eco-evolutionary imperative: revisiting weed management in the midst of a herbicide resistance crisis. *Sustainability* 8(12), 1297; doi:10.3390/su8121297
2. Type: Journal Articles Status: Published Year Published: 2017 Citation: Carr, P.M., S. Briar, G. Gramig, F. Menalled, and P. Miller. 2016. Current status and future outlook of organic conservation tillage in the U.S. Great Plains Region. International seminar on emerging trends in organic farming and sustainable agriculture. Dec. 29-31, 2016. Mahatma Gandhi University, Kottayam, Kerala, India.
3. Type: Conference Papers and Presentations Status: Published Year Published: 2016 Citation: S. Adhikari, L.A. Burkle, K.M. O'Neill, D.K. Weaver, A.J. Hansen, A. Adhikari, and F.D. Menalled. 2016. Effects of agricultural management systems on natural habitat distribution in the Northern Great Plains: Implications for pollinators. 101st Ecological Society of America meeting. Aug 7-12, 2016. Fort Lauderdale, FL.
4. Type: Conference Papers and Presentations Status: Published Year Published: 2016 Citation: Ishaq, S.L., S.P. Johnson, Z.J. Miller, E.A. Lehnhoff, S.K. Olivo, C.J. Yeoman, and F.D. Menalled. 2016. Farming systems modify the impact of inoculum on soil microbial diversity. American Society for Microbiology meeting. June 16-20, 2016. Boston, MA.
5. Type: Conference Papers and Presentations Status: Published Year Published: 2016 Citation: Grimberg, B.I. and F. Menalled. 2016. Science in action: Biological and ecological principles of urban agriculture. Environmental Education Symposium - Urban Agriculture: An Untapped Context for STEM Learning. 2016 NARST Annual International Conference. April 14-17. Baltimore, MD. USA
6. Type: Conference Papers and Presentations Status: Published Year Published: 2016 Citation: Menalled, F.D. 2016. Weeds: there are other management strategies beyond herbicides. XXIV Argentinean Association of Direct Seeding Producers (Aapresid) Congress. August 3-5, 2016. Rosario, Argentina. (available on line at <https://www.youtube.com/watch?v=-RyuWGStQv8>. In Spanish)
7. Type: Conference Papers and Presentations Status: Published Year Published: 2016 Citation: Menalled, F.D. 2016. For every complex (agricultural) problem, there is an answer that is clear, simple, and wrong. Institute of the Ecosystem Rough Cut Series. October 19, 2016. Montana State University, Bozeman, MT.
8. Type: Journal Articles Status: Accepted Year Published: 2018 Citation: Orloff, N., J. Mangold, Z. Miller, and F. Menalled. Accepted with minor revisions. A meta-analysis of field bindweed (*Convolvulus arvensis* L.) and Canada thistle (*Cirsium arvense* L.) management in organic agricultural systems. *Agriculture, Ecosystems and Environment*.
9. Type: Book Chapters Status: Accepted Year Published: 2018 Citation: Menalled, F. In Press. Sustainable agriculture and integrated weed management. In *Weed Control. Sustainability, Hazards and Risks in Cropping Systems Worldwide*. N. E. Korres, N. R Burgos, and S. O. Duke, eds. Science Publishers.
10. Type: Journal Articles Status: Published Year Published: 2017 Citation: Lehnhoff, E., Z. Miller, P. Miller, S. Johnson, T. Scott, P. Hatfield, and F. Menalled. 2017. Organic agriculture and the quest for the holy grail in water-limited ecosystems: Managing weeds and reducing tillage intensity. *Agriculture* 7, 33; doi:10.3390/agriculture7040033.
11. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Seipel, T., S. Ishaq, and F. D. Menalled. 2017. Impact of predicted climate scenarios and cropping systems on crop yield and weed communities. Ecological Annual Society of America Annual Meeting. August 6-11. Portland, OR.
12. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Ishaq, S.L., T. Seipel, A.M. Thornton, and F. D. Menalled. 2017. Soil bacterial diversity in response to stress from farming system, climate change, weed diversity, and wheat streak virus. Ecological Annual Society of America Annual Meeting. August 6-11. Portland, OR.
13. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Orloff, N. F. Menalled, and J. Mangold. 2017. A

meta-analysis of field bindweed (*Convolvulus arvensis*) and Canada thistle (*Cirsium arvense*) management in organic agricultural systems. Western Society of Weed Science Annual Meeting. March 13-16. Coeur D'Alene, ID. 14. Type: Book Chapters Status: Awaiting Publication Year Published: 2018 Citation: Grimberg, B. and F. Menalled. In Press. Science in action: Biological and ecological principles of urban agriculture. In Designing urban agriculture programs to improve STEM learning and teaching. Patchen, A. Barnett, M. Esthers, L., and Knobloch, N., eds. Springer. 15. Type: Journal Articles Status: Published Year Published: 2017 Citation: Carr, P.M. 2017. Guest editorial: conservation tillage for organic farming. Online. Agriculture 7(3), 21; doi:10.3390/agriculture7030021 16. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Orloff, N., J. Mangold, F. Menalled, and Z. Miller. 2016. A meta-analysis of Canada thistle (*Cirsium arvense*) management in organic perennial systems. 4th Conference of the Northern Rockies Invasive Plant Council. October 19, 2016. Boise ID. 17. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Seipel, T., S. Ishaq, and F. D. Menalled. 2017. Impact of management systems and predicted climate scenarios on weed communities. Western Society of Weed Science Annual Meeting. March 13-16. Coeur D'Alene, ID. 18. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2017 Citation: Menalled F, T. Seipel, and S. Ishaq. 2017. Agroecology, resilience, and climate change: a perspective from the semiarid agroecosystems of North America. Havana, Cuba. 19. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Grimberg, B., F. Menalled, S. Ahmed, E. Colter, and Z. Miller. 2017. Agricultural professionals' perceptions about climate change. Western Society of Weed Science 36th Annual Meeting. March 13-16, 2017. Coeur d'Alene, ID 20. Type: Other Status: Published Year Published: 2017 Citation: Bauer, B., S.C. McKenzie, F. Menalled, J. Mangold, G. Pederson, and N. Silverman. 2016. Climate Science 101 for Montana. Montguide. Montana State University Extension MT201614AG. Nov. 2016 (available on line at <http://msuextension.org/publications/AgandNaturalResources/mt201614AG.pdf>.)

2015/09 TO 2016/08 What was accomplished under these goals? 1. Potential for integration of livestock into organic systems to reduce tillage intensity and mitigate GHG emissions. Measurements of trace soil gas emissions of N<sub>2</sub>O, CH<sub>4</sub>, and CO<sub>2</sub> begun in April of the 2016 using a static chamber sampling system. The work is on-going and will be run for another season in 2017. Preliminary analysis of the N<sub>2</sub>O emission over time indicated that the profiles showed greater emission activity from the no-till chemical system (NT) relative to the organic grazed (OG) and organic tilled (OT) systems. These results were likely a result of the chemical inputs of urea fertilizer applied to NT system as chemical inputs of fertilizer N are known to result in production of N<sub>2</sub>O due to nitrifier-denitrification. The elevation of N<sub>2</sub>O emission activity persisted for approximately 7 weeks after N fertilizations, which is consistent with our previous understanding of fertilizer-induced emissions. 2i. Evaluate how critical ecological interactions are modified by management systems and environmental variables. At wheat phase of the three cropping systems (NT, OG and OT), we establish three climate treatments (ambient temperature/ambient precipitation, increased temperature/ambient precipitation, and increased temperature/decreased precipitation), two plant treatments (wheat monoculture, and wheat/*B. tectorum* biculture), and two disease treatments (with or without Wheat Streak Mosaic Virus, WSMV). To increase temperatures and reduce precipitation we established 1.4 m bottom diameter open-top chambers (OTC) and rain out shelters which reduce precipitation by 50%. Temperature were recorded continuously using i-button data loggers. Soil moisture were recorded twice weekly via Delmhorst GB-1 gypsum sensor blocks. WSMV was mechanically applied on May 4, 2016 using an air compressor and sprayed following established protocols. We monitored weed and soil microbial communities, soil moisture and temperature, and wheat yield and are processing samples. 2ii. Model critical ecological interactions impact the long-term sustainability of organic systems. To complement the field studies described in 2i. we conducted a growth chamber study aimed at assessing Wheat Curl Mite, the vector of WSMV, growth rate under contrasting plant neighborhood conditions (wheat monoculture, *Bromus tectorum* monoculture, and wheat - *B. tectorum* mixture). Preliminary results indicated differences in Wheat Curl Mite (WCM) population growth rate across plant neighborhoods, with larger growth rates in the wheat monoculture, intermediate in the wheat - *B. tectorum* mixture, and lowest in the *B. tectorum* monoculture. The information gathered in 2i and 2ii will be used in year three of this study to model WCM and *B. tectorum* growth under different climate scenarios. 3i. Assess livestock integration on agricultural production. The 2016 harvest of winter wheat and lentil is complete; safflower harvest will occur after this report (October 2016). Yield of the OG system were much more positive than in previous years, due in part to more suitable soil moisture conditions at seeding both in the fall (winter wheat) and spring (lentil). We have evolved a practically competitive reduced tillage Organic- Grazed system that results in ~36 consecutive months of no-till during a 5-yr crop rotation, followed by reduced tillage prior to spring-sown lentil and safflower. While it may not be feasible to attempt a completely no-till organic system with current knowledge and technology, we have achieved a reduction in tillage of ~50-60% with a ~30% yield reduction for lentils and between 0-18% yield reduction for wheat, depending on the rotation state. 3ii. Develop enterprise budgets. The information gathered in 2i, 2ii, and 3i will be used in year three of this study to develop enterprise budgets to assess economic trade-offs and impacts of integrating sheep and crop

production. 4. Management of perennial weeds in organic small-grain production. We completed our studies aimed at assessing management practices that could help minimize the spread and impact of field bindweed (*Convolvulus arvensis*), one of the biggest threats to the production of organic small-grains. We are currently processing the samples and expect to obtain our first preliminary results within the next four months. We are also conducting a systematic review of previous field bindweed and Canada thistle (*Cirsium arvensis*) control and management studies in organic and diversified cropping systems for the Northern Great Plains region. To do that, we conducted topic searches of the Web of Science® (1864-2015) and Agricola® (1970-2015) databases and used a modified meta-analysis framework to analyze the results. We will complete this study within the next twelve months. 5. Develop training opportunities and educational resources. Four undergraduate students, two MS candidates, two research technicians, and Post-doctoral associates collaborated in this project. Our research was presented at these courses: AG SC 342. Dr. Emily Glunk. Forages. Current enrollment: 32 students. ENSC410/LRES 510. Dr. Timothy Seipel. Biodiversity Survey and Monitoring. This undergraduate course utilized the Ft. Ellis field site to assess the impact of management systems on biodiversity. MSU AGSC 428/ LRES 529 Sustainable Cropping Systems. Offered by Dr. P. Miller. Topic included ecologically based weed management and integrated crop - livestock systems. Enrollment: 30 students. ANRN 222. Livestock in Sustainable Systems. Dr. Hatfield revised concepts of sustainable livestock production. Enrollment: 99 students. MSU LRES 110. Introduction to Land Resources and Environmental Sciences. Dr. Menalled provided guests lectures on ecologically based weed management and integrated crop - livestock systems in organic fields. Enrollment: 95 students. Finally, on October 19, 2016 Dr. Menalled will present our results at the Montana Institute on Ecosystems Rough Cut Lecture Series (available on-line at <http://montana.adobeconnect.com/roughcutscience/>)

6. Design and disseminate extension activities. We surveyed our target audience in terms of perceptions, knowledge and attitudes regarding climate change. We are currently analyzing the data. Between October 2015 and August 2016, we presented results obtained from our research in nine extension/outreach talks, for a total of 370 participants. Great Falls, MT. October 23, 2015. Climate change impacts and mitigations in Montana. Farmers Union. 60 participants Bozeman, MT. November 3, 2015. Using sheep to manage sheep and cover crops. NRCS Soil health workshop. 45 participants Bozeman, MT. December 4, 2015. Integration of crops and livestock. Montana Organic Association Annual Meeting. 65 participants Conrad, MT. December 8, 2015. Grazing alfalfa and alternative forages. Wool Pull 19 participants Joliet, MT. March 2, 2016. Cover crops, what can they do for me? 38 participants Bozeman, MT. December 10, 2015. Talking about climate change. MSU-Extension climate science conference. 50 participants Sheridan, MT. February 2, 2016. Using sheep to manage sheep and cover crops. Cover Crop Seminar. 20 participants Helena, MT. February 2, 2016. Using sheep to manage sheep and cover crops. Cover Crop Seminar. 38 participants Bozeman, MT. June 6, 2016. Integration of crops and livestock. Extension Agents update. 35 participants We will present our results in two upcoming eOrganic webinars (integration of sheep grazing and small grain production and perennial weed management in organic systems). Emily Glunk, Perry Miller, and Susan Tallman (NRCS) are preparing the extension publication "Cover crops for shorter growing seasons" to be published at the Progressive Forage Grower. 7. Evaluate the success and adjust protocol of research, educational, and outreach activities. Dr. Grimberg will conduct the first evaluation of our research, educational, and outreach objective on January 2017. \*\*PUBLICATIONS (not previously reported):\*\*

2015/09 TO 2016/08 1. Type: Journal Articles Status: Awaiting Publication Year Published: 2016 Citation: Johnson, S., Z. Miller, P. Miller, E. Lehnhoff, and F. Menalled. In Press. Cropping systems modify soil biota effects on wheat (*Triticum aestivum* L.) growth and competitive ability. Weed Research 2. Type: Journal Articles Status: Accepted Year Published: 2017 Citation: Ishaq, S., S. Johnson, Z. Miller, E. Lehnhoff, S. Olivo, C. Yeoman, and F. Menalled. Accepted with Revisions. Impact of cropping systems, soil inoculum, and plant species identity on soil bacterial community structure. Microbial Ecology 3. Type: Book Chapters Status: Accepted Year Published: 2017 Citation: Grimberg, B. and F. Menalled. In Press. Science in action: Biological and ecological principles of urban agriculture. In Designing urban agriculture programs to improve STEM learning and teaching. Patchen, A. Barnett, M. Esthers, L., and Knobloch, N., eds. Springer 4. Type: Conference Papers and Presentations Status: Published Year Published: 2016 Citation: B.I. Grimberg and F. Menalled. 2019. Science in action: Biological and ecological principles of urban agriculture. 2016 NARST Annual International Conference. April 14-17. Environmental Education Symposium - Urban Agriculture: An Untapped Context for STEM Learning. Baltimore, MD. USA.

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# Quantifying and Predicting the Effects of Ecological Weed Management Strategies on Organic Agroecosystems to Inform Farmer Decision Making

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## NON-TECHNICAL SUMMARY

The **organic** community has largely failed to adopt ecological **weed** management (EWM) strategies despite research touting the benefits to **weed** suppression and the achievement of diverse on-farm objectives. Our prior research indicates that adoption is limited by a farmer's ability to make the complex value-based tradeoffs required when predicting how complex suites of management strategies will perform over time. Our central hypothesis is that adoption of a decision support framework (DSF) that deliberately links performance of EWM strategies to farmer values using the best available science, and employs tools aimed at thoughtfully facilitating tradeoffs, will lower barriers to on-farm experimentation with EWM and result in superior outcomes for **organic** farmers, the environment and society. We plan to develop a software-based DSF that can be used to inform **weed** management decisions, and test the efficacy of the framework with farmers and extension professionals. Our DSF will present the predicted impact of EWM across diverse objectives, and assist farmers in the selection of an optimal suite of EWM strategies for their farm. This is of particular importance given that **weeds** are one of the biggest management challenges in the **organic** agroecosystem, and a barrier to conventional farmers who desire to transition. The expected results of this project are a more informed population of farmers better prepared to assess the tradeoffs required by **weed** management, a population of extension professionals better prepared to engage **organic** farmers about the benefits of EWM, and ultimately greater adoption of EWM strategies over time.

## OBJECTIVES

The primary goal of this project is to produce a decision support framework that employs science-informed and values-based criteria to accurately predict the impact of ecological **weed** management strategies on soil health, resource competition, management costs and farmer quality of life, thus allowing individual farmers to explore outcomes and make thoughtful tradeoffs across a diverse set of farm-based and socially relevant objectives. We will pursue this objective through the following specific research and extension aims. Obj 1: Revise the current structure of the prototype DSF based on feedback from farmers regarding clarity in design, accuracy of the objectives and strategies included, and ease of use of the interface. Obj 2: Improve and expand the

predicted outcome measures in the prototype DSF through one-on-one farmer surveys and focus groups, a meta-analysis of the literature on EWM, and a long-term field experiment examining the interactions between management, seed bank suppression and soil health. Obj 3: Assess the impact of the fully parameterized DSF, through a series of decision quality experiments with farmers. Obj 4: Release the completed DSF, and related training and educational tools to extension professionals, \*\*organic\*\* farmers and those interested in further parameterization or expansion of the framework.

## APPROACH

Methods for Aim 1: Revise the current structure of the prototype decision support framework (DSF) based on one-on-one interviews with farmers regarding clarity in design, accuracy of the objectives and strategies included, and ease of use of the interface. Methods for Aim 2: Improve and expand the predicted outcome measures in the prototype DSF through one-on-one farmer surveys and focus groups, a meta-analysis of the literature on EWM, and a long-term field experiment examining the interactions between management, seed bank suppression and soil health. Methods for Aim 3: Assess the impact of the fully parameterized DSF, through a series of decision quality experiments with farmers. Methods for Aim 4: Release the completed DSF, and related training and educational tools to extension professionals, \*\*organic\*\* farmers and those interested in further parameterization or expansion of the framework through a series of educational workshops and extension and scientific publications. Evaluation will consist of monitoring overall project implementation throughout the duration of the grant period. The evaluator Lekies will work closely with co-PD's and senior personnel to determine if the goals are met in terms of planned activities with farmers and extension professionals, desired numbers of participants, implementation of the field experiment, and outputs such as workshops, the user guide, and other publications. The goal of Aim 1 is the completed revision of the prototype DSF based upon farmer feedback in the first year of the grant period. Examined will be the inclusion of farmers in the process and the overall efficacy of the revision process. The goal of Aim 2 is the completed development of performance measures. Examined will be the inclusion of farmers and expert advisory panel in the process, the number of completed surveys and focus groups, and the completion of meta-analyses in the first two years of the grant period. Additionally, the long-term field experiment will be examined to determine if it has been implemented as planned through discussions with co-PI's and research associates and site observations. The goal of Aim 3 is the completed implementation and field testing of the DSF in the second and third years of the grant period. The number of participants in the experiments, the number of completed focus groups, and overall efficacy of the experiments will be examined. The goal of Aim 4 will include the completion of the user guide/extension publication, as well as the hosting of workshops for farmers and extension professionals. Assessment will include the number of participants, inclusion of targeted participants, and examination of finished materials. Evaluation of the outcomes of project aims on farmers' understanding of EWM, as well as the ability of the DSF to assist farmers with making critical tradeoffs, reducing barriers, and reducing uncertainty related to the use of EWM will be gathered through surveys and focus groups that are designed into the aims of the project. Additionally, the ability of the DSF to help farmers with identifying effective EWM approaches, estimating the impacts of practices, and making values-consistent \*\*weed\*\* management decisions will be examined through implementation and field testing of the DSF; survey and focus group data will be gathered from farmers in experimental assessment of decision quality as described above. The development of performance measures will be assessed through the long-term field experiment designed to examine the interactions between management, seed bank suppression, and soil health. The effectiveness of workshops for farmers and extension professionals will be evaluated through participant observation at workshops and surveys conducted with participants after the workshops. A subset of farmers and extension educators will be asked to provide feedback on the user guide. A report of evaluation findings will be completed at the end of each project year.

## PROGRESS

2015/09 TO 2019/08 Target Audience: The main audience for this phase of the project has been organic grain farmers in the state of Ohio and across the country. Other audiences reached through our partnerships with the Ohio Ecological Food and Farming Association include organic supplement and seed dealers and consultants, and governmental and non-governmental organizations with a policy focus. We also targeted extension personnel in Ohio and throughout the country. In this final year, we focused on dissemination and outreach activities to better reach our target audience with the final products of the project. Changes/Problems: We were unable to hold the planned train-the-trainer workshops in Ohio and Indiana due to a lack of interest among partners for an additional workshop just focused on the DSF. Instead, we focused our attention on developing new educational products that were not originally included in the proposal and disseminating these new products and information about the tool with the intended networks through other means (e.g., existing meetings, listserves,

newsletters, etc). Generally speaking, we found it much harder than expected to disseminate the tool through our planned networks, including University Extension and organic farming organizations. Despite consistently positive feedback from the farmers who helped develop and test the tool, there was great resistance among those who work with farmers to endorse and use the tool. To begin, there are very few people in Extension that explicitly support organic agriculture, which highlights a gap, in particular in portions of the midwestern United States, where supporting organic research and outreach is not a priority. There is not a clear system for supporting organic agriculture, and these networks for dissemination need to be strengthened to ensure that University science can play a role in this space. For those who do directly support organic agriculture, such as our partners at OEFFA, there was resistance to the tool despite endorsement from organic farmers, which perhaps highlights a lack of trust and skepticism toward University science. What opportunities for training and professional development has the project provided? A postdoc was able to train and refine his skills with literature review, analysis and writing of manuscripts. A postdoc was also trained in setting up and implementing organic field trials on a University farm. Undergraduate students learned field and laboratory techniques to sample and analyze soil and plant samples. How have the results been disseminated to communities of interest? A web page on organic weed management was created and added to the OFFER (Organic Food and Farming Education and Research) website (see <<https://offer.osu.edu/research/eco-weed-mngt>>). Several articles, resources, case studies, and fact sheets were created to go along with it, including the decision-making tool and companion articles about decision making in weed control (details on each in products). Articles posted to this website were also directly shared with the nearly 50 subscribers to the website's news items, while the original article about the tool was shared with members of OEFFA and Ohio State educators via their listserv. Future articles are planned on organic weed control, which will refer readers to this web page with additional information and resources about organic weed management. A short video (<https://offer.osu.edu/organic-weed-manager>) and a print info sheet on the tool (<<https://offer.osu.edu/sites/offer/files/imce/Files/DSF%20fact%20sheet%20approved.pdf>>) were created and shared at a booth at: Ohio Produce Growers & Marketers Association Meeting in Columbus, OH (1/2019) Ohio Ecological Food and Farming Association (OEFFA) meeting in Mt. Hope, OH (2/2019) Ohio Ecological Food and Farming Association Annual Conference in Dayton, OH (4/2019) Specialty Crops Roundtable at Ohio Agricultural Research and Development Center (OARDC) in Wooster, OH (2/2019) Farm Science Review in London, OH (9/2019) A package of information was distributed directly to 26 Academic researchers and educators across the United States who work with weed control and organic farming and teach organic and weed control classes. A similar package was sent to 48 county extension agents across Ohio. The package included a cover letter, links to the video and user guide explaining the tool (as well as the tool itself), and links to our organic weed control resource articles which they can use locally. A similar package was sent to 11,000 individuals across 44 states who are in the Maine Organic Farmers and Gardeners Association, the largest state-based organic organization in the U.S. Half of these members classify themselves as either farmers or gardeners, while the other half identify as supporters of MOFGA's mission. The packet of information was also highlighted in the Resources section of the OEFFA newsletter in Fall 2019, which goes out to 5,000 to 7,000 people in all 88 Ohio counties and across 37 states. The majority of the readers are crop and livestock farmers (~60%), while the rest are conscientious eaters, gardeners, buyers and retailers, educators and government and NGO personnel. A feature article in the fall OEFFA newsletter discussed the field trials that were part of this project and the concept of trade-offs in managing weeds. We also presented the tool in a teaching session at the Weed Science Society of America (WSSA) Annual Meeting. There was interest from the attendees in the tool serving an instructional purpose in the college classroom, which is why we shared it with Academics who teach classes where it might be useful (see above). Although it is difficult to evaluate how widespread its use in education might be, the tool is being used as an educational component of an undergraduate classes in Fall 2019 at the University of Maine. We conducted a webinar in early November 2019 that 51 people attended. The webinar was advertised through OEFFA, and the recording as well as a PDF of the slides have been made available on our OFFER website as well as on the OEFFA website (see Products for links). Several articles were written for scientific audiences including an article on the tool's development for Journal of Extension's Ideas at Work (in prep, to be submitted by December 2019), on the decision guide framework for Weed Science (published in 2019) and on the meta-analysis for cover crops (in review at Organic Agriculture). An article will be developed on the field experiments with conclusion of the 2019 field season. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

2017/09 TO 2018/08 Target Audience: The main audience for this phase of the project has been organic grain farmers in the state of Ohio and across the country, organic supplement and seed dealers and consultants, organic farming organizations, as well as OSU extension personnel. We have engaged organic farmers primarily via in-depth on-farm interviews, including facilitated walk-throughs with our decision support tool, and discussion during organic farm tours and workshops attended by organic farmers. We also had a national sample of farmers test the draft online tool. In this final year we are planning several dissemination and outreach activities to better reach our target audience with the final outputs of the project, including farmers and intermediaries in the

extension, outreach and retail side of agriculture. Changes/Problems: The field site where research was carried out is lacking in significant weed pressure. Therefore, many of the management strategies fail to yield reductions of the same marked significance we might observe on a field with a greater initial weed population. We also ran into challenges with the long-term hosting of the online decision support tool, but have developed a plan to host the site through the remainder of the project and will revisit long-term hosting beyond the project end with Ohio State information technology personnel in late Spring 2019. What opportunities for training and professional development has the project provided? A graduate student and two technicians in the OARDC Weed Lab were able to gain valuable experience quantifying weed populations and running seed bank exhaustive germination studies. One technician in the Soil Fertility Lab gained experience soil sampling and running soil health analyses in the lab. These skills will prove helpful for future work on this and other research projects. How have the results been disseminated to communities of interest? The decision-making framework is currently available online and available for public use. Forty-five farmers from across the Midwest used the tool as part of the initial experimental testing. What do you plan to do during the next reporting period to accomplish the goals? We are currently working on an academic manuscript describing the rationale for the framework, its development and results from the online deployment. We are also developing two videos, a short (under 5 minutes) and long (30 minutes) version that will walk prospective users through the tool's design and functions. These videos will be used at upcoming grower meetings. We will also be finalizing a user guide/manual for the decision support framework to pair with the video tutorials. We will present the tool during at least four "train-the-trainer" meetings or events over the winter, as well as conduct a live webinar for the Ohio Ecological Food and Farming Association. Finally we plan to develop a series of extension publications highlighting the decision support framework and online tool, as well as different approaches to weed management. All of these products will be highlighted on multiple websites and distributed to extension offices and extension specialists throughout Indiana and Ohio through multiple listserves. Finally, we hope to target teachers as a new audience who may want to use the tool as an exercise in sustainable agriculture courses. We plan to connect with the Sustainable Ag Teaching Coalition to explore opportunities, and present the tool at the Sustainable Ag National Conference as well as in a teaching session at the Weed Science Society of America. We also hope to connect with beginning farmer/journey person programs (e.g., MOFGA, Practical Farmer IOWA) to explore dissemination opportunities. The literature review of organic crop management effects on weed control and soil health indicators will be completed in early 2019 and the results will be summarized and published in a peer-reviewed journal article. In regards to the field trials, next steps involve continuing the research begun in summer of 2017 with another season of data collection in 2019. Upon completion of the 2019 field season the field trial findings will be formally analyzed and summarized in a publication.

2016/09 TO 2017/08 Target Audience: The main audience for this phase of the project has been organic grain farmers in the state of Ohio and across the country, organic supplement and seed dealers and consultants, organic farming organizations, as well as OSU extension personnel. We have engaged organic farmers primarily via in-depth on-farm interviews, including facilitated walk-throughs with our decision support tool, and discussion during organic farm tours and workshops attended by organic farmers. We now have a national sample of farmers testing the draft online tool. Changes/Problems: The meta-analysis was delayed, but data collection will occur in the winter of 2018. We still plan to complete this objective, but not on the original timeline. The post-doc Doug Bessette accepted at tenure-track position at Michigan State University. Instead of replacing him on the project, we established a small sub-award to MSU to allow him to continue working on the project in his capacity as an Assistant Professor. What opportunities for training and professional development has the project provided? The post-doctoral researcher (Bessette) earned a position as an Assistant Professor (Tenure-Track) at Michigan State University due in large part to his work on this project. In his Job Talk at MSU he presented a summary of the project's intent and design and acknowledged NIFA support. He also presented the project update at the NIFA Project Director's Meeting. Two graduate students are also receiving training as a result of the field trials. How have the results been disseminated to communities of interest? Results have been disseminated to scientific audiences through a new journal article and to organic farmer audiences and interested stakeholders through the draft online tool. The project director also shared the project findings and draft DSF with the Ohio Ecological Food and Farming Association Staff during a brownbag luncheon. What do you plan to do during the next reporting period to accomplish the goals? Next steps for the DSF involve 1) increasing the number and type of farmers who engage with the DSF either via increased recruitment online or face-to-face meetings with Organic Advisory Panel (OAP) members and local farmers (e.g., at the OEFFA annual conference, farm tours and farm visits); 2) analyzing the data collected via the DSF to assess its effectiveness and ease-of-use, and 3) updating the DSF where necessary and incorporating improved measures acquired via the meta-analysis and the long-term field trials. A series of train-the-trainer workshops will then be conducted once the DSF is final, and a user manual developed to ensure it's more widespread use and implementation. In regards to the field trials, next steps involve continuing the research begun in summer of 2017 with another

season of data collection in 2018. The meta-analysis data will also be collected over winter 2018, and analyzed in spring/summer of 2018.

2015/09 TO 2016/08 Target Audience: The main audience for this phase of the project has been organic grain farmers in the state of Ohio, organic supplement and seed dealers and consultants, as well as OSU extension personnel. We have engaged organic farmers primarily via in-depth on-farm interviews, including facilitated walk-throughs with our decision-support tool, and discussion during organic farm tours and workshops attended by organic farmers. The latter include poster presentations at the Ohio Ecological Food & Farm Association (OEFFA) Annual Meeting, and the Organic Food and Farming Education and Research (OFFER) Organic Planning Session. Changes/Problems: Obj. 2 specifies that we would conduct a meta-analysis of the existing literature to try and improve predicted outcome measures. A review of the literature demonstrates a lack of studies examining and comparing outcomes from different organic weed management practices, such as different cover crop rotations or cultivation techniques/timing. While studies exist comparing more generalized organic to conventional production, or specific organic crops in foreign countries, little exists with regard to organic grain or vegetable farming in the U.S. (and more specifically in the U.S. Midwest). This hole in the literature may problematize the meta-analysis portion of Obj. 2. What opportunities for training and professional development has the project provided? The post-doctoral researcher (Besette) assigned to this project has attended numerous organic farm tours, workshops and conferences in an effort to learn more about the organic farming community in the state of Ohio, and how they make weed management decisions. These activities have been critical in ensuring the decision support tool aligns with these farmers' values, current knowledge and weed-management objectives. Additionally, one undergraduate research assistant gained valuable experience in developing and conducting a meta-analysis, as well as learning about organic farming and weed management via attendance at conferences and workshops. How have the results been disseminated to communities of interest? The conceptual design and intent of our decision-support framework has been presented both at the Ohio Ecological Food and Farm Association Annual Conference and the Ohio Food and Farming Education and Research Program Organic Planning Session. As we are still in the development phase with regard to the decision support framework, no results based on collected data or its public deployment have been disseminated. However, all members of our Organic Advisory Panel have argued that their efforts in evaluating the framework have led them to think about weed management differently (and positively). Determining the extent to which they have disseminated new (longer-term, more holistic) ways of thinking to their neighbors and fellow organic farming community remains a goal for the next reporting period. What do you plan to do during the next reporting period to accomplish the goals? In this next period, we will begin a series of decision quality experiments and surveys to assess elements of the decision support framework, in particular the amount and type of information provided and different framings of information (for instance, alternative-focused vs. value-focused frames and primers). We will also incorporate pre- and post-test assessments of farmers' knowledge of ecological weed management strategies to examine the effectiveness of the tool. We will also begin the on-farm field trials, which are intended to improve the predicted outcome measures; however, definitive data regarding these measures will not be available until after the end of the project.

## IMPACT

2015/09 TO 2019/08 What was accomplished under these goals? Objective 1 Revise the current structure of the prototype DSF: Although this work was largely completed, we did further refine the tool in the final year of the project in response to advisory team feedback and an online deployment, removing components that were critical for the initial evaluation of the tool and the decision quality research component, but that made the tool cumbersome for end users. Looking back at our original tasks, we were able to complete both, which were to solicit farmer feedback on the prototype DSF and incorporate that feedback into the prototype, which in fact moved from being a planned excel-based tool to an online app. Obj 2 Improve and expand the predicted outcome measures in the prototype DSF through one-on-one farmer surveys and focus groups, a meta-analysis of the literature on EWM, and a long-term field experiment examining the interactions between management, seed bank suppression and soil health. Looking back at our original tasks in this objective, we were able to complete all of them, including a meta-analysis, field trials (wrapping up this year), and several iterations of feedback on the DSF from farmers and our advisory team. Specifically this past year, we conducted a systematic and comprehensive literature review on the effects of different weed control strategies on weed communities and soil health. Our review confirmed the lack of published studies examining both soil health and weed communities. As a second step, we modified our literature review to examine how cover crops can contribute to both weed control and soil health. Similar to the first review, we found few studies reporting both weed community and soil health parameters. We discussed our literature review findings and identified critical research priorities in an article that

is currently under peer-review in the journal *Organic Agriculture*. A key outcome was a change in knowledge, in particular recognizing that the literature on weed management and soil health is more limited than we expected and thoughtful field trials are needed to fill this gap in the science. We also successfully transitioned 5 acres to organically certified ground. While this was not originally an explicit objective or task in the proposal, this farm did not have any fields under certified organic management before, so there is now increased long-term capacity for organic research at Ohio State. We also implemented an organic trial to examine the tradeoffs between weed control strategies and soil health. The trial is currently in its third year and following harvest in 2019, data on both weed communities and soil health will be analyzed and prepared for a peer-reviewed publication. While a change in knowledge is expected, it is too early to assess this outcome. However, the University and organic agriculture in general gained increased capacity as an organic ag plot was developed as a result of this grant.

Obj 3: Assess the impact of the fully parameterized DSF, through a series of decision quality experiments with farmers. We completed the two asks outlined here, which were to conduct experimental field testing of the parameterized DSF and incorporate additional farmer feedback into the online DSF. The results of the experimental assessment were published in a peer reviewed journal article. The results indicated that the tool was not only successful in educating farmers about different ecological weed management strategies, but also communicating the long-term benefits of EWM, improving farmers' trade-off analysis, and providing a pathway for farmers to investigate and pursue EWM strategies. Results showed the DSF encouraged participants to pursue a more complex seedbank elimination strategy over their current practices, recognizing that strategy's distinct advantage in the long term. Ultimately, when provided an opportunity to deliberate upon and analyze their goals, our DSF showed that farmers identify different goals and pursue better-performing weed management strategies from the ones they rely upon on a day-to-day basis. We had several intended short-term outcomes that could be evaluated through this objective. Specifically, that farmers would be more informed about EWM outcomes, that barriers to use of EWM would be lowered, that farmers would have an increased ability to make tradeoffs, and that uncertainties about EWM outcomes would be reduced. Our initial qualitative and quantitative tests of the DSF indicated that these outcomes were achieved for farmers who used the tool.

Obj 4: Release the completed DSF, and related training and educational tools to extension professionals, organic farmers and those interested in further parameterization or expansion of the framework. We had three original tasks proposed here, to develop a DSF user guide and make it available through University Extension, conduct farmer and "train the trainer" extension workshops, and post the DSF and user guide on multiple public websites. This work is detailed under how the results were disseminated and what products were developed. However, we did release the completed DSF and user guide and developed several related educational products that can be used in combination with the tool. We also disseminated these materials directly to multiple audiences through multiple venues. As reported in our previous annual report, we were unable to hold workshops dedicated to the DSF with our target audience, so we focused on disseminating the tool through other means (including a webinar). While assessing the impact of these products will be an ongoing task, we do have evidence that we have achieved several medium-term outcomes related to this objective, including identification of effective EWM strategies, as several new educational products were developed to better highlight these approaches. It is more difficult to assess if the DSF accurately predicts the impacts of EWM as the meta-analysis revealed few lessons learned from the literature that we could incorporate, and we recognize that the DSF doesn't represent the full complexity of an organic system when it comes to the impacts of different management decisions on soil health, cost, etc. Longer-term, we think the DSF can continue to be improved to more accurately predict impacts as it gathers baseline data from users. We did gain an improved understanding of farmer decision making for ecological weed management, but it is difficult to assess if extension professionals are better prepared to engage farmers as we do not have that feedback from the professionals who received information about the tool. If anything we found that extension professionals and other intermediaries were resistant to using such a tool (details discussed below and in changes/problems to report). While the results from Objective 3 indicate that users of the tool were able to make values consistent weed management decisions and to estimate the impacts of practices, the intermediaries (Extension, OEFFA) that were also a target audience of Objective 4 have been skeptical. We may have a long way to go before decision support tools are accepted as a way of educating audiences, informing decisions etc. Similarly, it was difficult to evaluate our proposed outcome related to integration of University science into on-farm decision making, as the tool was based on scientists opinions about performance of different weed management strategies (the actual science is lacking). It became clear over the course of this project that the credibility gap between organic farmers and Universities is still quite large, and needs to be addressed before University science can be fully integrated into on-farm decision making.

**\*\*PUBLICATIONS (not previously reported):\*\*** 2015/09 TO 2019/08

1. Type: Journal Articles Status: Published Year Published: 2019 Citation: Bessette, D., Wilson, R., Beaudrie, C., & Schroeder, C. (2019). An online decision support tool to evaluate ecological weed management strategies. *Weed Science*, 67(4), 463-473. doi:10.1017/wsc.2019.21
2. Type: Journal Articles Status: Under Review Year Published: 2020 Citation: Can cover crops mitigate the trade-offs between tillage for weed control and soil health in organic systems? In review. *Organic Agriculture*.
3. Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: Doohan, D, D. Bessette, C. Beaudrie, S. Culman, and

R. Wilson. 2019. ♦Helping farmers navigate complex decisions about managing weeds in organic systems♦. Presented in a section on Teaching and Extension at the Weed Science Society of America Annual Meeting. 4. Type: Websites Status: Other Year Published: 2019 Citation: Organic Weed Management. The Ohio State University. <https://offer.osu.edu/research/eco-weed-mngt>. 5. Type: Websites Status: Other Year Published: 2019 Citation: Organic Weed Manager. The Ohio State University. Decision Support Tool <https://organicweedmanager.com/>. 6. Type: Other Status: Published Year Published: 2019 Citation: False seed bed technique extension article. The Ohio State University. <https://offer.osu.edu/blog/june-13-2019-1200am/make-withdrawal-your-soil-weed-seed-bank-stale-seedbed-technique>. 7. Type: Other Status: Published Year Published: 2019 Citation: Decision support tool extension article. The Ohio State University. <https://offer.osu.edu/blog/march-20-2019-1200am/online-tool-examines-organic-strategies-weed-management>. 8. Type: Other Status: Other Year Published: 2019 Citation: Decision Support Tool Webinar. The Ohio State University. 9. Type: Other Status: Published Year Published: 2019 Citation: Giant Ragweed: A Weed of Extremes extension article. The Ohio State University. <<https://offer.osu.edu/blog/september-27-2019-137pm/giant-ragweed-weed-extremes>>.

2017/09 TO 2018/08 What was accomplished under these goals? We deployed the decision support framework online and received 45 completed responses. Those responses demonstrate positive user experiences, self-reported learning, and suggest the decision-analytic tasks included work to improve participants' understanding and decision-making regarding EWM. The framework remains online and is open to the public for use ([www.organicweedmanager.com](http://www.organicweedmanager.com)) We developed our final year dissemination plan with the help of the advisory team and other key stakeholder groups (e.g., Ohio Ecological Food and Farming Association). We also made a few refinements to the online tool to increase its educational value (e.g., highlighting additional resources at the end of the tool). A comprehensive literature review was also undertaken to look at the effects of tillage intensity on weed pressure and carbon sequestration. The literature review efforts are currently being expanded by a newly hired post-doc partially funded on the grant. Peer-reviewed literature is being surveyed to assess the weed control and soil health consequences of organic crop management. Evaluation activities have been on-going and consist of monitoring overall project implementation and achievement of project objectives. Along those lines, in addition to regular sub-team meetings (within the decision support tool and field research teams), we held a full team meeting and an external advisory team meeting in fall 2018 to develop and finalize the dissemination plan for the final year of the project. We received excellent suggestions about broadening our dissemination of the tool into the educational space (undergraduates, 4-H, etc). We continued the long-term field experiment established in spring 2017 at the North Central Agricultural Research Station in Fremont, OH to investigate the effects of tillage for weed management on weed seed bank suppression and soil health, with and without organic matter addition. The field is in the second year of transition to organic. The experimental field measures 300 feet in width x 380 feet in length, and is divided into 20- x 50-foot plots. The cropping system is a corn-soybean-barley rotation, with each crop present each year. The four treatments include a low intensity conventional tillage with and without manure, and a high intensity tillage with and without manure, with 4 replications. This creates 16 plots per crop. As in 2017, soil samples were taken from all plots in February of 2018. Eight random 5/8"-diameter soil cores were taken from the top 8" of the soil profile in each experimental plot, and used in the following processes. A portion of the soil was sieved through an 8-mm sieve to remove stones and break large clods, and then air dried. A subsample was sent to Spectrum Analytic Inc. (Washington Courthouse, OH) for standard soil tests (total nutrients, base saturation, pH, CEC, OM), and another subsample was used to determine soil health indicators (POXC, respiration and soil protein analysis). Another portion of the 2018 soil samples was used to characterize the germinable weed seed bank using the exhaustive greenhouse germination method (Cardina and Sparrow 1996). Soil samples from each plot were sieved as above and spread in 17-cm long x 12.5-cm wide x 5-cm deep plastic cell trays. Trays were placed on a flood table in a 25/20°C (day/night) greenhouse with no artificial lighting, and watered from below as needed by flooding the table. Emerged weed seedlings were periodically identified, counted and removed. After emergence ceased (about 3 months), samples were placed in a 4°C cold room for 8 weeks to break secondary dormancy in any remaining seeds. Beginning fall 2018, soil will then be re-sieved and returned to the greenhouse, the process repeated for a total of three emergence periods in the greenhouse. For the 2017 seed bank samples, the second and third emergence periods were completed as described in fall 2017 through spring 2018 and the data summarized for analysis. We also estimated field weed emergence in each plot during the 2018 growing season by identifying and counting weeds in two 1/2-m x 1/2-m quadrats per plot. Counts were taken before all tillage, planting and cultivation events. Another year of data collection will continue in the next year. Soil nutrient, soil health, weed seed bank, field weed emergence, and yield data will be compared across years. \*\*PUBLICATIONS (not previously reported):\*\* 2017/09 TO 2018/08 Type: Journal Articles Status: Published Year Published: 2018 Citation: D Bessette, S Zwickle, R Wilson. 2018. In the weeds: distinguishing organic farmers who want information about ecological weed management from those who need it. *Renewable Agriculture and Food Systems*, 1-12

2016/09 TO 2017/08 What was accomplished under these goals? Regarding Objectives 1, 3 & 4, we revised and improved the decision support framework (DSF) via multiple iterations with our web development team, eventually deploying the DSF online ([organicweedmanager.com](http://organicweedmanager.com)) for testing with an initial population of 181 organic vegetable and grain farmers in the state of Ohio (still ongoing). The DSF improvements include cutting-edge HTML visualizations, which allow farmers to engage the tradeoffs between their values and the performance of strategies more effortlessly and intuitively. We also developed an evaluation survey for the online tool and are testing the impact of the tool on our farm audience, as well as identifying what types of farmers engage the tool and who specifically benefits from that engagement. Regarding Objective 2, a long-term field experiment was established in spring 2017 at the North Central Agricultural Research Station in Fremont, OH to investigate the interactions among weed management, weed seed bank suppression and soil health. The field is in the first year of transition to organic. The experimental field measures 300 feet in width x 380 feet in length, and is divided into 20- x 50-foot plots. The cropping system is a corn-soybean-barley rotation, with each crop present each year. The four treatments include a low intensity conventional tillage with and without manure, and a high intensity tillage with and without manure, with 4 replications. This creates 16 plots per crop. Soil samples were taken from all plots in February 2017. Eight random 0-8" soil cores (5/8" diameter) were taken from each experimental plot. Soil processing in the lab involved sieving through an 8-mm sieve to remove stones and break large clods, with subsequent air drying. Subsamples were sent to Spectrum Analytic Inc. (Washington Courthouse, OH) for standard soil tests (total nutrients, base saturation, pH, CEC, OM). Soil health indicators (POXC, respiration and soil protein analysis) were conducted on the remaining soil samples. Additional 0-8" soil cores were collected in February 2017 from all plots for determination of the weed seed bank. The germinable seed bank was characterized using the greenhouse germination method (Cardina and Sparrow 1996). The soil samples from each plot were sieved as above and spread in 17-cm long x 12.5-cm wide x 5-cm deep plastic cell trays. Trays were placed on a flood table in a 25/20°C (day/night) greenhouse with no artificial lighting, and watered from below as needed by flooding the table. Emerged weed seedlings were periodically identified, counted and removed. After emergence ceased (about 3 months), samples were placed in a 4°C cold room for 6 weeks to break secondary dormancy in any remaining seeds. Soil will be re-sieved and returned to the greenhouse, the process repeated for a total of three emergence periods in the greenhouse. Field emergence of weeds in each plot during the 2017 growing season was estimated before all tillage, planting or cultivation events, by identifying and counting weeds in two ½-m x ½-m quadrats per plot. Early reproductive leaf tissue samples were collected from soybean and corn plots in August 2017. Tissue samples were dried, ground and sent to Spectrum Analytic Inc. for total tissue nutrient analysis. Evaluation activities have been on-going and consist of monitoring overall project implementation and achievement of project objectives. Along those lines, in addition to regular sub-team meetings (within the decision support tool and field research teams), we held a full team meeting with our external advisory members in May 2017. We presented the draft online decision support tool and received very positive feedback and some suggestions for refinement moving forward. \*\*PUBLICATIONS (not previously reported):\*\* 2016/09 TO 2017/08 Type: Journal Articles Status: Under Review Year Published: 2017 Citation: Bessette D., S. Zwickle, & R.S. Wilson (in review) In the weeds: Distinguishing those organic farmers who want information about ecological weed management from those who need it. *Renewable Agriculture & Food Systems*.

2015/09 TO 2016/08 What was accomplished under these goals? Regarding Obj 1, we constructed an Organic Advisory Panel (OAP) made up (currently) of 8 members: 5 organic grain growers, one organic seed/weed consultant, one member of OSU extension and one organic farm manager. With each member of the OAP we conducted an in-depth interview (1-2 hours) and facilitated walk-through with the decision support framework to assess its design and ease of use. Modifications of the existing prototype include: 1) streamlining its design and interface to reduce cognitive load and make the questions more straightforward, 2) providing clear directions upfront to increase transparency with regard to the questions asked of farmers, 3) linking the science and values more clearly and obviously, helping to make more clear the intention of the tool and the tool's benefit to farmers, 4) simplifying how the results are presented and how farmers engage and analyze tradeoffs, and 5) making the overall design more intuitive and aesthetically pleasing. Based on farmers' feedback, we have also added targeted tutorials and background information. Regarding Obj 2, in addition to the in-depth interviews with farmers, we have engaged multiple farmers in discussion during farm tours and presentations at conferences regarding our predicted measures. A meta-analysis was begun, but progress has been slowed due to a lack of relevant peer-reviewed literature regarding outcome measures. Longterm field experiments have been planned and are due to begin in the spring of 2017. Work on Obj 3 and Obj 4 began in late 2016 (after the reporting period) and will continue into 2017. \*\*PUBLICATIONS (not previously reported):\*\* 2015/09 TO 2016/08 1. Type: Journal Articles Status: Published Year Published: 2016 Citation: Zwickle, S., Wilson, R., Bessette, D., Herms, C., & Doohan, D. (2016). Facilitating ecological weed management decisions by assessing risk-benefit tradeoffs. *Agroecology and Sustainable Food Systems*, 40(7), 635-659. doi:10.1080/21683565.2016.1166170 2. Type: Conference Papers and Presentations Status: Published Year Published: 2016 Citation: Bessette, D., Wilson, R.,

Culman, S., Doohan, D., & Lekies, K. (2016). Quantifying and predicting the effects of ecological weed management strategies on organic agroecosystems to inform farmer decision making. Organic Food and Farming Education and Research (OFFER) Program, Organic Planning Session. Wooster, OH.

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# Reinventing Sustainable Protection Systems for Cucurbit Production

<b>Accession No.</b>	1007167
<b>Project No.</b>	IOW05444
<b>Agency</b>	NIFA IOWA
<b>Project Type</b>	OTHER GRANTS
<b>Project Status</b>	NEW
<b>Contract / Grant No.</b>	2015-51106-23971
<b>Proposal No.</b>	2015-06288
<b>Start Date</b>	01 SEP 2015
<b>Term Date</b>	31 AUG 2018
<b>Grant Amount</b>	\$499,974
<b>Grant Year</b>	2015
<b>Investigator(s)</b>	Gleason, M. L.
<b>Performing Institution</b>	IOWA STATE UNIVERSITY, 2229 Lincoln Way, AMES, IOWA 50011

## NON-TECHNICAL SUMMARY

The goal of this two-state (Iowa and Kentucky), three-year project is to help **organic** growers in the eastern half of the U.S. produce **cucurbit** crops more profitably while building soil and protecting ecosystem services. Both field objectives -- 1) meshing new row cover technology with mulch and cover crops to defend muskmelon and acorn squash against major diseases and insect pests with minimal pesticide use and enhanced activity of natural enemies, and 2) adapting the new row cover systems for mechanized handling and multi-year re-use -- meet grower priorities. We will also compare profitability of the new strategies to existing practices and track changes in stakeholder perceptions over the course of the project (Objective 3). For students, we will publish two online case studies that explore strategies for managing pests and diseases sustainably (Objective 4). Grower outreach (Objective 5) will include a Community of Practice website, a blog, on-farm trials, field days, and trade journal articles. Long-term accessibility of the online case studies and Community of Practice website will insure impact beyond the project's time frame. Stakeholders will guide our direction through surveys and an Advisory Panel. The project directly addresses **Organic** Transitions Program 2015 priorities of enhancing ecosystem services and biodiversity with mulching and cover crops (Priority 1), and developing innovative crop management strategies to overcome barriers to **organic** transitioning (Priority 4).

## OBJECTIVES

Goals. We will help **organic cucurbit** growers to: i) overcome disease, pest, and weed problems that prevent sustainable **organic** management of muskmelon and winter squash (Priority 4 of this RFA), and ii) protect and build soil quality while conserving natural enemies (Priority 1 of this RFA). Supporting Objectives. Evaluate innovative systems that integrate row covers and between-row mulches into **organic** muskmelon and winter squash production. Evaluate nylon-mesh row cover material for durability, compatibility with mechanization, and potential for multi-year re-use. Compare costs and returns for the new production systems. Develop and publish two online case studies in **organic cucurbit** management. Share the project's messages with **cucurbit** growers and extension educators.

## APPROACH

In row cover trials (Objective 1A), treatments will include: 1) No row covers, 2) Spunbond row covers, removed at start of bloom, replaced 2 weeks later; wire hoops, 3) Nylon mesh row covers, removed at start of bloom, replaced 2 weeks later; conduit hoops, and 4) Nylon mesh row covers, full season, with bumble bees under row cover; conduit hoop. We will assess row cover systems and mulch systems in separate field plots each year. Both experiments will be arranged as split plot, randomized complete block experiments, with the split plots as muskmelon (cv. Athena) or acorn squash (cv. Table Ace). We will contrast standard wire hoops (Treatment 2) with innovative galvanized electrical conduit (EMT) hoops made with a commercially available hoop bender (Treatments 3 and 4). Mulch trials (Objective 1B) will focus on weed control and ecosystem services. Treatments: 1) Nylon-mesh row cover, removed for 2 weeks during bloom, then replaced; bare ground, 2) Nylon-mesh row cover, removed for 2 weeks during bloom, then replaced; cover crop, and nylon-mesh row cover, removed for 2 weeks during bloom, then replaced; crop residue mulch. We will establish cover crops and apply mulches in the soil strips between black plastic-mulched rows. The Treatment 2 cover crop will be an 4:1 mixture of annual rye (*Lolium multiflorum*) and red clover (*Trifolium pratense*), seeded immediately after transplanting to ensure quick establishment and weed suppression. Objective 2. We hypothesize that: 1) mid-weight nylon-mesh row covers will dramatically out-perform mid-weight spunbond polypropylene row covers in durability during mechanized handling and prolonged weather exposure; 2) the nylon mesh row covers will experience negligible tunnel heating during summer compared to the spunbond material; and 3) combining galvanized metal conduit hoops supports will provide more wind-resistant support than traditional bowed wire hoops under field use. We will conduct annual field experiments on transitioning **organic** land at the Iowa State University Horticulture Research Station Research Farm near Gilbert, IA, and on certified land at the University of Kentucky **Organic** Farming Unit in Lexington. In field trials, we will quantify time and labor requirements for deploying, securing, retrieving, storing, and redeploying nylon-mesh and spunbond row cover types, as well as their season-long durability under field conditions. We will make hourly measurements of air temperature and relative humidity annually from June 1 through August 31 with sensors and dataloggers located at 6, 12, and 18 inches above the ground in three separate tunnels of each row cover type in KY and IA during each year of the project in order to encompass as complete a range of environmental variation as possible. Objective 3. We will calculate a partial budget annually and for the 3-year project period. A partial budget highlights the effects of changes in selected aspects of farm operations. The project team is experienced in developing partial budgets for IPM options on muskmelon. Objective 4. The case studies will focus on the potential value of using our new row cover systems to deter pest and disease attacks and safeguard sustainability in **organic cucurbit** production (Case 1) and the value of **organic** mulches in managing **organic cucurbit** crops (Case 2). The cases will thrust students into decision-making roles as owners of diversified **organic** vegetable farms in the eastern half of the U.S. Objective 5. Outreach initiatives will include a CoP website, 50 virtual field day videos, 2 blogs, 18 on-farm demonstration trials, presentations at winter meetings, and trade journal articles.

## PROGRESS

2015/09 TO 2019/08 Target Audience: Commercial growers of cucurbit crops in the eastern half of the U.S. Changes/Problems: Results of the row-cover field experiments (Objective 1) diverged consistently and markedly between Iowa and Kentucky in all 3 years of the project. Results in Iowa have consistently showed substantially higher marketable yield for both muskmelon and acorn squash with the full-season mesotunnel system compared to traditional low tunnels or non-covered plots. In contrast, no consistent advantage in marketable yield of either crop with full-season mesotunnels in comparison to the other treatments has been found in the Kentucky experiments. We surmise that this divergence may be due to several contributing factors: 1) unusually low populations of cucumber beetles in the Kentucky trials, which may tend to limit the advantage of fullseason protection of the crops by mesotunnels; 2) problems in securing edges of mesotunnel fabric to the ground surface, along with weed growth along these edges, may have resulted in openings that allowed squash bugs to enter the mesotunnels, thus lessening their protective function for acorn squash; and 3) differential efficiency of pollination under full-season mesotunnels by purchased bumble bees in Iowa vs. Kentucky. The mulch trials revealed shortcomings for several strategies. The living mulch we used in Iowa - red clover and annual rye - failed to compete with grass weeds that gradually overgrew these plots. Furthermore, shredded crop-debris mulch was expensive, not always available, and prone to tying up soil nitrogen after being tilled in at the end of the season. The KY project team tested a promising alternative to shredded mulch in 2018: teff, which is an ancient type of cereal crop. In a rainy year, teff did an excellent job in filling the bare-soil alleys between rows of the mesotunnel system. However, this strategy will need further testing in multiple sites before it can be recommended to organic cucurbit growers. The PIs on the current project are exploring the mesotunnel system further under a current OREI grant (2000-2022). The main aims are to determine feasibility and economics of extending mesotunnels to commercial-farm scale, and optimizing pollination and weed control in these systems.

What opportunities for training and professional development has the project provided? M.S. graduate Hayley M. Nelson at ISU (graduated May 2019) took leadership for coordinating all aspects of the Objective 1 ISU field trials. Ms. Nelson presented the project to attendees at three ISU field days during the project. In Kentucky, PhD graduate Amanda Skidmore (graduates May 2019) took responsibility for day-to-day conduct of the Objective 1 field experiments under the guidance of co-PIs Mark Williams and Ricardo Bessin. Undergraduate research training during Year 2: ISU undergraduate research assistant Jordan Peterson conducted the Objective 2 field trials evaluating agricultural engineering aspects of the mesotunnels, under the guidance of co-PI Brian Steward and ISU undergraduate research assistants Alex Hernandez, and assisted Hayley Nelson in conducting the ISU field experiments. How have the results been disseminated to communities of interest? Nothing Reported What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

2015/09 TO 2016/08 Target Audience: Commercial growers of cucurbit crops throughout the eastern half of the U.S. Changes/Problems: We are currently puzzled by the nearly opposite results obtained in 2016 muskmelon row cover trials in Iowa and Kentucky. Full-season ProtekNet significantly boosted marketable yield of muskmelon in Iowa compared to the other treatments; in Kentucky, however, this treatment had the lowest marketable yield. Visual observations in Kentucky suggested that pollination was inadequate under the ProtekNet covers despite the presence of purchased bumble bees; the result was few fruit and rampant vegetative growth. The criterion for timing of introduction of the bees was observation of male and female flowers on at least 50% of the plants in a subplot; however, it is possible that this threshold delayed bee introduction in Kentucky excessively. Therefore, we will consider revising this threshold for 2017, possibly to the following: bees will be deployed when the first female flowers are observed within a subplot. We anticipate that this change could widen the time window for successful pollination of muskmelon, and thereby result in higher yield. What opportunities for training and professional development has the project provided? PhD candidate Hayley M. Nelson at ISU took leadership for coordinating all aspects of the Objective 1 ISU field trials, as well as coordination of Objective 1 methodology with University of Kentucky. In addition, Ms. Nelson presented the project to attendees at an ISU field day on August 8, 2016. Rachel Herzberg, an undergraduate agricultural engineering major at ISU, coordinated the Objective 2 field trials in Iowa. How have the results been disseminated to communities of interest? Outreach events and videos are described under Other Products. In addition, on-farm demonstration trials were conducted in both states during 2016. A field day was held during August 2016 at an on-farm trial site: the farm of Eric Walles (Farmer Eric's Organics) in Versailles, Kentucky. What do you plan to do during the next reporting period to accomplish the goals? The project team will hold three teleconferences (in December 2016, February 2017, and March 2017) to discuss 2016 results and plan for Year 2 field trials. The project's economists on the team will conduct stakeholder surveys and begin economic analysis of the field results (Objective 3). Work on development of the two case studies will begin in January 2017, with the goal of submitting the cases for publication in December 2017. Video segments describing the outcomes of the Year 1 field trials will be placed on the project website (<http://cucurbit.plantpath.iastate.edu>), which will become operational on December 19, 2016.

## IMPACT

2015/09 TO 2019/08 What was accomplished under these goals? OBJECTIVE 1A: Evaluate nylon-mesh row cover systems in organic muskmelon and acorn squash production in Iowa and Kentucky. We conducted 3 years (2016-2018) of field experiments at university farms in Iowa and Kentucky to evaluate new row cover systems for production of organic muskmelon and acorn squash. We compared 4 treatments: 1) a full-season row cover using a nylon-mesh row cover material (ProtekNet) with purchased bumble bees provided for pollination; 2) ProtekNet as in Treatment 1, except the covers were removed for 10 days during bloom and no bees were added; 3) a standard-grower-practice control using spunbond polypropylene row (Agribon or Reemay) covers that were removed at the start of bloom; and 4) a no-row-cover control treatment. Organic insecticides were applied as needed when treatments were not covered by row covers. Treatment subplots were three rows wide and 30 ft long; ProtekNet was supported on 3.5-ft-tall hoops made from aluminum conduit, whereas Agribon was supported on standard galvanized 1.5-ft-tall wire hoops. Experimental design was a randomized complete block with 4 replications per treatment. Results from the Iowa muskmelon trial were consistently encouraging. The full-season ProtekNet and part-season ProtekNet treatments (1 and 2) produced nearly double the mean weight and number of marketable fruit compared to low tunnels (treatment 3) and significantly out-performed the non-covered control (treatment 4). Treatment 1 had no disease symptoms or pest injury; both ProtekNet treatments had significantly less than the noncovered control but not the Agribon treatment. The non-covered control treatment required an average of 3 insecticide applications whereas the covered treatments had no applications. For the acorn squash trial, the mean number and weight of marketable fruit in full-season mesotunnels (treatment

1) was significantly higher than in any other treatment, and about 2.5 times higher than in any of the other treatments. Incidence of disease symptoms and pest injury in treatment 1 was less than one-sixth the levels seen in any other treatment, but treatment 1 received no insecticide sprays compared to 4 to 11 sprays for treatments 2-4. In conclusion, full-season mesotunnels in Iowa resulted in a large increase in marketable yield of both muskmelon and acorn squash compared to low-tunnel or non-covered treatments. The relative contributions of more efficient pollination and more effective pest/disease control to enhancing marketable yield under these full-season tunnels remain to be determined. In Kentucky, field trials used a living mulch (teff, a grass species) to control weeds in 2018, rather than shredded miscanthus, which was used to suppress weeds in 2016 and 2017. Marketable yields did not differ among treatments in any of the three years. In the KY acorn squash plots during 2018, ProtekNet treatments (1 and 2) had significantly higher marketable yield than the other treatments, whereas there were no yield differences in the prior two years. The divergent row-cover results between Iowa and Kentucky during 2016-2018 leads us to conclude that the potential of full-season, nylon-mesh row covers to increase marketable yield on muskmelon and acorn squash may vary among geographic regions. OBJECTIVE 1B: Compare living mulch, crop-debris mulch, and bare ground for weed management in full-season mesotunnel systems for organic production of muskmelon and acorn squash. In Iowa, a spring-seeded annual rye-red clover mix (living mulch) was rapidly overgrown in each trial year by grass weeds in both cucurbit crops. Mulch type did not significantly impact marketable yield of either muskmelon or acorn squash, or the amount of reactive carbon in the soil. In Kentucky, shredded crop-debris mulch between rows resulted in significantly higher marketable yield than the other treatments, but marketable yield in acorn squash was not significantly different among treatments. The 3 years of field trials did not result in identifying a preferable mulching strategy among the options tested. OBJECTIVE 2: Evaluate nylon-mesh row cover material for durability, compatibility with mechanization, and potential for multi-year re-use. Iowa field trials with muskmelon at four sites during 2018 investigated effectiveness of several mechanisms for securing edges of nylon-mesh row covers (ProtekNet) to the ground surface: burying with soil, using PVC clips, and placing sandbags on the edges at intervals of either 5 or 14 ft. Burying fabric edges in soil showed no advantages over the other methods in preventing entry by cucumber beetles into the mesotunnels. We concluded that sandbags or PVC clips would be more efficient and less laborious for securing edges of nylon-mesh row covers than burying the edges with soil. OBJECTIVE 3 (economic analysis) is ongoing. OBJECTIVE 4. Case studies. A case study manuscript, authored by graduate student Hayley Nelson and Project Director Mark Gleason, was published in the online journal The Plant Health Instructor in 2019. OBJECTIVE 5 (outreach) events were detailed under the "Other Products" in three previous Annual Reports. \*\*PUBLICATIONS (not previously reported):\*\* 2015/09 TO 2019/08 Type: Journal Articles Status: Published Year Published: 2019 Citation: Nelson, H.M., and Gleason, M.L. 2019. Solving a disease management puzzle in organic muskmelon production. The Plant Health Instructor: <https://www.apsnet.org/edcenter/disimpactmngmnt/casestudies/organicmuskmelon/Pages/TheCase.aspx>

2015/09 TO 2016/08 What was accomplished under these goals? Impact statement. Our project can make it feasible to grow organic muskmelon and squash profitably and sustainably in the Midwest and East by overcoming the threat of losses from insect pests and bacterial wilt. In contrast with traditional organic production using spunbond row covers that are removed when the crop starts to bloom, our system - 3.5-ft-tall "mesotunnels" in triple-row blocks under nylon mesh row covers - offers full-season protection from insect pests and wilt. In our 2016 field trials in Iowa and Kentucky, the mesotunnels delivered higher marketable yield for acorn squash in both states and for muskmelon in Iowa, compared to alternative growing systems. Lower muskmelon yield in Kentucky under mesotunnels may have been caused by adding bees under the covers too late in the season. We foresee that the mesotunnel system, when the bugs are worked out, will make organic muskmelon and squash much easier and more reliable to grow than ever before, and lead to expanded acreage and profits for organic vegetable growers in the eastern half of the U.S. Objective 1) Evaluate innovative systems that integrate row covers and between-row mulches into organic muskmelon and winter squash production. For Objective 1A, we conducted 2016 field experiments at university farms in Iowa and Kentucky to evaluate two new row cover systems for production of organic muskmelon and acorn squash. We used the same experimental protocol in each state, comparing four treatments: 1) a full-season row cover using a nylon mesh row cover material (ProtekNet) with purchased bumble bees provided for pollination; 2) ProtekNet as in Treatment 1, except the covers were removed for 10 days during bloom and no bees were added; 3) a standard-grower-practice control using spunbond polypropylene row (Agribon or Reemay) covers that were removed at the start of bloom; and 4) a no-row-cover control treatment. Organic insecticides were applied as needed to treatments that were not covered by row covers. Treatment subplots were three rows wide and 30 ft long; ProtekNet was supported on 3.5-ft-tall hoops made from aluminum conduit, whereas Agribon was supported on standard galvanized 1.5-ft-tall wire hoops. Experimental design was a randomized complete block with 4 replications per treatment; the muskmelon trial was conducted separately from the acorn squash trial. Results in Iowa were encouraging: the full-season ProtekNet treatment yielded significantly more marketable muskmelon than the other treatments. In contrast, the Agribon and no-row-cover control had much lower marketable yield and higher incidence of cucurbit

bacterial wilt. Similarly, marketable yield of acorn squash was significantly higher for the full-season ProtekNet treatment than for the non-covered controls, and the other treatments were intermediate. Kentucky results for muskmelon were quite different: in a season with low cucumber beetle numbers and bacterial wilt pressure, the full-season ProtekNet treatment had the lowest marketable yield. This unexpected result was ascribed to introducing the bumble bees too late for optimal pollination, resulting in extreme vegetative growth but few fruit. The acorn squash results more closely resembled those in Iowa: number of marketable fruit was significantly higher for the full-season ProtekNet treatment than for the other treatments, and the lowest yield was for the standard polypropylene row cover treatment. Objective 1B contrasted living mulch, crop debris mulch, and bare ground between subplots of full-season ProtekNet row covers. In both Iowa and Kentucky, weight of marketable fruit did not differ among treatments for either crop, and weed pressure between rows was significantly lower in the shredded mulch treatment than for the living mulch or bare ground treatments. Objective 2) Evaluate nylon-mesh row cover material for durability, compatibility with mechanization, and potential for multi-year re-use. We conducted field trials at an ISU farm to explore aspects of mechanization of the handling of row covers, using 4 treatments in a factorial arrangement: Agribon or Proteknet row covers, with or without the use of a tractor-powered retrieval and storage device (Hi-Wer machine). Significantly more time was required for deploying and retrieving the larger conduit hoops (ProtekNet system) than the smaller wire hoops (Agribon system), and mechanical retrieval of each type of row cover was significantly faster with the Hi-Wer device than manual retrieval. Objective 3) Nothing to Report. Objective 4) Nothing to report. Objective 5) Share the project's messages with cucurbit growers and extension educators. Outreach events included three on-farm demonstration trials in each state. In KY, cooperators were Ben Abell (Rootbound Farm), John Bell (Elmwood Stock Farm) and Eric Walles (Farmer Eric's Organics). On each farm, a triple row of Athena muskmelon was planted under full-season ProtekNet row covers with straw mulch for weed control, and bumble bees were added when 50% of the plants had female flowers. As in the UKY field experiments, plants in the KY cooperator trials grew very well but fruit set and yield were low. We concluded that, as in the UKY field experiment, the bees were added under the row covers too late to insure good fruit set. \*\*PUBLICATIONS (not previously reported):\*\* 2015/09 TO 2016/08 No publications reported this period

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# Organic Decision Tools to Manage N for Production and Climate

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Performing Institution	UNIVERSITY OF ILLINOIS, 2001 S. Lincoln Ave., URBANA, ILLINOIS 61801

## NON-TECHNICAL SUMMARY

Efforts must be made to develop Agricultural Information Systems (AIS) that adequately describe and support complex **organic** farming systems. This project will leverage an existing **decision** support **tool** (goCrop™) that uses integrated web and mobile applications for crop and soil management to help farmers to plan, monitor, analyze, and report with ease. By drawing on existing collaborations with farmers, farm data, and modeling tools, this project will carry out an integrated Extension and research program to develop modules that can estimate plant available nitrogen (PAN) and greenhouse gas emissions (GHG) derived from nitrous oxide release from **organic** crop systems. Research will address the fact that existing calculators that estimate PAN and GHG emissions do not account for feedback resulting from improvements in soil health that would likely be expected from the use of **organic** practices. The PAN and GHG modules developed through the project will be integrated into the goCrop platform and tested for usability by **organic** farmers. By initializing simplified models with indicators of soil quality, and training farmers to record information about key drivers (cover crop and manure quantity and composition and soil moisture), we should be able to make associated **decision** support **tools** more accurate and provide users with enough detail to implement sound nutrient management and emissions reduction strategies. By using a consultative process to engage experienced **organic** farmers to develop a multipurpose data system to simultaneously satisfy **organic** planning and reporting requirements while also providing other conservation planning results, we can help **organic** grain farmers strike the right balance between GHG emissions and soil nitrogen (N) supply. This work will imbed the research in extension activities and develop educational content for eOrganic.

## OBJECTIVES

The hypotheses for this project are as follows. 1) Development of a multipurpose data system that allows farmers to satisfy **organic** planning and reporting requirements while also providing other conservation planning results such as GHG emissions will encourage them to adopt climate mitigation strategies. 2) By initializing simplified models with indicators of soil quality and training farmers to record information about key drivers (cover crop and manure quantity and composition and soil moisture), we should be able to make associated **decision** support **tools** more accurate. Our long term objective is to: Develop agricultural information systems that improve **organic** management, increase profitability, and protect the environment. Specific project objectives are to: 1) Evaluate usability and utility of calculators and models that can be used to estimate plant available nitrogen and

greenhouse gas emissions on **organic** farms.2) Develop affordable ways for farmers to initialize process models that feed needed **decision** support **tools**.3\*\*) Develop the goCropghg app to allow **organic** farmers to estimate plant available N and greenhouse gas emissions on their farms and determine if farm-based data of estimated plant available N and greenhouse gas emissions will affect farmer decisions in implementing climate mitigation strategies.

## APPROACH

Objective 1: Evaluate usability and utility of calculators and models that can be used to estimate plant available nitrogen and greenhouse gas emissions on **organic** farms: \1\ Beta test goCrop in VT and IL using mobile labs; \2\ Carry out field days to train farmers and study usability; \3\ Organize conference on tools to provide education and carry out tool evaluation; and \4\ Offer classes on campus and online through a MOOC. Objective 2: Develop affordable ways for farmers to initialize process models that feed needed **decision** support **tools**: \1\ Adapt the surrogate century model (inverse modeling) to predict changes in soil **organic** matter and active carbon pools on **organic** farms, use on farm data for calibration and validation; \2\ Develop cover crop and manure calculator - begin with existing tools and improve databases. We will obtain residues and soils and estimate moisture from beta-testing farms and calibrate models with their data; \3\ Develop a tool to estimate plant available N that combines weather, management and model results using a simple degree day calculation (local average of typical, dry and wet extremes and multiply this by SOC estimated by SCSOC; \4\ Draw on existing accounting tools, data sets, field scale modeling and statistical analyses to develop empirical functions that predict greenhouse gas emissions; and \5\ Use farmer-supplied information about current farming practices (cropping history, cultural practices and inputs), and estimated yields, or measures of soil quality to improve projections of SOC and available C and N. Objective 3: Use a modified Agile Development process using a management tool called JIRA. This will plan for and develop goCropghg to include two modules developed through objective 2 to estimate PAN and GHG: \1\ This begins with a discovery phase to develop user stories with information collected from beta-test farmers, surveys taken at events, and from project team members and summarize these in Confluence before finalizing mockups to be used in beta-test; \2\ Beta test by conducting interviews that use a script with primarily open-ended questions to guide the dialogue. Bugs will automatically be reported from the goCrop system using JIRA. Modifications will be made by developers as necessary; \3\ Develop web-service tools that draw on needed supporting data as they are finished in objective 2; and \4\ goCropghg will be released to public based on data received from the beta testers and other additional observations made by the team.

## PROGRESS

2015/09 TO 2019/08 Target Audience: Farmers were engaged in a winter Organic Grain Growers meeting in 2019 in a morning-long workshop presented by Michelle Wander (University of Illinois) and Dr. Heather Darby (University of Vermont Extension), with input from Ho-young Kwon (Argonne National Laboratory), Yushu Xia (University of Illinois), Emily Marriott (University of Illinois), Lindsey Ruhl and Penelope Hobbs (University of Vermont Extension). This workshop shared results from our cover crop sampling campaign and use of a nutrient management application to demonstrate how various organic practices impact soil organic matter, soil nitrogen supply to crops, and N loss through leaching and nitrous oxide emissions before inviting farmers to explore how management factors like the type and timing of tillage and fertilization interact with weather to determine the fate of nitrogen on individual farms. The research community was engaged at the 2019 Agronomy Crops and Soil Science Society meeting where Wander, Darby, Kwon, Xi, Marriott, Ruhl, and Hobbs shared how the team has been working to develop decision support tools for organic grain growers by leveraging existing resources and decision support tools to manage N which is frequently the most limiting nutrient for crop growth and one of our greatest environmental concerns. A weakness in existing tools that is of particular concern for organic growers is that models we rely on do not account for feedback that results from changes in SOM that accrue over time. An organic matter management module was developed for goCrop, which uses integrated web and mobile applications for farm record keeping by incorporating a parameterized soil organic matter model (PCSOM) derived from CENTURY/DAYCENT that was calibrated for organic farming systems. The module helps organic farmers estimate plant available N (PAN), changes in organic matter, water holding capacity, greenhouse gas (GHG) emissions, and N leaching loss. We will share what we have learned about how to lower transaction costs for tool use and combine information about crop rotations, soil test results, input applications, and yield projections in ways that benefit organic growers. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Farmers were engaged in a winter meeting in 2019 in a morning-long workshop presented by Michelle Wander (University of Illinois) and Dr. Heather Darby (University of Vermont Extension), with input from Ho-young Kwon (Argonne National Laboratory), Yushu Xia

(University of Illinois), Emily Marriott (University of Illinois), Lindsey Ruhl and Penelope Hobbs (University of Vermont Extension). This workshop shared results from our cover crop sampling campaign and use a nutrient management application to demonstrate how various organic practices impact soil organic matter, soil nitrogen supply to crops, and N loss through leaching and nitrous oxide emissions, before inviting farmers to explore how management factors like the type and timing of tillage and fertilization interact with weather to determine the fate of nitrogen on individual farms. How have the results been disseminated to communities of interest? Xia, Y., Kwon, H. and M. Wander. 2019. Estimation and Modeling of Field-Scale Soil Nitrous Oxide Emissions Based on Strategic Sampling Plans 2019 ASA-CSSA-SSSA International Annual Meeting, November 10-13. San Antonio, Texas. <<https://scisoc.confex.com/scisoc/2019am/meetingapp.cgi/Paper/120611>>. Wander, M., Darby, H., Marriott, E., Kwon, H. Ruhl, L. and Y. Xia. 2019. Tools to Manage Nitrogen Organically for Crops, Soils and the Environment. <<https://scisoc.confex.com/scisoc/2019am/meetingapp.cgi/Paper/120225>>. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

2017/09 TO 2018/08 Target Audience: We contacted organic grain and livestock farmers by e-mail in the North Central, Central and North Eastern United States using eOrganic and NOP lists to invite participation in our cover crop sampling project and farmer survey. We spoke with the public about organic agriculture and the environment at farmer-focused conferences. Changes/Problems: Due to rapidly changing technologies and audience preferences suggested by responses to our survey we are considering replacing the MOOC idea with other options for training and professional development that include the development of online accessible tutorials on how to use different features in goCrop, estimate cover crop biomass, and an organic N management tool through the eOrganic youtube channel. What opportunities for training and professional development has the project provided? Staff attended UVM goCrop workshops and the Climate Hub meeting; graduate students attended professional society meetings; undergraduate students engaged in sampling and analysis. How have the results been disseminated to communities of interest? Dr. Michelle Wander presented at the 2018 Illinois Organic Grain Conference. In this talk, titled "The Holy Trinity (tillage, fertility and rotation) and Soil Health on Your Farm", she introduced the cover crop sampling campaign to an audience of 175. Dissemination activities also included e-mail and phone interactions with individual farmers and web content. . What do you plan to do during the next reporting period to accomplish the goals? This summer we will use one-on-one and small group interactions with farmers along with discussions with the developer to finalize the input and display phases of discovery. In the next year we will finish processing samples, analyzing data, and preparing farmer reports for the cover crop sampling we conducted in the spring of 2018. By the fall of 2018 we will finalize model calibration and validation before using baseline estimates to create an N module calculator and database to be incorporated into the goCropghg module by UVM's developer before the 2019 MOSES Organic Farming conference where we plan to present a hand-on workshop demonstrating the use of our nitrogen management module for goCrop™. Our workshop, "Where is Your Nitrogen Going?", would explain how nitrogen losses from fields reduce productivity, profit and environmental health using a hands-on demonstration to illustrate how management decisions like the type and timing of tillage and fertilization interact with weather and soil to determine the fate of nitrogen and organic matter on cash grain and livestock farms. Users will be able to compare how different practices can impact soil N supply and N loss through leaching and nitrous oxide emissions.

2016/09 TO 2017/08 Target Audience: Farmers, technical service providers, and the interested research community. Changes/Problems: We are considering adjusting the scope to focus only on app development only for IL and VT as coverage of all states between presents challenges due to differences in reporting requirements and soil test interpretations. What opportunities for training and professional development has the project provided? We piloted a survey of farmer attitudes about climate and greenhouse gas emissions at Winter Nutrient Management Meetings in VT in 2016. Results from that and key informant interviews conducted in IL have informed design of beta-test materials. We are preparing mock ups of data visualization for beta testing with lifetime beta testers that will take place at Winter meetings 2017/2018. How have the results been disseminated to communities of interest? Nothing Reported What do you plan to do during the next reporting period to accomplish the goals? Model runs for beta-testing farms are being developed to share with collaborators. Derived variables will include plant available N, SOC, and direct and indirect N<sub>2</sub>O losses. We are currently working on modeling N mineralization and leaching coefficients derived from SCSOM for region-wide application and refining the picklists needed to allow field data to scale results from modeled output. This Spring, we will ask farmers to send cover crop samples and estimate biomass using simple methods to determine whether the cost and effort of sampling are necessary. Future activities will include the planning and offering of workshops for stakeholders interested in farmer crop and soil management to understand how farmers currently integrate goCrop and similar tools into their farming system, and an open-source asynchronous course to help farmers understand and use decision support tools for reporting and management.

2015/09 TO 2016/08 Target Audience: Members of the target audience included farmers, educators, and policy makers who are interested in the development and utility of agricultural information systems and decision support tools that can enhance soil stewardship and help mitigate climate change. Changes/Problems: To tailor the app for different users we need to adjust to state nutrient management regulations - this is more complicated than we anticipated. What opportunities for training and professional development has the project provided? Emily Marriott, project coordinator, has been trained in VT to use goCrop. Deb Heleba has been familiarized with SCSOM. How have the results been disseminated to communities of interest? Nothing Reported What do you plan to do during the next reporting period to accomplish the goals? We will calibrate and validate models, conduct beta tests with farmers, and work with goCrop developers.

## IMPACT

2015/09 TO 2019/08 What was accomplished under these goals? Blended methods were used to address all three objectives. A research survey (IRB #18631) assessed production and environmental concerns of organic grain and livestock farmers and explored their interest in decision support tools that could help them manage nitrogen, build soils, and protect the environment. That survey was designed using input gleaned from pilots conducted in 2016 in Vermont and early 2018 at the Illinois Organic Grain Conference. Responses suggested farmers were more concerned about impacts climate would have on agronomic performance than on environmental outcomes. Interestingly, when respondents were asked about their greatest environmental and agronomic concern, topics related to nutrient and manure management ranked the highest among four simplified categories. When asked about information they use or might be interested in receiving it seemed they were more interested in being able to estimate factors influencing production (i.e. nutrient and water supply) than environmental performance (erosion rates and greenhouse gas emissions). Half of respondents do not currently use any mobile or web apps or use only weather-related apps or web soil survey to make farm management decisions. Most don't use record keeping software either and of those that do, most use spreadsheets that they have designed themselves. Despite this, over a third of farmers responded that they are or may be interested in software that uses farm data to help inform decision-making. While only half were concerned about data-privacy issues, over half were not comfortable sharing their data with the federal government. Responders also had greater confidence in private entities than public institutions or public private partnerships holding and possibly using their data. Results were used to help design the user interface for a carbon and nitrogen management module being developed for UVM's goCrop platform. A major piece of this project included expansion of the Parameterized Century Soil Organic Matter Model (PCSOM) model (Kwon et al., 2013; Qin et al. 2018) which is a gridded model derived from the CENTURY model (Parton et al. 1987) coded into a nonlinear regression routine (SAS Institute, 2012). PCSOM runs simulations of SOM dynamics driven by: i) Crop residue inputs that are empirically calculated using observed crop yields, agronomic indices, and crop C and N composition, ii) SOM decay rate adjustments that reflect the influence of climatological, physical (e.g. tillage or other field operations), and input (e.g. fertilizer addition or residues returned) factors, and iii) Default values of model parameters. Detailed steps involved in model and data development and validation of N submodel development for GHG estimation will be covered in a manuscript prepared by Xia et al. Main model outputs include SOC stock for each SOM pool (kg C ha<sup>-1</sup>), N<sub>2</sub>O-N emissions (kg N ha<sup>-1</sup>), N leached and runoff (kg N ha<sup>-1</sup>). More importantly, it can perform an inverse modeling of observed data to estimate CENTURY/DayCENT parameters and their standard errors (SE) along with statistical significance and can conduct uncertainty analysis using Monte Carlo (MC) simulation. Data development needed to model organic systems required summary or collection of information describing historical land use, estimation of C and N inputs from cover crops and manures, which required allometric coefficients for agronomic and cover crops commonly grown on organic farms, and an expanded list of equipment-based decay coefficients used by the model to adjust rates. Efforts concentrated on improvement of estimates of cover crop and manure inputs because these were believed to be the largest source of uncertainty for organic growers due to a major weakness in existing tools which is that they do not account for feedbacks that result from changes in SOM that accrue over time. This has big implications for organic systems. For manure estimates we found that reporting requirements and material-based recommendations varied greatly among states within our coverage area and that use of reported statistics, look up tables related to manure quality based on manure type is completely inadequate for informed management. Comparison with measured values proves that farmers must test manures in order to understand and forecast the influence of additions on N availability and loss. To improve farmer's ability to quantify the benefits of cover crops we compared use of lookup tables, direct measurement and indirect visual methods to estimate aboveground biomass and nitrogen (N) additions and found that the spatial and temporal extent of currently available data are inadequate for many cover crop species. Direct measurement of cover crop species within growing regions can be used to develop predictive functions that are linearly related to height x ground cover functions to estimate cover crop biomass and N inputs.

An organic matter management module was developed for goCrop, which uses integrated web and mobile applications for farm record keeping, by translating PCSOM code into Javascript. A goCrop beta version of the N management module is being finalized. Farmer surveys and team discussion were used to identify topics that users would want to explore through the N management module interface. The resulting beta user interface allows the user to navigate through pick lists that draw values based on the location (soil type) and crop rotations where default values populated by modeled output can be replaced by use of drop down tabs that allow customization of a rotation by selecting a cover crop or manure type, or tillage practice (for example), or by construction of an individualized rotation. Code and supporting data allow farmers to use look-up tables or their own values to evaluate the effects of rotation, tillage type and timing, fertilization practices, and weather (typical, wettest years, driest years). The module helps organic farmers estimate plant available N (PAN), changes in organic matter, water holding capacity, greenhouse gas (GHG) emissions and N leaching loss. \*\*PUBLICATIONS (not previously reported):\*\* 2015/09 TO 2019/08 Type: Journal Articles Status: Under Review Year Published: 2020 Citation: M.M. Wander, E. Marriott, L. Ruhl and H. Darby. 2020. Three Ways to Estimate Cover Crop Biomass and Nitrogen Inputs. J. Agricultural and Environmental Letters. (Submitted).

2017/09 TO 2018/08 What was accomplished under these goals? To further objectives 1 and 2 above, we conducted an on-farm cover crop sampling project in the spring of 2018. The cover crop biomass sampling protocol developed in 2017 was refined and finalized. The protocol was designed to allow us to evaluate time- and cost-effective methods to estimate cover crop biomass that could be used as alternatives to clipping and weighing samples, and to inform nitrogen supply data tables used in goCrop. We solicited participants through eOrganic and Vermont's organic grain grower listserve, as well as through personal networks. We collected or obtained soil and cover crop biomass samples from roughly 50 fields on 16 farms in Vermont, New York, Illinois, Indiana, and Pennsylvania. Samples are being analyzed for carbon and nitrogen content and soil incubations will be used to assess nitrogen mineralization potential. Individualized reports including cover crop biomass and nitrogen content will be provided to each participating farmer. Data gathered from this project will be used in the development of data tables to support plant available N estimates in goCrop and validate modeled cover crop data. Plan to refine procedure and use as preliminary results that inform next steps. Several field pairs from the participating farms are also being sampled for nitrous oxide emissions during the 2018 growing season. Data will be used for model calibration and validation. The farmer survey piloted in 2016 in Vermont was modified and reissued in Illinois at the 2018 Organic Grain Conference. Based on the results of those two surveys, we developed a research survey (IRB #18631) to assess the primary production and environmental concerns of organic grain and livestock farmers and explore their interest in decision support tools that could help them manage nitrogen, build soils, and protect the environment. The survey was open from July through August. Certified organic farmers in the North Central, Central and North Eastern United States growing field or forage crops were invited via email (from USDA's NOP list) to complete the survey. We received 56 responses from farmers in Illinois, Indiana, Ohio, Wisconsin, Iowa, Pennsylvania, and New York. Survey data is currently being analyzed but preliminary results indicate that respondents are more interested in being able to estimate soil nitrogen supply and soil moisture than greenhouse gas emissions. About three quarters of respondents do not currently use any mobile or web apps or use only weather-related apps or web soil survey to make farm management decisions. Most don't use record keeping software either and of those that do, most use spreadsheets that they designed themselves. About three quarters of farmers responded that they are or may be interested in software that uses farm data to help inform decision-making. Responses indicate that farmers would trust public institutions (land grant universities, Cooperative Extension) and private research entities more than federal agencies (Natural Resource Conservation Service, USDA, or NOP) to serve as data repositories for farm information used to estimate soil nitrogen supply, carbon sequestration, and greenhouse gas emissions. The modeling team made considerable progress with thinking on what and how we will deliver the data generated by the model and how it will be integrated into the goCrop app. Team members began engaging the goCrop app developer on this work. There are two short term goCrop ghg developments to meet the ghg module goals. To increase user-friendliness, the developer is exploring connecting goCrop to the SSURGO soil database in order to autofill related soil type information. The second is expanding goCrop functionality by modifying cover crop forms to account for new information pertinent to calculating nitrogen availability and adding nutrients from cover crops into the field-by-field nutrient balancing tables. In September, collaborators will complete the goCrop ghg discovery phase by meeting with the developer to finalize the ghg module workflow and report output. Additionally, we plan to develop an excel spreadsheet that calculates N<sub>2</sub>O emissions, plant available N, N leached that can be expressed by crop-type, or averaged across the season using a weather average from 50 years or just the past 10, or using wet year or dry year scenarios. We will be able to offer a downloadable version of the spreadsheet (calculator) in order to expand our reach to additional farmers who aren't using goCrop. \*\*PUBLICATIONS (not previously reported):\*\* 2017/09 TO 2018/08 No publications reported this period.

2016/09 TO 2017/08 What was accomplished under these goals? The team reviewed goCrop modules to identify components to extract/retain or delete for a general model that covers the Northeast and Midwest. Team members reviewed nutrient management requirements by state to see what needed to be turned on or off for app generalization to the Northeast and Midwest where nutrient and manure management requirements vary greatly. After review, the team agreed on numerous scenarios describing organic grain and livestock practices applied across the region to be modeled by county for all states in the region. Farm scenarios used by collaborating farmers in IL and VT have been built in goCrop to help us prepare for beta testing. After identifying data needs, we collected data sources for model inputs and the goCrop look up tables that will be used to scale model output. Data libraries for cover crop and manure coefficients and crop data bases have been developed. In addition, we have developed a N<sub>2</sub>O database for model calibration/validation that covers the range of systems described. A large amount of effort has been devoted to expanding the capacity of the Surrogate Century Soil Organic Matter (SCSOM) model (Kwon and Hudson, 2010; Kwon et al., 2013), which was developed using the carbon and plant growth sub-models described in the CENTURY model (Parton and Rasmussen, 1994) and the hydrologic and nitrogen sub-models from the DAYCENT model (Parton et al., 1998). To refine model inputs, we also updated data sets estimating land use change with remote sensing analyses and national statistics to estimate county-level information describing soil properties, weather, fertilizer and manure inputs, and crop rotation. The soil hydrologic sub-model was developed using equations from the DAYCENT model adapted to run on a monthly time step. For this, detailed soil water characteristics were estimated by combining soil data (e.g. sand, silt, and clay contents), calculated soil organic C contents, and empirical equations derived from Saxton and Rawls (2006). Derived variables include saturation moisture, wilting point moisture, and drained upper and lower limits. Soil moisture simulated by SCSOM was compared to North American Soil Moisture Database (NASMD) at county-level for moisture sub-model validation. The soil N sub-model was adapted to run on a monthly time step. Model performance was evaluated by comparing direct emissions estimated by SCSOM with field based observations (185 records from corn-based systems) reported in 30 studies conducted in the region. Site-specific information including N input rate, fertilizer type, grain yield, cropping system, tillage information, residue removal rate, and management history were used as model inputs; while county-level information of soil properties and climate conditions were obtained from SSURGO and CRU, respectively based on FIPS of the selected records. UVM personnel have developed protocols for cover crop sampling to be used by farmers who are enlisted in our study of cover crop sampling and quality. A solicitation for cover crop sampling and measurement from farmers in VT and IL will be shared in Fall 2017. Sample and data reporting results will be analyzed next year. \*\*PUBLICATIONS (not previously reported):\*\* 2016/09 TO 2017/08 No publications reported this period.

2015/09 TO 2016/08 What was accomplished under these goals? For the last reporting period we established regular team meetings, started reviewing literature and the goCrop tool to identify and develop datasets needed to add desired functionality, and outlined work plans for the coming year. In 2016 we have summarized values from primary and review literature needed for lookup tables that will support goCrop calculations, met with developers and designers to determine what changes need to be made to the app, completed the first run on the modified SCSOC model (now complete SCSOM model that includes weather, hydrologic, and crop growth modules coded in SAS), and are calibrating the hydrologic model. Planning for 2017 farmer meetings for beta testing is ongoing. \*\*PUBLICATIONS (not previously reported):\*\* 2015/09 TO 2016/08 No publications reported this period.

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