

ORG Project Details

Award Year 2016

8 Research Projects

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Decision Support to Quantify Ghg Mitigation and Ecosystem Services from Organic Production Systems

Accession No.	1010372
Project No.	COL0-2016-06180
Agency	NIFA COL\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2016-51106-25712
Proposal No.	2016-06180
Start Date	01 SEP 2016
Term Date	31 AUG 2019
Grant Amount	\$499,990
Grant Year	2016
Investigator(s)	Schipanski, M.

NON-TECHNICAL SUMMARY

As organic foods have gained broad consumer support and organic food vendors have increasingly adopted sustainability metrics to quantify the relative impact of different production systems and supply chains on environmental services, we need improved, data-driven decision support tools that include common organic management practices. This project will improve technologies and tools to document and optimize the environmental services and climate change mitigation ability of organic farming systems. We will improve two online decision support systems (COMET-Farm and the Cool Farm Tool) for quantifying the impacts of land use and management practices on soil C and GHG emissions from agricultural systems at the farm-scale. We will improve the capacity of multiple stakeholder groups, including organic farmers, buyers, and students to understand and evaluate organic management practice impacts by: 1) Synthesizing and integrating data on cover crops, organic amendments and management intensive grazing into COMET-Farm and the Cool Farm Tool; 2) Engaging diverse stakeholder groups to assess, refine, and test improved decision support systems that reflect realistic organic management practices; and 3) Developing learning modules that integrate GHG decision support systems into undergraduate curriculum. This project will leverage existing stakeholder networks and extensive modeling and software infrastructure. These improved decision support systems will enable the industry to deliver improved storytelling about organic beyond the label and help to identify opportunity areas for working with farmers to improve both productivity and profitability as well as deliver on corporate commitments to meet GHG reduction goals.

OBJECTIVES

Our long-term goal is to provide decision support tools that support organic producers in optimizing the environmental services provided by organic farming systems and inform supply chain valuation programs that reward producers for good stewardship. We will achieve our long-term goal through the following specific objectives and expected outcomes: Objective 1: (Research) Improve the capacity of existing decision support systems (COMET-Farm and the Cool Farm Tool) to provide full GHG accounting and evaluation of key management options in organic systems, with an emphasis on inclusion into the tools of: crop rotations with cover crops and use of organic amendments for crop production, and inclusion of management intensive grazing for organic dairy and beef production. Objective 2: (Outreach/Extension) - Assess, refine, test and deliver user-friendly decision support systems, developed in close collaboration with stakeholders, that reflect realistic organic

management practices and can be used to evaluate organic production system effects on soil C and GHG emissions. Objective 3: (Education) - Develop online learning modules that integrate GHG decision support systems into undergraduate and graduate curriculum.

APPROACH

Approach We will assemble, through the end of the first year of the project, all relevant literature from field studies for each of cover crop practices on GHG and soil C, in a comprehensive database. In some cases we anticipate the need to query authors directly for additional details about the study, which are not always included in journal publications. We will also work with our stakeholder community to seek out information that may be in the 'gray literature' - i.e., in internal reports, in non-indexed journals or as yet unpublished form, that are not readily accessible through standard searches of referred journals. To improve the capacity of tools to estimate organic amendment impacts on GHG and soil C, we will leverage existing databases on manure and compost nutrient content and integrate new data quantifying GHG emission impacts of manure management practices. We will compile available data on intensive grazing systems, pasture productivity and plant dynamics as well as field measurement of soil C and GHG fluxes as a function of grazing system, in our data collection. Data obtained from the literature search will be archived in a MS-Access® database along with ancillary data on location, source reference, etc. If sufficient studies are available to directly estimate climate-zone specific soil C stock change factors for one or more of the practice types, we will fit the data using linear mixed-effect models. The model will include fixed effects for climate, soil depth, soil type and time and random effects for site and site-by-time interactions to account for dependence among observations from repeated measures at a site. Empirical factors derived from the analysis will be incorporated into the Cool Farm Tool. Because different cover crop types, different organic amendments and different pasture systems vary in their responses, the same field experimental data needed to develop empirical models is needed to parameterize and validate the DayCent model for the new practices. We will employ standard techniques of splitting the field study data sets of soil GHG responses to management practices, using a portion for parameterization and calibration and reserving the remaining studies for independent validation, computing standard model comparison metrics for model evaluation and iterative model refinement. Once the model performance has been optimized for each of the practices, revised parameter files and practice-specific databases and the updated DayCent webservice module will be integrated into the backend of the COMET-Farm system and Cool Farm Tool. We will gap-fill the emission and stock change database needed in the Cool Farm Tool for the new practices, by conducting a meta-model analysis using DayCent. The newly parameterized DayCent that is embedded within COMET-Farm will be used to simulate a large number of instances of each of the organic practices for randomly selected locations in the US, stratified by the major climate regions represented in the Cool Farm Tool and for soil types categorized by major texture types: coarse (e.g. sand, sandy loam), medium (e.g., loam, silt loam) and heavy (e.g., clays, clay loam, silty clay loam). Then the model results are treated as 'observations' that can be analyzed and aggregated into appropriately scaled stock change and emission factors using a modified version of the linear mixed effect model. The stock change and emission factors derived from the meta-model analysis will then be incorporated into the factor database that is used for GHG calculations in the Cool Farm Tool. The GUIs will be changed to allow users to specify cover cropping and double cropping more easily and to enable multi-year scenario planning to allow comparing alternative rotations. Multiple organic matter addition options will be added and capabilities to enable users to connect residue handling to compost production and utilization for life cycle accounting. Our stakeholder group will help inform the changes to the GUI to ensure usability while meeting the requirements for user inputs to drive the revised soil C and GHG emission algorithms. In year 1, we will host three stakeholder workshops co-located with regional organic farming conferences and near key supply chain stakeholders. These 1-day workshops will engage buyers and suppliers throughout the supply chain in discussions about effective uses of GHG quantification for encouraging, motivating and rewarding good practices and solicit input from stakeholders on the key organic practices to integrate into the decision support tools. We will collect and summarize case studies documenting benefits to farmers and other supply chain stakeholders. We will build understanding of these benefits received and anticipated over the course of the two years through stakeholder interviews in year 3 and in quantification of benefits from agronomic practices as modeled in the tools. In year 3, a subset of stakeholders from the year 1 workshops will be invited to a workshop to test and provide feedback on the decision support tools with the revised practices integrated. In advance of the workshop, we will provide instructions and support to participants to input their production or supply chain practices into both tools. During the workshop, we will solicit input on the user interface of the tools, the management menu options, as well as providing information on the science behind the estimates and the relative uncertainties of different estimates. Stakeholder feedback will be utilized to further improve and refine the management options and the user interface of both tools. We will utilize existing resources as well as input from stakeholder meetings to define and prioritize student learning outcomes related to GHG emissions and mitigation in organic agriculture. We will then utilize backwards design to create teaching materials that help students work towards being able to accomplish the

stated learning outcomes. Modules will be structured in two ways: 1) they will consist of specific case studies that allow students to examine scenarios at a specific farm, based on inputs provided by growers at stakeholder workshops; or 2) allow students to use tools for a place-based exploration of farming in their community. Both approaches have strengths and tradeoffs. With specific case studies, students will be able to learn about an operation in depth, using existing data to form conclusions, but such examples may not be directly relevant to student experiences. To students in the semi-arid High Plains, for example, the production challenges of New England are downright foreign, and vice versa. Specific farm case studies may allow remote exploration of a new place. In contrast, a place-based approach that could allow students to enter their home town and zip code into COMET-Farm as a starting point, would allow students a thorough exploration of scenarios relevant to their area, but would require more instructor involvement and background knowledge of regional farming systems to thoroughly guide student work. Therefore, learning modules will include a combination of these approaches, to give students the breadth and depth necessary to be able to understand and apply their skills in this area and provide support to instructors. Scenarios explored in these modules will meet National Organic Program requirements as well as practices cost-shared by NRCS. All courses will utilize student evaluations and formative assessments to measure success in meeting the stated student learning outcomes.

****Progress**** 09/01/16 to 08/31/21 ****Outputs**** Target Audience: Our target audiences include organic producers and ranchers, organic grower certification organizations, resource conservation agencies, organic food companies, students, the general public, researchers and extension personnel. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Two PhD students received mentoring and professional development through this project during this final reporting period. This project expanded faculty and research scientist professional networks, including linkages across the Cool Farm Alliance, through our project advisory board to private sector partners, National Resource Inventory staff and partners, FFAR OpenTEAM partners, and other colleagues. More than 90 undergraduate students received training in how to use freely available online decision support tools to simulate greenhouse gas emissions associated with different agricultural management practices. Student reflections highlighted the following areas of learning: 1) 11 students specifically mentioned something to the effect of "small changes can have big impacts", and a majority of students talked about specific choices of on farm practices that contribute to lower carbon emissions (18 of 30); 2) 14 of 30 students became more aware that there are a large range of variables that play into carbon emissions and that each operation is different. Also realizing that there are benefits and downsides to the variety of different methods that are used to manage agricultural emissions. Students reflected on positive changes and impact over time from conservation management practices.; 3) Many students commented on how management practice changes can lead to multiple benefits, including healthier soils, reducing carbon emissions, and a healthier environment as a whole. How have the results been disseminated to communities of interest? Results have been disseminated via research publications, presentations at scientific meetings, presentations at stakeholder meetings such as the Cool Farm Alliance annual meeting, and in the classroom via the outlined teaching activities. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

****Impacts**** What was accomplished under these goals? Objective 1. Research-based tool development Cover crop improvements in COMET-Farm The final publication documenting the calibration and validation process for improving the DayCENT model's capacity to simulate soil carbon changes for cropping systems that include different cover crop species was completed. In addition, through a new collaboration inspired by this project, a nationwide simulation of cover scenarios using DayCENT was completed and these data are currently being analyzed. Cover crop integration into Cool Farm Tool The dataset from the previously reported cover crop meta-analysis published from this project was used to develop regression equations to generate a proposed revision to the Cool Farm Tool cover crop module. During this final reporting period, additional regression testing and data analysis was done to determine best fit and evaluate this new model relative to the existing Cool Farm Tool methodology. This new model significantly improved upon the existing Cool Farm Tool methodology for estimating the greenhouse gas changes associated with cover crop practices. In addition, a new framework was developed for quantifying soil carbon in the Cool Farm Tool based on IPCC 2019. This new framework was designed such that when it comes to cover cropping in temperate climates, the new models developed based on regression equations from the meta-analysis dataset can be utilized. The revised methodology has been proposed and approved by the Cool Farm Alliance methods committee It has now been submitted to a stakeholder review processes that will run to mid-September 2021. Improving knowledge of the effects of organic amendments and grazing systems on soil carbon changes A 3-year field study evaluating the short and longer-term effects of compost additions to irrigated, improved pastures and non-irrigated semi-native pasture was completed. We found that the application of organic nitrogen in the form of compost increased plant production and soil carbon and nitrogen in surface soils in the irrigated, but not the dryland semi-native pasture. Aboveground biomass increased approximately 40% under the organic amendment in the improved pasture, while belowground biomass only differed between treatments in the first experimental year. In the improved pasture, soil organic carbon stocks increased by 1.3 Mg C ha⁻¹ yr⁻¹ after accounting for the C supplied by the organic amendment. Soil inorganic carbon was highly variable in both experiments contributing to about half or

more of total soil carbon at depth. This variability reduced our capacity to detect total soil C stock changes under the organic amendment below 10 cm, demonstrating the importance of considering soil inorganic carbon in carbon stock change estimates under improved soil management practices in semi-arid systems. Objective 2. Stakeholder outreach The revised Cool Farm Tool methodology and research results were presented at the 2021 Annual Conference of the Cool Farm Alliance. Over 250 people, from 122 companies, academic and non-profit organizations attended this meeting, held virtually on April 28. In addition, over the course of the last year Cool Farm Alliance added 42 new members growing from 77 to 118 members and partners. The growth and reach of the Cool Farm Alliance provide an indication of the scale of potential impact from this work. We continued to partner with Stonyfield Farms to develop case studies of organic dairy systems and improve the utility of the COMET-Farm Tool for simulating these complex systems. Objective 3. Education The Cool Farm Alliance launched a new Cool Farm Tool E-learning Course with updated video tutorials and user manuals for Crops, Beef, Dairy and Biodiversity, as well as guidance and resources for companies and farmers on how to get started and for creating sustainable action plans. We completed and published a manuscript outlining case study examples using COMET-Farm, COMET-Planner and the Cool Farm Tool for undergraduate agriculture courses. These case studies integrate learning about agricultural best management practices with the implications of these practices on climate change mitigation and greenhouse gas emissions. The use of these decision-support tools designed for farmer and industry/supply chain use allows students to represent the specificity of agricultural management practices, compare across management scenarios over realistic spatial and temporal scales, and make predictions on the impact of these practices. This information was tested in one undergraduate course at the University of Wyoming with 45 students and one course at Colorado State University with 45 students, shared through a seminar at the University of Northern Colorado, and is currently being integrated into a webpage that is near completion. **Publications** - Type: Journal Articles Status: Published Year Published: 2021 Citation: McClelland, S.C., Paustian, K., Williams, S., and Schipanski, M.E. (2021). Modeling cover crop biomass production and related emissions to improve farm-scale decision-support tools. *Agricultural Systems*, 191, p.103151. - Type: Journal Articles Status: Published Year Published: 2021 Citation: Jabbour, R., McClelland, S.C. and Schipanski, M.E. (2021). Use of decision-support tools by students to link crop management practices with greenhouse gas emissions: A case study. *Natural Sciences Education*, p.e20063. - Type: Conference Papers and Presentations Status: Published Year Published: 2021 Citation: Hughes H., S. McClelland, J. Hillier, M. Schipanski, K. Paustian. Cover crop impacts on soil carbon storage: Parameterising relationships for decision support tools. EuroSoil 2021. O014 H. Hughes1,* , S. McClelland2, J. Hillier1, M. Schipanski2, K. Paustian2

PROGRESS

2019/09 TO 2020/08 Target Audience: Our target audiences include organic producers and ranchers, organic grower certification organizations, resource conservation agencies, organic food companies, students, the general public, researchers and extension personnel. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? One graduate student received science communication and leadership training through the School for Global and Environmental Sustainability Leadership Fellows program. Undergraduate students received training and assisted with field-based research and soil analyses. How have the results been disseminated to communities of interest? We have continued to contribute to a new learning community of research, extension, and natural resource personnel interested in compost and grazing effects on grasslands of the Western U.S. Research results were presented at the Ecological Society of America annual meeting. What do you plan to do during the next reporting period to accomplish the goals? During this final reporting period, we will finalize publications, complete improvements to the Cool Farm Tool, and leverage our work to support broader collaborations. The Cool Farm Tool revised methodology for estimating cover crop impacts on soil carbon based on our team's research will be proposed to the Cool Farm Alliance and will hopefully be adopted. Manuscripts from the organic amendments and grazing field studies will be submitted. We will convene our advisory board for one final meeting to solicit input for the best ways to share our findings and to increase the longevity and impact of our work. We will continue collaborations with Stonyfield Farms and OpenTEAM to ensure that the GHG tools include management options realistic for organic dairy systems. We will collaborate with colleagues who conduct the National Greenhouse Gas Inventory to evaluate the potential impact of different cover crop scenarios on soil carbon stock changes.

2017/09 TO 2018/08 Target Audience: Our target audiences include organic producers and ranchers, organic grower certification organizations, resource conservation agencies, organic food companies, students, the general public, researchers and extension personnel. Changes/Problems: Due to the delay in funding and the decision to hire a PhD student rather than a postdoc, the project deliverables are delayed by about 6-9 months. The overall objectives will still be met on this delayed timeline. What opportunities for training and professional development has the project provided? An undergraduate intern conducted an independent research project to

evaluate the effects of compost additions on soil nitrogen dynamics in rangelands. The graduate student completed teaching assistant training and is receiving mentoring in teaching and research. How have the results been disseminated to communities of interest? Our team has presented lectures and workshops related to greenhouse gas emissions from agriculture at multiple conferences and stakeholder events. What do you plan to do during the next reporting period to accomplish the goals? We will complete the cover crop synthesis and integration into COMET-Farm during the next reporting period. This will then be used to inform improvements in the Cool Farm Tool. The organic amendments and management intensive grazing literature syntheses will be completed and integration into the tools will be initiated. Stakeholder workshops will be held that, in conjunction with input from our stakeholder advisory board, will inform user interface development and identify tool improvement priorities to improve adoption and usability for organic producers and food companies. The plan for hosting stakeholder workshops was amended and two in-person workshops will be facilitated this winter 2019 for 10-15 organic crop consultants and a session at the Cool Farm Alliance Annual General Assembly in March 2019 for 10-15 participants. COMET-Farm will likely do a similar workshop with either the Natural Resources Conservation Service (NRCS) staff or other COMET-Farm stakeholders. The curriculum modules will be developed based on scenarios using improved COMET-Farm and Cool Farm Tool interfaces.

2016/09 TO 2017/08 Target Audience: We have engaged food supply companies, organic producers, organic certifiers and other scientists during the first year of the project. Changes/Problems: We were delayed in hiring the proposed post-doctoral position and decided instead to staff the position with an excellent graduate student who had relevant literature synthesis experience and greenhouse gas emissions knowledge. This has delayed our timeline by about 6 months from what was initially proposed. What opportunities for training and professional development has the project provided? The graduate student presented an overview of her research proposal at the CSU Graduate Student Showcase and is receiving training in model use and development. 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? The next year will be important for moving from the initial phase of the work that is focused on literature synthesis and integration into the decision support tools to increased stakeholder engagement in adapting tools to meet their needs. Our goal is to publish the results from the cover crop synthesis and complete the cover crop calibration and validation work in DayCent. In addition, we will hold at least one stakeholder workshop and we will begin the development of the online learning modules.

IMPACT

2019/09 TO 2020/08 What was accomplished under these goals? Objective 1: Research-based tool development
Cover crops A cover crop meta-analysis that analyzed how different management and environmental factors affect soil carbon changes was published. The DayCent model was calibrated and validated using a broader cover crop dataset and for the introduction of an additional cover crop species, sunn hemp. This will improve the capacity of COMET-Farm to estimate greenhouse gas emissions and soil carbon changes associated with cover crop practices. This model improvement and analysis was submitted for publication. The meta-analysis dataset was used to develop regression equations to generate a proposed revision to the Cool Farm Tool cover crop module with expected completion in spring 2021. Organic amendments and management intensive grazing systems We completed a 3-year field-based research study to evaluate the effects of compost additions on pasture productivity and soil carbon dynamics. Objective 2: Stakeholder Outreach We collaborated with Stonyfield Farms and OpenTEAM partners to collect organic dairy farm management practice data across a range of farms during the 2020 field season. Objective 3: Curriculum Development The COMET-Farm tool has been used within the curriculum of several undergraduate courses at CSU and the University of Wyoming. Dr. Jabbour developed similar teaching modules using the Cool Farm Tool and submitted a manuscript for publication to highlight how these online tools and different case studies can be integrated into agricultural courses. This is particularly timely and relevant given the high demand for online teaching resources in response to the COVID-19 pandemic. **PUBLICATIONS (not previously reported):** 2019/09 TO 2020/08 1. Type: Journal Articles Status: Published Year Published: 2020 Citation: McClelland, S.C., Paustian, K., Schipanski, M.E. 2020. Management of cover crops in temperate climates influences soil organic carbon stocks: a meta-analysis. *Ecological Applications*. <https://doi:10.1002/eap.2278>. 2. Type: Journal Articles Status: Submitted Year Published: 2020 Citation: McClelland, S.C., K. Paustian, S. Williams, M.E. Schipanski. (submitted) Modeling cover crop biomass production and related emissions to improve farm-scale decision-support tools. *Agricultural Systems* 3. Type: Journal Articles Status: Under Review Year Published: 2020 Citation: Jabbour, R., S.C. McClelland, M.E. Schipanski. (submitted) Use of decision-support tools by students to link crop management practices with greenhouse gas emissions: A case study. *Natural Sciences Education* 4. Type: Conference Papers and Presentations Status: Published Year Published: 2020 Citation: McClelland, S.C., M. Schipanski. Above and

belowground community responses to infrequent compost applications in semi-native and improved pastures. Ecology Society of America annual meeting. August 6-9, 2020.

2017/09 TO 2018/08 What was accomplished under these goals? Objective 1. Research-based tool development Cover crops (estimated 75% completion - on schedule) During this reporting period, the literature/data search has been completed for Cover Crops. The graduate student with the aid of two undergraduate students has entered ~100 papers into the database. Cover crop studies have been used to calibrate and validate the DayCent model which informs COMET-Farm. Options on the graphical user interface to include cover crops is now fully operational in the development version of COMET-Farm, including species selection, planting and termination dates, and other management options (fertilization, irrigation, amendments, tillage). Work is ongoing with model parameterizations and testing for grass/forb/legume mixtures as well as specific cover crops including cereal rye, sun hemp, brassicas (canola, carinata), sudan grass, clover, vetch pea and radish. Organic amendments (estimated 65% completion) Major improvement in the DayCent model operating within COMET-Farm has been to partition total N in organic amendments (e.g., manure, compost) into both organic and inorganic (i.e., mineral N forms) as a function of different types (e.g., sources, waste handling procedures) of organic amendments. This change gives a better representation of short term crop responses to N availability vs larger term feedbacks on soil processes. Testing of the new algorithm is ongoing with published datasets. We also have a new collaboration (with outside support) with UC-Berkeley to obtain some new (unpublished) data sets on compost addition to pastures to test the system with. We are only marginally behind the original planned schedule. Management intensive grazing systems (estimated 50% completion) The literature search for Management Intensive Grazing, completed in fall 2017, yielded 200-300 papers of which 100-150 were relevant. Field data is being collected from on-farm research focused on the interaction of management intensive grazing and organic amendment additions to irrigated and non-irrigated grasslands. Objective 2: Stakeholder Outreach A workshop was hosted at Expo East in Baltimore, MD on September 14, 2017. Initial findings from the meta-analysis and CoolFarm Tool mock-ups of potential interface changes to cover crop and grazing modules for feedback were shared during the workshop. The team also presented at several other conferences and workshops. Objective 3: Curriculum Development The Climate Change module introduces concepts related to climate change and agriculture and was piloted on three undergraduate agriculture students at the University of Wyoming, and feedback was sought from these students to improve the clarity of the module. This objective was scheduled for completion in project years 2 and 3. ****PUBLICATIONS (not previously reported):**** 2017/09 TO 2018/08 1. Type: Conference Papers and Presentations Status: Accepted Year Published: 2019 Citation: McClelland, S. R. Conant, M. Haddix, M. Schipanski. Soil health impacts of infrequent compost application in irrigated perennial pasture system. Soil Science Society of America, January 7-10, 2019. 2. Type: Conference Papers and Presentations Status: Accepted Year Published: 2019 Citation: Jackman, J. S. McClelland, M. Schipanski. Impact of compost soil amendment on nitrogen availability in grazed perennial grasslands Soil Science Society of America, January 7-10, 2019.

2016/09 TO 2017/08 What was accomplished under these goals? We hired a graduate student who started in June 2017 to initiate the literature review work required to improve the COMET-Farm and Cool Farm Tool to include key organic practices. A comprehensive literature review was completed for studies that included cover crops and greenhouse gas measurements and/or soil carbon measurements and/or basic cover crop growth dynamics. These studies have undergone an initial screening and the top priority papers have been entered into a database that can be used to calibrate and validate the DayCent model, which is the process-based model that informs COMET-Farm. In addition, the preliminary comprehensive literature review for studies focused on management intensive grazing was completed. Under Objective 2, we presented and led a stakeholder workshop at the Natural Products EXPO East in Baltimore, MD, to communicate the project goals and solicit feedback. Our team members also participated in a FFAR listening session to discuss opportunities to improve inter-operability across decision support tools, including tools such as FarmOS and others. In terms of project management, we held monthly team conference calls and hosted 2 webinars for our advisory board that provided an introduction and overview of both decision support tools. ****PUBLICATIONS (not previously reported):**** 2016/09 TO 2017/08 Type: Conference Papers and Presentations Status: Accepted Year Published: 2017 Citation: D. Malin. Decision support tools: Measuring carbon in agricultural supply chains. Organic Agriculture: Climate Change Champion panel presentation. Natural Products Expo East. Baltimore, MD, September 15, 2017.

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The Development of an Organic Crop Budgeting Tool to Help Advise Producers

Accession No.	1010457
Project No.	KS1011727
Agency	NIFA KAN\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2016-51106-25716
Proposal No.	2016-06199
Start Date	01 SEP 2016
Term Date	31 AUG 2019
Grant Amount	\$369,853
Grant Year	2016
Investigator(s)	Ibendahl, G. A.

NON-TECHNICAL SUMMARY

Budgets are one of the most important tools producers use when deciding on which crops to grow. Even producers growing conventional crops, with which they have much experience, rely on crop budgets. Crop budgets are some of the most requested publications that Extension specialists publish. Producers receptive to growing organic crops face two hurdles: first, very few organic crop budgets exist; and two, these producers have no experience growing organic crops. Thus, there is much uncertainty about the production practices, the cost of inputs, and the profitability of organic crops. These producers need a tool which can generate an organic crop budget so that they can assess the profitability of organic crops for their farm operations. Without a way to eliminate some of the uncertainty about organic profitability, potential organic producers will probably continue to grow conventional crops. Our objective in this proposal is to determine the production practices of organic producers, collect price information about the needed inputs, develop a crop budgeting tool, and produce organic crop budgets so that the profitability of organic crops can be estimated for a producer. This contribution is significant because we are developing a regionalized database of inputs and prices for organic crop production that doesn't currently exist and integrating this database into an organic crop budgeting tool that will make it significantly easier for producers and Extension personnel to estimate organic profitability. This project addresses the recently added priority area for development of educational tools for Cooperative Extension personnel.

OBJECTIVES

The long-term goal is to provide the most effective decision aids and the most complete and accurate information about the profitability of organic crops so that any potential producer of organic crops can make good decisions about whether or not to actually grow organic crops. Our objective in this proposal is to determine the production practices of organic producers, collect price information about the needed inputs, develop a crop budgeting tool, and produce organic crop budgets so that the profitability of organic crops can be estimated for a producer. The specific objectives of the project are: Identify the production practices and the inputs required for a range of organic crops and regions of the country. ?Our approach will be to identify a contact (probably a state Extension specialist) from a state or several states within a USDA-ERS farm resource region (9 regions in all) and survey them to find the production practices used for some of the major organic crops within each region. ?Develop a database of organic inputs and prices of those inputs on a regional. Our approach will be to take the inputs identified from objective (1) and build a regional price database by calling input suppliers for their cost to

purchase the inputs. Where prices of inputs don't readily exist (i.e., manure), techniques based on a review of literature will be used. ?Develop an organic crop budgeting tool that is clear, easy to use, and that produces accurate, timely, and relevant information about the revenue and expenses for organic crops?Our approach will be to take the Kansas State Budget Generator (which is an offshoot of the Mississippi State Budget Generator) and modify it to include all the inputs needed for organic production and to allow it to generate budgets that vary by region. ?Develop a set of organic budgets for the major organic crops in each of the regions used in objective (1).Our approach will be to take the production practices identified in objective (1), the crop budgeting tool and prices identified in objectives (2) and (3), and produce a set of regional organic crop budgets for the major organic crops. ?Distribute the organic crop budgeting tool developed in objective (3) and the organic crop budgets developed in objective (4) to Extension personnel across the countryOur approach will be to take organic crop budgeting tool and the associated budgets that were produced and first make them available on the Kansas State University AgManager.info website. Next the tool and the budgets will be provided to state Extension specialists across the country who work with budgets or organic crops.

APPROACH

METHODSCollecting feedback - Because the organic crop budgeting tool being developed will be hosted on one of the leading farm management sites (AgManager.info), it should receive a lot of exposure. We plan to build into the budgeting tool a frontend link that asks for feedback. This link should work something like the links that many mobile apps provide when those apps first open. If users follow the provide link on the startup screen of the organic budget generator, they will be taken to a page where they can rate the tool and provide feedback.We plan to also work with other state Extension specialists and gather their feedback directly or have those specialists help us identify end users of the organic budgeting tool. The feedback and suggestions we gather will help direct the tool as it develops. An initial version of the organic budgeting tool is planned after year one of this project and it will be improved based on feedback during the remainder of the project.**Activities** - Before any organic budgets can be developed, the major organic crops within a region must be identified along with the inputs that are being used to grow these crops. We plan to use the nine USDA-ERS farm resource regions: Eastern Uplands, Heartland, Southern Seaboard, Northern Crescent, Fruitful Rim, Northern Great Plains, Basin and Range, Prairie Gateway, and Mississippi Portal. Within these nine regions, we will identify five of the major organic crops for a particular region. With nine regions and five organic crops per region, we will have 45 sets of production practices to identify. A set of surveys and telephone calls to key state Extension specialists within each region will help us identify the needed production practices.**Budgeting tool** - A key technique of the budget generator tool is treating each trip across the field as a separate input item. Thus producers and Extension personnel can think about production practices in a sequential manner as they develop budgets. For each field trip, users can input the type of machinery operation and also any inputs used. This sequential approach is a time tested method of generating budgets and was first developed for the Mississippi State Budget Generator. None of the spreadsheet budgeting tools approach their budgets in a similar fashion. The result is a budget that is less prone to errors.The generation of production practices, the list of inputs, and the price of those inputs will be done through surveys and direct communication with state Extension specialists. Some of the pricing information may require a review of literature to determine the appropriate pricing technique. Manure pricing is an example of an input where prices may not be directly available.**Monitor and evaluation of Research, Extension, and Education activities** - The budgeting tool will include a link on the introduction screen that will take users to a site where they can provide feedback and rate the tool. As we expect to have the first version of the tool posted to the AgManager.info website by the end of the first year, we will have two years to generate feedback. Also, on the AgManager.info site we will have links posted requesting feedback along with any printed versions of the budgets.We also plan to send out surveys to state Extension personnel working on budgets to gauge their feedback to the budgeting tool and the budgets. Finally, we will have the limited set of currently available organic budgets to use as a check on the regional budgets we produce. There should be agreement with the expected costs and returns. ****Progress**** 09/01/16 to 08/31/21 ****Outputs**** Target Audience: The final target audience is to reach Extension agents and organic producers themselves with a decision making tool that will help organic producers develop a crop budget. Because organic crop budgeting is just a subset of traditional crop budgets, our tool was expanded to handle any kind of crop budget. As a result, we are reaching non-organic farmers and farmers who are looking to transition to organic crop production.We did interact with organic growers in Kansas to determine their crops and what they are interested in. The graduate student working on this project also used a test farm in Illinois to identify some of the issues with converting to organic We have presented preliminary results of our work at several academic conferences including the SAEA (Southern Agricultural Economics Association) meetings and the WAEA (Western Agricultural Economics Association) meetings. In addition we have presented at the Kansas State Risk and Profit conference which is a two day conference for farmers, lenders, and others working in agriculture. This conference typically has 150 people attend. We have also demonstrated this tool to the Kansas Extension agents and shown them how they can use this tool. A series of instructional videos is

posted on AgManager so that anyone interested in using the tool can get up to speed. We were able to reach farmers, lenders, Extension specialists, students, and others interested in agriculture and budgets by posting information on AgManager.info. The AgManager.info site is one of the leading sources of agricultural information across the country. While AgManager may not be quite as well known as FarmDoc, the AgManager site does have a broad reach and most people connected with agriculture have used the site. K-State is one of the leading universities producing crop budgets and this tool helps provide access to the variables that farmers need to evaluate the profitability of various crop practices using a variety of production practices including both conventional and organic crop budgets. Our budgets are especially valuable to those producers looking to analyze those budgets in more detail as we provide a database of inputs that go down to the specific input level.

Changes/Problems: Covid limited the opportunities to develop specific budgets outside of Kansas. However, the organic budgeting tool is fully functional and producers should be able to easily develop their own crop budgets. The ability to compare a non-organic budget to an organic budget should be of great interest to those looking to transition to organic production. There are currently a series of videos on YouTube (via AgManager) that explain how to use the tool. These instructional videos will be expanded to include more detail about developing a budget from scratch or modifying an existing budget to make it fit a specific region. What opportunities for training and professional development has the project provided? This crop budgeting tool has been demonstrated extensively in Kansas both to producers and county Extension agents. In addition, the tool has been shown to Extension professionals from other states at various meetings. AgManager has links to instructional videos that can help a new user learn how the tool works. There are additional trainings planned within Kansas for use of the budgeting tool. These trainings will also be provided on AgManager.info as they occur. Because this tool is also used to generate the 60 or so crop budgets that Kansas State produces each year, the tool is in continual refinement with ongoing education. How have the results been disseminated to communities of interest? All of the tools are available on AgManager.info. These include the budget generator tool and the machinery cost tool. The instructional videos are linked from AgManager back to YouTube.

What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

****Impacts**** What was accomplished under these goals? The major accomplishments of this project were to develop an organic crop budgeting tool and a database of organic inputs and prices. There is no other tool in the country that can help a producer estimate the cost to produce an organic crop just by inputting the steps of production like the tool developed here. The tool has a full database of machinery information and a limited set of organic inputs already in place. In addition, users can add their own specific machinery or their specific inputs and the budgeting tool will take care of the cost calculations, the unit conversions, and generate the appropriate cost per acre for the production step. The budget generation process is easy for most users as nearly all budgets can be produced by using a set of drop-down menus. Only a few quantities are actually required to be entered during the budget generation process. To develop these tools and databases, we examined crops across the county. There were also two offshoots of this project. The first offshoot was the development of a machinery cost tool. This is built into the budget generating tool but was spun off as a separate deliverable since mechanized weed control is important to organic crop producers. The second was a crop budget and leasing tool. This tool uses the budgets from the budget generator to examine combination of crops and various lease arrangements. Until this project started, there was only one tool in the country that helped producers develop their own crop budgets, the Mississippi State Budget Generator. The Mississippi tool, however, was at least 30 years old and was developed in FoxPro. The tool has not seen any development in the last 20 years and FoxPro has long been unavailable. The result is the Mississippi State Budget Generator is difficult to use compared to modern software. In addition, the tool has no ability to limit inputs for organic production. Nearly all other crop budgets in the country are either hard copy PDF files or possibly an Excel spreadsheet. While many of these allow a user to input their own numbers, that kind of input assumes a user actually knows what that cost is. For some things like fertilizer, that might be fairly simple. However, because organic production relies on a great deal of machine usage for weed control, the issue is much bigger. Estimating the machinery costs is probably the most difficult part of a crop budget as it involves not only the variable costs like fuel and labor but it also requires estimating the fixed costs that go along with owning and using a machine and implement. Agricultural engineers have developed formulas that can calculate these costs but the formulas are complicated and a typical producer has little interest in spending hours estimating machinery costs. The end result is that a typical crop budget published on the web, is difficult to modify. Trying to develop a new budget from scratch is nearly impossible with the available tools. The ability to develop a crop budget from scratch is where the organic crop budget developed as part of this grant really shines. To develop a crop budget, producers have 5 stages to go through. First, there is a page to enter some basic crop information like the budget name, date, and interest rates. The second page is where the crop output is selected. This includes the expected quantity and the price. This second page is what generates the gross revenue. The third page is where production inputs like fertilizers, seeds, pesticides, etc. are selected. The user just needs to enter the quantity as the rest of the process is via drop-down menus. Because this tool can do both organic and conventional crop budgets, there is a switch users can check to limit available inputs to just organic inputs. The fourth page is where the machinery operations are entered. This is entered again via drop-down menus. The user just needs to input

the number of trips. Users have the option of either using a custom rate or their own machinery for a particular field operation. The budget tool itself takes care of all the calculations that go into producing a cost per acre for a specific field trip with a specific set of equipment. The tool calculates the labor, fuel, repair, and fixed cost on a per acre basis. The last page is to combine any budgets together and then print them out. The back-end databases are readily accessible to users and the budget tool makes it easy to add new machines and inputs. This is especially important as many organic products use speciality products that vary greatly by price.

Specific objectives:

- 1) identify production practices and inputs: These vary widely but machinery use is much more prevalent with organic crop production as there are limited weed control options for organic producers. We identified an entire range of equipment as part of this process.
- 2) develop a database of organic inputs and prices: We have made the database of inputs readily available to users and the process of adding new inputs and machines is straight forward. Users can adjust the current set of input prices if needed. The database side of the budgeting tool has seven sections:
 - 1) Universal inputs - This page has the fuel prices and the interest rates.
 - 2) Products page - This page is where the end products are listed. While products can be entered directly into the budget section. The database side allows a user to store an end product for use in other crop budgets.
 - 3) Various labor rates per hour are stored here. Currently the database includes operator labor, irrigation labor, additional labor, harvest labor and other labor. Users can add more labor types as needed.
 - 4) Custom operations - This part of the database consists of custom operation surveys from both Iowa and Kansas. Included in these surveys is a wide range of custom rates for a wide variety of field operations. The custom operations are divided into 13 categories. Users can add their own rates if needed.
 - 5) Machinery - This page has all the machinery cost information for a wide variety of tractors, harvesters, and implements. There are also a wide variety of sizes. Implements are already matched with a tractor. If a user wants to add their own specific machinery, they need to include the cost, life, salvage value, and hours per year. The rest of the needed inputs are fairly standard across equipment. New tractors require a fuel consumption per hour. Based on this information, the calculator can calculate the labor, fuel, repair and maintenance and fixed costs both on a per hour and per acre basis.
 - 6) Op Inputs - This page has the operating inputs like seeds, fertilizers and pesticides. Because many inputs can't be used in organic production, each input has a check box to indicate if allowed for organic production. This prevents a user from accidentally choosing a non-organic input for an organic budget.
 - 7) Irrigation - This page has the cost of irrigation equipment. It is very similar to the machinery page.
- 3) develop an organic crop budgeting tool: We fully addressed this objective with a tool that exceeded what was planned. The spin off tools are extras that came about.
- 4) develop organic budgets for crop regions: Because of covid, this objective was not fully realized. When exploring crop budgets across the U.S. it was obvious they varied tremendously. Thus a single budget for a region wouldn't be that helpful. However, because of the ease of the budget development and the example budgets included, tailoring a budget to a specific crop in a specific region shouldn't be difficult.
- 5) distribute the budgeting tool: The crop budgeting tool has been distributed through AgManager.info at Kansas State University. This site has a wide reach and is a go-to site for many Extension professionals as well as farmers. In addition, this tool has been demonstrated in Extension meetings and at professional workshops. There are instructional videos available on YouTube.

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PROGRESS

2016/09 TO 2017/08 Target Audience: The final target audience is to reach Extension agents and organic producers themselves with a decision making tool that will help organic producers develop a crop budget. During this first year, our major priority was to identify all the major organic crops in each state. Because of the nature of this work, we were in the data collection phase and did not produce any deliverables. We did interact with organic growers in Kansas to determine their crops and what they are interested in. The graduate student working on this project also used a test farm in Illinois to identify some of the issues with converting to organic

Changes/Problems: We have increased the detail from the 9 ERS regions to the state level. We eventually wanted to get to the state level anyway and as there was data available about organic crop production at the state level, we decided to minimize the ERS region approach. The ERS regions don't seem to be used much from our analysis. What opportunities for training and professional development has the project provided? Nothing Reported 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 should have the survey of organic production practices and inputs completed during this next year. We will also start work on identifying the cost of each of the inputs. Both of these databases will be key elements of the organic crop budgeting tool. We will continue work on the budgeting tool as well during this next period

IMPACT

2016/09 TO 2017/08 What was accomplished under these goals? We have worked on identifying the major organic crops in each region. We actually now have all the organic crops for each state. In the database we have developed, we have the biggest organic crops by both volume and also by value. We will use this list of major organic crops to develop the survey to producers and Extension educators to find out more about the production practices and inputs. We are currently developing an on-line survey instrument that will ask these producers and Extension educators about what inputs they are using, how much of the input, and what other production practices they are following. Basically, this survey will ask for what happens each time they do something with a field of a particular organic crop. The database of organic crops will be used to guide this survey. We have also starting working on the organic crop budgeting tool. **PUBLICATIONS (not previously reported):** 2016/09 TO 2017/08 No publications reported this period.

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Leveraging Management to Speed Degradation of Bio-based Mulches in Soil

Accession No.	1010456
Project No.	NEB-22-383
Agency	NIFA NEB\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2016-51106-25711
Proposal No.	2016-06178
Start Date	01 SEP 2016
Term Date	31 AUG 2019
Grant Amount	\$499,718
Grant Year	2016
Investigator(s)	Wortman, S.

NON-TECHNICAL SUMMARY

Polyethylene (PE) plastic mulch is commonly used in organic vegetable production, but disposal is a serious environmental problem. Bio-based mulch (biomulch) is a sustainable alternative to PE mulch because it can be incorporated into soil and biologically degraded. Biofabric mulches, in particular, show promise as a replacement for PE mulch on organic farms because they are 100% bio-based and more durable than other types of biomulch, but they are often slow to degrade in soil. The goal for this integrated project is to develop practical management tactics to speed the degradation of biofabric mulch in soil and transfer results to organic farming stakeholders and students. A field study will be conducted to test the effects of mulch incorporation method, compost, and cover crops on the rate of biomulch degradation. We will collect soil chemical, physical, and microbial data at six-month intervals to understand the drivers of biomulch degradation and determine the fate of degraded biomulch in soil. Project results will be disseminated through conferences, publications, social media, webinars, and YouTube videos. Lastly, project results will be used in a new online class titled, "Innovations in Sustainable Agriculture," which will feature guest lectures from innovators in the green industry. Our project goals are compatible with ORG goals to "demonstrate the potential for organic farming systems to provide essential environmental services" (soil decomposition of a waste product) and "develop cultural practices and other allowable alternatives to substances recommended for removal from the National Organic Program" (biofabric as a replacement for PE mulch).

OBJECTIVES

The long-term goal for the proposed project is to increase the environmental sustainability of organic agriculture by reducing the demand for polyethylene mulch in vegetable production. This will be achieved by developing practical on-farm methods for speeding soil degradation rates of biofabric mulches and transferring this new information to organic farmers and students interested in organic farming. The project goal is framed by three research objectives, one education objective, and one extension objective: Objective 1. Explore management strategies that increase the rate of biomulch degradation after incorporation in soil. Objective 2. Characterize the microbial drivers of biomulch degradation in soil. Objective 3. Determine the fate of biomulch after decomposition in soil and the effects on soil properties. Objective 4. Develop curriculum for and teach a new undergraduate course titled, "Innovations in Sustainable Agriculture." Objective 5. Disseminate project results to stakeholders including, organic farmers, researchers, and policy-makers.

APPROACH

Toward completion of the first three project objectives, a 3×2×2×2 factorial randomized complete block design field experiment will be replicated across two diverse locations in Nebraska. Locations will include transitional or certified organic land at the Agricultural Research and Development Center near Mead, NE and the Panhandle Research and Extension Center near Sydney, NE. The experimental factors and treatment levels will include: Factor 1: Post-harvest biomulch management Treatment 1: Biomulch removed for disposal and field roto-tilled (control) Treatment 2: Biomulch incorporated in soil via roto-till Treatment 3: Biomulch incorporated in soil via flail-mow + roto-till. Factor 2: Compost amendment Treatment 1: No compost (control) Treatment 2: 10 Mg ha⁻¹ compost applied at time of biomulch soil incorporation. Factor 3: Cover crops Treatment 1: No cover crop (control) Treatment 2: Cereal rye (*Secale cereale*) + hairy vetch (*Vicia villosa*) mix planted after biomulch soil incorporation in year one and in the fall of year two Factor 4: Farmer choice (e.g., irrigation) Treatment 1: TBD (control) Treatment 2: TBD. In mid-May of year one, the experimental biofabric (3M Comp.) will be field-applied to raised-beds with a bed shaper/mulch layer and green bell pepper (*Capsicum annuum*) seedlings will be transplanted with 46 cm between plants. Peppers will be harvested regularly through late-September, and experimental treatments (above) will be imposed at the time of biomulch soil incorporation in early-October. Biomulch will be sampled regularly over the course of 24 months (details below), but during that time we will mimic an on-farm scenario and continue annual crop production in the experimental area. We will rotate to beans (*Phaseolus* spp.) in year two and a cole crop (*Brassica* spp.) in year three. Immediately following biomulch soil incorporation in year one, soil from within a 2 m² (1 × 2 m) quadrat will be excavated to recover biomulch residues via sieve. Recovered residues within each plot will be cleaned and surface area will be measured using a portable leaf area meter. Residues will then be distributed evenly among eight nylon mesh bags (250 µm mesh; 15 × 15 cm) along with 500 g of field soil from respective experimental plots and buried to roto-tillage depth (approximately 10 cm) within each original sampling quadrat. The location of each mesh bag will be marked with flags and two of the eight bags will be recovered at each sampling interval (6, 12, 18, and 24 months after soil incorporation). One bag will be used to clean and measure the surface area of recovered residues; the other bag being immediately frozen for microbial analyses. Remaining mesh bags will be temporarily removed from plots during field operations that could potentially disturb the samples (e.g., tillage or planting) in year two and three. From the surface area data, we will calculate percent mulch area remaining (PMAR) at each sampling interval. We will monitor environmental conditions at each site and within experimental plots to account for possible factors driving biomulch soil degradation. Weather data will be collected for all years of the experiment from the High Plains Regional Climate Center (<http://www.hprcc.unl.edu/>). Soil temperature will be continuously measured in each experimental plot using HOBO Pendant temperature loggers (Onset Computer Corp., Bourne, MA). We will collect soil samples to roto-tillage depth within each experimental plot at the time of biomulch soil incorporation and at every mesh bag sampling interval thereafter. Ten samples per plot will be aggregated into one composite sample, sieved, and immediately sent to Ward Labs (Kearney, Nebraska) for complete chemical analysis. For biofabrics to be considered a "success" and potentially compatible with certified organic agriculture, we will need to achieve less than 10% PMAR by 24 months. We will use analyzed data to determine which suite of management practices is most effective for speeding the rate and final amount (PMAR) of biomulch degradation in soil. Toward objective 2, frozen mesh bags will be briefly thawed in the refrigerator to allow passage of the soil through a 4 mm sieve. Biomulch fragments greater than 4 mm will be removed using tweezers, stored in plastic bags and refrozen for further analysis. Soil and biomulch passing through the sieve will be partitioned into three subsamples for analysis of soil microbial biomass and microbial community structure using fatty acid methyl ester (FAME) profiling (Drijber et al., 2000), soil enzyme activities important to residue decomposition (Bowles et al., 2014), and soil chemical properties (pH, EC, NO₃⁻, NH₄⁺, Bray P; Ward Labs, Kearney NE). To evaluate the impact of the mesh bag environment on the decomposer community, soil cores will be taken from bulk soil in selected plots for comparison purposes. Biomarker fatty acids specific to bacteria and fungi can be used to calculate the relative abundance of these two taxonomic groups in soils (Frostegard et al., 2011; Strickland and Rousk, 2011)). The enzymes targeted for this research include nine enzymes \C-cycling (α-galactosidase, β-glucosidase), C/N-cycling (β-glucosaminidase), N-cycling (aspartase, L-sparaginase, urease), P-cycling (acid phosphatase, alkaline phosphomonoesterase) and S-cycling (arylsulfatase) important to plant residue decomposition and nutrient cycling, as these are the processes potentially impacted by the presence of biomulch and its subsequent decomposition. To accomplish the third objective, soils will be sampled using the clod method for wet aggregate stability determination (Nimmo and Perkins, 2002) from selected plots at the time intervals outlined in objective 1. Bulk soil from the 0-15 cm depth will be collected using a shovel with a flat base, gently broken up into smaller clods, then dried in labelled paper bags for 72 h in a nonheated forced-air drying oven. Half the sample will be sieved to obtain at least 100 g of aggregates between 4.75- and 8-mm. The second half will be passed through a 2 mm sieve for chemical analyses. Wet aggregate stability will be determined using a mechanical device containing nested sieves with 4.75, 2, 1, 0.5 and 0.25 mm diameter openings, stacked in

descending sequence (Blanco-Canqui et al., 2014). Aggregate data will be corrected for sand content. Recovered aggregates from selected size classes will also be subjected to dispersion and wet sieving and/or density separation to isolate fragments of biomulch incorporated into stable aggregates. Project results will be disseminated to target audiences through a combination of grower (e.g., Nebraska Sustainable Agriculture Society) and academic meetings, USDA NIFA PD meetings, peer-reviewed publications, and online tools (project website, Twitter, and YouTube videos). Project activities, results, and personnel will also contribute to the development of a new online undergraduate course titled, "Innovations for Sustainable Agriculture." Biomulch is an innovative solution to a long-standing environmental problem in vegetable farming (polyethylene mulch use) and the topic will provide a logical case-study and starting point for the development of this new class. The objective of the new course would be to present, discuss, and explore the science of and market potential for innovative products, technologies, or techniques that could improve the sustainability of agriculture. The course will feature guest lectures from industry (including key personnel from this project) on a regular basis to help students identify sustainability problems in the food system and potential industry solutions for those problems.

PROGRESS

2016/09 TO 2020/08 Target Audience: Project results were communicated to researchers, educators, and students interested in organic agriculture through the following presentations during the this final reporting period: Wortman, S.E. Innovations in biomulch composition and applications. American Society for Horticultural Sciences Annual Conference, Plasticulture Professional Interest Group Workshop (Invited). Orlando, FL. August 2020. (40 organic and specialty crop researchers and educators attended oral presentation and workshop discussion) Wortman, S.E. Biobased inputs for weed management in specialty crops. Iowa State University, Department of Horticulture Seminar Series (Invited), Ames, IA. October 2019. (30 students and educators interested in organic agriculture attended the seminar) Drijber, R. A., M. B. Samuelson, E. Reid, E. S. Jeske, H. Blanco, M. Mamo, and S. E. Wortman. 2019. Biodegradable mulch loss and legacy effects on vegetable crop yield, soil microbial communities and soil properties. ASA-CSSA-SSSA Annual Meeting, San Antonio, TX. (on display at conference for one day and viewed by approximately 50 organic researchers and educators) Organized and co-hosted seminar with Nebraska Innovation Studio. Seminar speaker: Dr. Ignatius Kadoma, 3M Comp. Topic: Bio-based mulch innovations for Organic Farming. September 2019. (attended by 30 students, researchers, and educators interested in organic agriculture) Wortman, S.E. Innovations and Entrepreneurship in Urban and Organic Agriculture. "Growing Plants for a Purpose - Urban Ag Event" for Omaha Bryan Urban Agriculture Program. Organized by Tai Pleasant, Department of Agronomy and Horticulture. September 2019. (attended by 40 high school students interested in urban and organic agriculture) Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Two graduate students (Mitchell Ben Samuelson and Elise Reid) were trained and objectives 1, 2, and 3 formed the basis of their thesis. They were both mentored by Dr. Ashley Thompson (post-doc) currently a faculty at Oregon State. Twelve undergraduate students were trained in field and lab research methods as a result of this project, and were mentored by graduate students and post-doctoral associate. A visiting research scientist from Brazil, Mauro Tofanelli, also received training in greenhouse and lab techniques related to biodegradable mulch and organic agriculture. How have the results been disseminated to communities of interest? Findings were presented to 40 students from Bryan High School in Omaha, NE enrolled in the urban agriculture pathways program. This presentation was part of an outreach and undergraduate student recruitment event. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

2017/09 TO 2018/08 Target Audience: At least 20 Extension educators, at least 30 organic farmers, at least 30 organic researchers, and an unmeasurable number of general public received information about this project through one field day, a poster at a grower conference, three posters at academic conferences, and segments on public radio and television. Presentations: Samuelson, M. B., R. Drijber, E. Jeske, and S. E. Wortman. 2018. Assessing microbial communities of compost extracts and their effects on lettuce growth after residue incorporation in soil. American Society for Horticultural Science (ASHS) Annual Conference. Washington, D.C. Thompson, A. A., M. B. Samuelson, I. Kadoma, R. Drijber, and S. E. Wortman. 2018. Commercial biostimulants increase biodegradation of polylactic acid based agricultural mulches containing alfalfa or soy particles. American Society for Horticultural Science (ASHS) Annual Conference. Washington, D.C. Wortman, S. E., and D. Lambe. 2018. Innovations for Agriculture: Prototyping solutions to sustainability challenges. NACTA Annual Conference, Ames, IA. Samuelson, M. B., R. Drijber, E. Jeske, T. Powers, R. Higgins, and S. E. Wortman. 2018. Biological properties of compost extracts and effects on residue processing. SARE/ATTRA Our Farms, Our Future Conference. St. Louis, MO. Vegetable Research Field Tour, Kansas State University Extension Agents and Specialists. June 2018. Interviewed for segment about biodegradable mulch on NET/Nebraska Extension "Backyard Farmer." August 2018. <https://extensiontv.unl.edu/v/5815> Research collaboration featured in 3M

Annual Sustainability Report, in article titled, "Biodegradable mulch material gets field test." May 2018. Interviewed about bio-based mulch research for Nebraska Extension Almanac. January 2018. <https://extensionalmanac.unl.edu/Changes/Problems:NothingReported> What opportunities for training and professional development has the project provided? Two graduate students (Mitchell Ben Samuelson and Elise Reid) are being trained on this project, and research in objectives 1, 2, and 3 will form the basis of their thesis projects. They both worked closely with a post-doctoral associate, Ashley Thompson, who recently accepted a faculty position at Oregon State University in year two of this project. Six undergraduate students have been trained in field and lab (soil chemical, physical, and microbial) research methods as a result of this project, and have been managed by the graduate students and post-doctoral associate. How have the results been disseminated to communities of interest? An unmeasurable number of general public received information about this project through segments on public radio and television and through a corporate sustainability report. Interviewed for segment about biodegradable mulch on NET/Nebraska Extension "Backyard Farmer." August 2018. <https://extensiontv.unl.edu/v/5815> Research collaboration featured in 3M Annual Sustainability Report, in article titled, "Biodegradable mulch material gets field test." May 2018. Interviewed about bio-based mulch research for Nebraska Extension Almanac. January 2018. <https://extensionalmanac.unl.edu/> What do you plan to do during the next reporting period to accomplish the goals? During the next reporting period, we will complete all project objectives. We will conduct at least two additional mulch recoveries from bulk soil and litter bags during a third and final season of crop production (rotating to broccoli) in the original biomulch plots. We will continue to collect soil chemical, physical, and microbial data at each biomulch recovery interval, in addition to crop growth and yield data. Dissemination of project results will continue through grower conferences and field days and also through development of additional YouTube videos. We will offer Innovations for Agriculture for the third time, and begin to document learning outcomes and create reusable learning objects (e.g., open access case studies) from the course.

2016/09 TO 2017/08 Target Audience: Over 100 vegetable and specialty crop growers were reached during the first reporting period through three presentations at grower conferences, one field day, and one webinar. We also reached organic researchers, educators, and students through one invited seminar and an Extension in-service and field tour. Presentations: Integrating fertility and weed management in hop production. Hops Field Day and Scouting Workshop. Midwest Hops Producers. Plattsmouth, NE. July 2017. 25 attendees. Bio-based weed management tools for specialty crops. Nebraska Sustainable Agriculture Research and Education (SARE) Webinar. July 2017. Archived online: <http://nesare.unl.edu/sarewebinars> "Quick Hitters" Specialty Crops Research Update and Field Tour. Community Environment Landscape Systems In-Service and Field Day. Nebraska Extension. Lincoln, NE. June 2017. 20 attendees. Bio-based weed management tools for specialty crops. Small Scale Farming Workshop. Nebraska Extension. Nebraska City, NE. April 2017. 20 attendees. Blasting, biomulch, and cover crops: Non-chemical weed control for vegetable crops. Great Plains Growers Conference. St. Joseph's, MO. January 2017. 30 attendees. Blasting, biomulch, and cover crops: Multifunctional weed management tools for vegetable crops. Nebraska Sustainable Agriculture Society, Healthy Farms Conference. Columbus, NE. January 2017. 20 attendees. "Blasting and biomulch: Developing new physical weed control strategies in vegetable crops." South Dakota State University, Plant Science Department, Brookings, SD. October 2016. 30 attendees. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? One graduate student (Mitchell Ben Samuelson) is being trained on this project and research in objectives 1, 2, and 3 will form the basis of his thesis. This student is working closely with a post-doctoral associate (Ashley Thompson) on our team to conduct lab and field studies. Together they are working to train, develop, and supervise a team of four undergraduate students working part-time on this project. Through this experience, Mitchell and Ashley are gaining valuable experience in time and personnel management, and combined with the undergraduate students, they are all gaining valuable training and experience in lab and field sampling and analytical techniques. 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? During the next reporting period, we will make progress toward all five project objectives. Toward our three research objectives, we will continue managing our field trials at Lincoln and Scottsbluff and implement experimental treatments to speed the rate of biomulch degradation in soil, including the use of compost, cover crops, irrigation (farmer choice), compost extract (farmer choice), and a mixture of all treatments. We will bury mulch residues in soil and litter bags and recover samples for analysis of mulch degradation and microbial community composition (objectives 1 and 2). We will also determine any changes in soil physical structure resulting from soil incorporation of biomulch residue (objective 3). A second M.S. graduate student, Elise Reid, will begin working on this project and this research will form the basis of her thesis. Toward our teaching objective, Dr. Wortman will offer "Innovations for Agriculture" for the first time, collect data on student products and learning outcomes, and improve curriculum for subsequent offerings. In addition, industry collaborators will be recruited for participation in the course as mentors during the design process (objective 4). Lastly, we will

continue outreach efforts by presenting project activities and results at grower conferences and field days and increase our project reach by developing YouTube videos and other online project resources (objective 5).

IMPACT

2016/09 TO 2020/08 What was accomplished under these goals? Objective 1. Explore management strategies that increase the rate of biomulch degradation after incorporation in soil. Objective 2. Characterize the microbial drivers of biomulch degradation in soil. Objective 3. Determine the fate of biomulch after decomposition in soil and the effects on soil properties. We completed a 3-year field experiment in two locations - Lincoln and Scottsbluff, NE - to explore management strategies (compost, compost extract, cover crops, and a combination of all three) for increasing biomulch microbial degradation in soil and to determine the effect of biomulch on soil biophysical properties. In year one, two biomulch products (100% bio-based PLA mulches: biodegradable, bioplastic film) were laid and red peppers planted. In the fall after harvest was concluded, pepper residues were shredded, compost and compost extract treatments were applied to appropriate treatments, and biomulch was incorporated in soil with two passes of an articulating spader tillage implement. Immediately prior to incorporation, half of the biomulch was removed from the field (as a control) and that biomulch was cut into squares and used for in situ incubation and litter bag trials. Initial weight of biomulch squares was recorded and placed in litter bag with 500 g of sieved soil from respective plots. Eight litter bags were then buried in each plot to a depth of 10-15 cm. Two bags were removed every 6 months for a period of 24 months. A baseline estimate of biomulch residue in soil was determined after soil incorporation using diagonal transects through each plot and sampling with a golf hole cutter to a depth of 15 cm. Residues were sieved, washed, and weighed. Eight soil cores have been sampled from each plot every 6 months for chemical analyses. Soil temperature and moisture sensors were installed to a depth of 5 and 30 cm, respectively. A mustard or rye/vetch cover crop was planted in spring 2018 (prior to sweet corn planting) and fall 2018 (after sweet corn harvest and preceding 2019 cabbage crop). Two mesh litter bags were recovered in spring 2018, fall 2018, spring 2019, and fall 2019 to determine the rate of biomulch degradation (bag one) and the microbial community composition on and around the biomulch residue (bag two). Residues from bags were immediately frozen for microbial analyses, and extraction and fatty acid methylated ester (FAME) analysis was conducted. In addition, we collected soil physical and soil chemical data at every 6 month sampling interval. In June 2018, we planted sweet corn and monitored growth, physiology, and yield to assess legacy effects of biomulch residues on subsequent crop performance. For the same reasons, we planted cabbage in May 2019 across the entire experimental area. Mulch mass loss, tensile strength, and qualitative presence by bulk recovery were not affected by treatments which included cover cropping and high rates of compost. Likewise, management had little impact on microbial community structure present on mulch surfaces. Instead, location and mulch type were strong drivers of degradation rate, while mulch type alone was the primary driver of mulch-associated microbial community. Bioplastic mulch was nearly completely undetectable after 12 months of burial at Lincoln, but 67% of bioplastic mulch mass remained at Scottsbluff after 12 months and 50% remained after 24 months. PLA biofabric mass loss was initially more rapid at Scottsbluff, but after 12 months this difference was not prominent with 33% and 37% remaining at Scottsbluff and Lincoln, respectively. By 24 months after soil incorporation, 30% of PLA biofabric mass still remained in soil at both locations. While mesh bags are instrumental in detecting mass changes over time, we showed that they are a strong driver of microbial profiles present in soil and mulch sample fractions, so caution is warranted in interpreting mesh bag results as representative of field status of mulch. Compost amendment increased sweet corn yield by 34-43% and macronutrient availability in 2018 (N-71%, P-75%, K-16.9%) compared to all other treatments at Scottsbluff. Biomulch residues in soil did not influence sweet corn crop yield ($p < 0.05$). Cabbage yield increased in compost treatments in 2019 at Lincoln ($p = .0045$), and decreased in plots with cover crops ($p < 0.0001$). The PLA biofabric increased water stable macroaggregates compared to the control at both locations in the spring of 2019, whereas the bioplastic decreased macroaggregates compared to the control at Lincoln. Increased water stable aggregates were attributed to enhanced fungal colonization of the PLA mulch. Organic amendments improved soil sorptivity both years at Scottsbluff and in 2019 at Lincoln. Initial results of this study suggest that the effects of biobased mulch residues on soil macronutrients and yield are inconsequential compared to the effects of compost application. Biodegradable PLA based mulches may have a positive effect on soil properties after soil incorporation, although they are slow to degrade even with added amendments. Common organic management practices including use of compost, compost extract, and cover crops had little effect on the degradation rate of two different bio-based or biodegradable mulches in this study. Instead, mulch composition and local environmental conditions explained differences in degradation rates over time. While the degradation rate was unphased by soil management, we did observe any negative effects of biomulch residues on subsequent crop yield or soil properties; in fact, there is some evidence that the PLA biofabric improved soil health. Given these results, it may be necessary to review the current requirement that any biobased mulch used

in USDA certified organic systems be biodegraded in soil by 90% within 2 years. PLA biofabric was not degraded by 90% after 2 years in this study, but we observed only neutral or positive effects of the residues in soil.

Objective 4. Develop curriculum for and teach a new undergraduate course titled, "Innovations in Sustainable Agriculture." "Innovations for Agriculture," a course developed in fall 2017 through this project, was taught for the third time in fall 2019. Using biobased mulch innovations as the first case study, we introduce students to a framework (rooted in design thinking) for defining challenges, assessing status quo approaches to challenges, and developing innovative products or technologies to better address those challenges. Students have the opportunity to research, develop, prototype, test, and pitch an agricultural innovation of their own creation (including, but not limited to, OMRI-approved products and technologies for organic stakeholders). Each student in this course presented a total of seven innovation "pitches" during the semester, and end-of-semester surveys indicated that 100% agreed that the class improved their oral communication skills. Students worked in teams to compare and design solutions to five unique challenges in agriculture and 100% agreed that they are now more comfortable working in teams to solve complex problems. Students created and pitched their final prototype to a panel of experts and at least two students indicated that they plan to pursue development of their prototype after the course.

Objective 5. Disseminate project results to stakeholders including, organic farmers, researchers, and policy-makers. Project results have been published in two M.S. student theses and are open-access to organic farmers, researchers, and policy-makers. We are in the process of preparing both theses for publication in peer-reviewed journals to increase the impact and reach of this research. During the final year of the project, project results were disseminated to over 190 organic researchers, educators, and students through two presentations at national scientific conferences, open seminars at Iowa State University and the University of Nebraska, and a high school outreach event. **PUBLICATIONS (not previously reported):** 2016/09 TO 2020/08 1. Type: Theses/Dissertations Status: Published Year Published: 2019 Citation: Samuelson, M.B. 2019. Microbial response to biodegradable mulch: Can degradation rate be accelerated by management? Theses, Dissertations, and Student Research in Agronomy and Horticulture. 179. <https://digitalcommons.unl.edu/agronhortdiss/179> 2. Type: Theses/Dissertations Status: Published Year Published: 2019 Citation: Reid, E.V.H. 2019. Legacy effects of biodegradable mulch and soil amendments on vegetable crops and the soil. Theses, Dissertations, and Student Research in Agronomy and Horticulture. 178. <https://digitalcommons.unl.edu/agronhortdiss/178> 3. Type: Other Status: Published Year Published: 2019 Citation: Samuelson, M. B., S. E. Wortman, and R. Drijber. 2019. Assessing the quality and possible functions of compost extracts in organic systems. eOrganic Fact Sheet. <<http://eorganic.org/node/33458>>.

2017/09 TO 2018/08 What was accomplished under these goals? Objectives 1, 2, & 3: We are currently in year two of a three-year field experiment across two locations - Lincoln and Scottsbluff, NE - to explore management strategies for increasing biomulch microbial degradation in soil and to determine the effect of biomulch on soil biophysical properties. In year one, two different biomulch products (100% bio-based fabric mulch vs. biodegradable, bioplastic film) were laid in each field and red peppers were planted. In the fall after harvest was concluded, pepper residues were shredded, compost and compost extract treatments were applied, and biomulch was incorporated in soil with two passes of an articulating spader tillage implement. Immediately prior to incorporation, half of the biomulch was removed from the field (as a control) and that biomulch was cut into squares and used for in situ incubation and litter bag trials. Initial weight of biomulch squares was recorded and then placed in litter bag with 500 g of sieved soil from respective field plots. Eight litter bags were then buried in each plot to a depth of 10-15 cm. Two bags will be removed every 6 months for a period of 18 months. A baseline estimate of biomulch residue in soil was determined after soil incorporation using diagonal transects through each plot and sampling with a golf hole cutter to a depth of 15 cm. Residues were sieved, washed, and weighed. Eight soil cores were sampled from each plot for chemical analyses. Also at this time, soil temperature loggers were installed to a depth of 5 cm in each plot and soil moisture sensors were installed to a depth of 30 cm in a subset of plots. Beginning in fall 2017, irrigation water was applied intermittently, and in spring 2018 a mustard cover crop was planted in appropriate treatments. The first two mesh litter bags were recovered in spring 2018 to determine the rate of biomulch degradation (bag one) and the microbial community composition on and around the biomulch residue (bag two). We also used the golf hole cutter transect method to compare estimates of degradation between litter bags and bulk soil. Residues from bag two were immediately frozen for microbial analyses, and extraction and fatty acid methylated ester (FAME) analysis is currently underway. In addition to biomulch recovery and analysis, we collected soil physical data - aggregate stability, penetration resistance, and water infiltration - and soil chemical data in spring 2018. In June 2018, we planted sweet corn throughout the entire experimental area and monitored growth, physiology, and yield to assess residual effects of biomulch residues on subsequent crop performance.

Objective 4: A new course - "Innovations for Agriculture" - was developed, approved, and taught for the first time in fall 2017 and will be taught again in fall 2018. Using bio-based mulch innovations as the first case study, we introduce students to a framework (rooted in design thinking) for defining challenges, assessing status quo approaches to challenges, and developing innovative products or technologies to better address those challenges. Students have the opportunity to research, develop, prototype,

test, and pitch an agricultural innovation of their own creation (including, but not limited to, OMRI-approved products and technologies for organic stakeholders). Students learn prototyping skills at the Nebraska Innovation Studio Maker Space, and interact with innovators from industry, including project cooperater Ignatius Kadoma from 3M Company. There were six students in the inaugural class, and 12 students (the maximum capacity for this hands-on class) are enrolled for the fall 2018 semester. Objective 5: We have prepared one publication for submission to the journal "Polymers" and a special issue on Recent Advances in Bioplastics. This paper summarizes the soil incubation study completed in year one of the project where we studied two prototype biomulch products (with plant-based residues embedded in the mulch matrix) and the effects of biostimulants on biomulch degradation and microbial respiration. A second publication is in preparation for submission to "Renewable Agriculture and Food Systems" to summarize results of recently completed studies that characterized the chemical and biological properties of a diverse suite of compost extracts and their effects on crop seedling performance in residue-rich soils. In year two, project results were disseminated to organic researchers and educators through one field day (20 participants) and three professional abstracts and poster presentations at the American Society for Horticultural Science annual meeting. At least 30 organic farmers were reached through a poster presentation at the North Central Region SARE annual conference. Project information was disseminated to the general public via a radio interview with Nebraska Extension almanac and television segment on NET Television's Backyard Farmer (<https://extensiontv.unl.edu/v/5815>). The project was also featured in the 3M Annual Sustainability Report (https://www.3m.com/3M/en_US/sustainability-report/all-stories/full-story/?stor_yid=16e7a9d6-5214-42d5-a685-f12b56f54669). **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? Objectives 1 and 2: We completed a soil incubation study in the lab to determine the effect of compost and commercially available microbial inoculants on the rate of soil respiration and biomulch degradation. Data was collected for respiration, mulch physical characteristics and decay, and microbial communities adhering to biomulch. Analyzed results will be used to inform treatments for the larger field experiment. Moreover, this incubation study, combined with the larger field study were used to leverage additional funding through a graduate student grant from North Central Region Sustainable Agriculture Research and Education (NCR SARE). This complementary project funding will enable us to systematically characterize chemical and biological properties of compost and compost extracts that may be useful for speeding degradation of agricultural residues, including bio-based mulches. Objectives 1, 2, & 3: A field experiment was initiated in Lincoln, NE and Scottsbluff, NE where red peppers were planted into a 100% bio-based fabric mulch (potentially allowable for use on organic farms) or a biodegradable, bioplastic film (not 100% bio-based, and not allowed for soil incorporation on organic farms). After a full field production season, mulches will be soil incorporated and experimental treatments for speeding microbial degradation of biomulch will be implemented. Objective 4: Curriculum was developed for a new course titled, "Innovations for Agriculture." This course has been approved by the College of Agricultural Sciences and Natural Resources at the University of Nebraska and will be taught for the first time in Fall 2017. Objective 5: Project background, goals, and approach were presented to over 100 vegetable and specialty crop growers through three presentations at grower conferences, one field day, and one webinar. We also reached organic researchers, educators, and students through one invited seminar and an Extension in-service and field tour. **PUBLICATIONS (not previously reported):** 2016/09 TO 2017/08 No publications reported this period.

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Developing Advanced Perennial Legume-grass Mixtures Harvested as Stored Feeds to Improve Herd Productivity and Mitigate Greenhouse Gas Emissions in Organic Dairies in the Northeast

Accession No.	1010680
Project No.	NH.W-2016-06181
Agency	NIFA NH.W\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2016-51106-25713
Proposal No.	2016-06181
Start Date	01 SEP 2016
Term Date	31 AUG 2019
Grant Amount	\$499,559
Grant Year	2016
Investigator(s)	Brito, A.

NON-TECHNICAL SUMMARY

Our recent and ongoing assessment of the research and extension needs of the northeastern organic dairy industry revealed that improving forage production and quality should be prioritized. However, one of the major limitations for feeding high-forage rations is decreased milk production and nutrient use efficiency and increased outputs of nitrogen (e.g., N₂O in manure) and carbon (as enteric CH₄) to the environment. On the other hand, energy-dense forages may improve the balance and synchrony of water soluble carbohydrates and nitrogen release in the rumen of dairy cows, while increasing organic matter digestibility ultimately reducing nitrogen and methane outputs to the environment. Perennial legumes and grasses grown in mixtures and selected to increase forage quality via energy-dense stored feeds (e.g., baleage) have strong potential to increase milk production and decrease greenhouse gas emissions of dairy farms transitioning to organic agriculture. However, the feasibility of maintaining species composition within legume-grass mixtures throughout the growing season during multiple cropping years remains to be determined. It is also unknown how microbial fermentation impacts the energy to nitrogen ratio of legume-grass mixtures when they are harvested as stored feeds. This project will fill these knowledge gaps by advancing the scientific understanding about how potential changes in species persistence and forage botanical composition in various legume-grass mixtures across multiple years affect forage quality and stored feed fermentation characteristics and, consequently, milk production and greenhouse gas emissions when fed to organic dairy cows. Through this project, we will partner with three organic dairy farmers in the Northeast who will set up demonstration plots and coordinate field days, thus becoming peer leaders in their rural communities. With guidance and evaluation provided by a Research and Extension Advisory Board, we will enhance learning opportunities among other organic dairy farmers, researchers, educators, and general public via workshops, field days, social media, newsletters, and webinars.

OBJECTIVES

Our long-term goal is to help northeastern organic dairy farmers improve milk production while reducing feed costs and greenhouse gases (GHG) emissions by feeding high-quality forage crops. Realization of our goal will ultimately enhance the social, economic, and environmental sustainability of organic dairies in the Northeast and

beyond. Project Objectives: Our team, with the guidance from regional organic dairy stakeholders, aims to develop advanced perennial legume-grass tertiary mixtures harvested as stored feeds to improve herd productivity and mitigate GHG in organic dairies in the Northeast through the following objectives: Objective 1: Assess the agronomic performance and silage quality of energy-dense legume-grass tertiary mixtures over multiple years using small plots and laboratory mini-silos. Objective 2: Evaluate the impact of energy-dense legume-grass tertiary mixtures harvested as baleage on milk production, GHG emissions, and whole-farm profitability and environmental impact by integrating feeding trials, modeling approaches, and agronomic data. Objective 3: Deliver best management practices for producing nutritionally superior organic milk through enhanced learning opportunities among farmers, industry, researchers, educators, students, and general public via workshops, field days, and webinars. Objective 4: Evaluate research and extension activities through the collective actions of project Research and Extension Advisory Board, eOrganic, scientific community, and from direct feedback of stakeholders after completion of workshops, field days, and surveys. We will accomplish our research goals by: 1) addressing the impact of grass-legume tertiary mixtures on species persistence and yield through agronomical trials, 2) assessing the impact of grass-legume tertiary mixtures on the quality and fermentation characteristics of stored feed using mini-silos, 3) evaluating the effects of feeding stored feed consisted of different grass-legume tertiary mixtures on milk production, N use efficiency, and GHG emissions in organic dairy cows, 4) using modeling approaches to estimate whole-farm GHG emissions, and 5) integrating income over feed costs and risk analysis to assess the profitability tradeoffs of incorporating different forage crop mixtures into dairy rations. We will accomplish our extension goals by: 1) engaging transitioning and organic dairy farmers in a peer-learning program via workshops and field days, 2) disseminating educational information via webinars and social media outlets such as Facebook, Twitter, and YouTube, 3) presenting study results at farmer-oriented conferences, as well as extension and professional regional, state, and national meetings such as the University of Vermont Organic Dairy Producers Conference, Northeast Organic Farming Association-NY Organic Dairy and Field Crop Conference, Northeast Organic Dairy Producers Alliance Annual Field Days and Conference, Northeast Pasture Consortium Annual Meeting, American Dairy Science Association Annual Meeting, and American Society of Agronomy Annual Meeting, and 4) publishing project results on peer-reviewed leading journals and farmer-oriented venues in addition to project newsletters and fact-sheets. Project outreach activities will be conducted in coordination with eOrganic, the Northeast Pasture Consortium, and the USDA Northeast Regional Climate Hub. Finally, our research and extension activities will be evaluated by the project Research and Extension Advisory Board combined with eOrganic evaluation of webinars, peer-review evaluation of scientific manuscripts, and direct feedback from stakeholders after completion of workshops, field days, and surveys.

APPROACH

AGRONOMIC PERFORMANCE AND SILAGE QUALITY Research sites: The experiments will be conducted at the University of Vermont-Horticultural Research Farm Center and at the University of New Hampshire-Burley-Demeritt Organic Dairy Research Farm. Year 1 will be used to establish the forage crop systems with baseline measurements only. Experimental design and forage crop systems: Each study will be arranged in a split plot experimental design. Main effect (whole plot) treatments will include the three target legumes (alfalfa, red clover, and birdsfoot trefoil) and subplot treatments will include three grass combinations: 1) meadow fescue with an early maturing timothy, 2) meadow fescue with a late maturing orchardgrass, and 3) meadow fescue with a late maturing perennial ryegrass resulting in nine treatments. Alfalfa has become the reference legume for stored feeds making the alfalfa mixtures our control treatment. Seeding rates will be done to target botanical composition levels at 70:15:15 for legumes and their companion two grasses, which will be seeded in the same proportion. Cultivar selection will be based on recommendations from forage evaluation programs at Cornell University and the University of Wisconsin, as well as from commercial plant breeders. Treatments will be planted with certified organic seed on spring of 2017 (Year 1) using a Carter small plot forage seeder. Each plot (experimental unit) will be 2.5 m by 7.5 m in area. At each site, the treatment levels will be replicated across four blocks yielding a total of 36 experimental units per cutting. We anticipate three to four cuttings/year per treatment. Sampling and nutrient analyses: Intensive sampling will begin in Year 2 (the first full harvest season) and continued through Year 3. Because the maturity of the three legumes vary, the timing of first cutting will be based on target neutral detergent fiber concentration of 45 to 50% for each main effect legume treatment (determined by a pre-harvest quadrat sampling one week before anticipated harvest). Thereafter harvests will be at 35 to 40-day intervals. Measurements taken at each harvest will include dry matter yield and forage quality parameters. Yield will be determined by cutting and weighing forage from a 1 m by 7 m strip taken from one side of each plot using a Carter small plot forage harvester. A 400-g sample of harvested material from each plot will be collected and used for determining dry matter content (freeze-dryer) and a 100-g subsample of dried sample collected for forage analyses. The dried samples will be ground to pass a 1 mm screen. Samples will be analyzed for forage quality using Near Infrared Reflectance Spectroscopy. Forage components included in wet chemistry calibrations

will include crude protein, water-soluble carbohydrates, neutral and acid detergent fiber, in vitro digestible neutral detergent fiber, ether extract, and ash. In one cutting per year, forage from each plot will be cut in the afternoon, wilted in wide swaths, and chopped next day around noon at approximately 50% dry matter and ensiled in laboratory mini-silos using four field replicates per treatment and two incubation times (one and 128 days). Silage sample extracts will be used to determine pH, CNCPS fractions, organic acids, and ethanol using wet chemistry and chromatographic methods by a commercial laboratory.

FEEDING TRIALS, MODELING, AND GHG EMISSIONS

Legume-grass tertiary mixtures establishment: The University of New Hampshire-Highland House hay fields (see Facilities) will be used for establishing the three legume-grass tertiary mixtures on Year 1 to be harvested as baleage on Years 2 and 3.

Animals and experimental design: On Year 2 (n = 24 cows), 24 mid-lactation Jersey cows housed in a bedded-pack barn at the University of New Hampshire-Burley-Demeritt Organic Dairy Research Farm will be assigned to one out of three forage-based treatments fed as baleage: 1) alfalfa-meadow fescue-timothy mixture, 2) birdsfoot trefoil-meadow fescue-timothy mixture, or 3) red clover-meadow fescue-timothy mixture. A randomized complete block design (n = eight cows/treatment or three blocks of eight cows/treatment) with a two-week covariate and a 12-week data collection period will be used. The feeding trial will be replicated on Year 3. Cows will be blocked by parity and days in milk, and will be fed and milked twice daily. Body weight and body condition score will be recorded in the last week of the covariate and monthly during the 12-week data collection period after the afternoon milking. Diets will be fed as total mixed rations consisted (dry matter basis) of 80% baleage and 20% of a corn meal/soybean meal-based grain mixture. Feeds, milk, blood, feces, and urine samples will be taken during the last week of the covariate period and during the last week of each month thereafter (weeks four, eight, and 12).

Feed, milk, and blood collection and analyses: Total mixed rations, feed ingredients, and feed refusals will be collected weekly, pooled by period (i.e. monthly), freeze-dried, ground (1-mm screen), and later analyzed for dry matter, ash, total N, neutral detergent fiber, acid detergent fiber, gross energy, and minerals using wet chemistry and mass spectrophotometric methods by a commercial laboratory. Ammonia, pH, organic acids, CNCPS fractions, and ethanol will be determined on baleage extracts as done for silages (see above). Milk samples will be analyzed for fat, protein, lactose, total solids, milk urea-N, and fatty acids using mid-infrared reflectance spectroscopy and gas chromatography. Blood samples will be collected from the tail vein approximately four hours after the morning feeding and later analyzed for plasma urea-N.

Fecal and urine collection and analyses: Fecal grab samples will be collected once daily for three consecutive days, pooled, and analyzed for nutrients and indigestible acid detergent fiber for determination of digestibility. Spot urine samples will be taken once daily for three consecutive days concurrently with the fecal samples, pooled, and analyzed for creatinine, allantoin, uric acid, urea, ammonia, and total N using colorimetric methods and commercial kits. Carbon emissions measurements and analyses: Methane and CO₂ emissions will be measured using the GreenFeed system (C-Lock Inc., Rapid City, South Dakota) throughout the two-week covariate and 12-week data and sample collection periods.

Simulation of economic performance and GHG emissions: A whole-farm budget, in which the total cost of production is compared against revenues will be used to predict annual net return using the Integrated Farm Systems Model (IFSM). Total GHG emissions will be assessed at the whole-farm level by the IFSM and include sources and sinks of CO₂, CH₄, and N₂O.

EVALUATE RESEARCH AND EXTENSION ACTIVITIES

We expect that the majority of the anticipated 1,000+ organic dairy farmers who will attend on-farm field days, winter conferences, regional presentations, peer learning program, and the Advisory Board meetings will learn new practices that will strengthen organic dairy farming in the Northeast. (1) Workshop/conference surveys will be delivered after every event. At all events farm names and contact information will be gathered with the surveys designed to help determine if the information was useful, will be implemented on farms, and if it will improve farmer livelihoods. (2) Organic dairy farmers who participate in the peer learning program and the Research and Extension Advisory Board will work closely with the project team to collect information regarding impact of new tools, ideas, and markets gained through their participation in the project. Evaluation will be also provided by informal and formal reviews from peer scientists.

****Progress****
09/01/16 to 08/31/21

****Outputs**** Target Audience: We directly served organic and conventional dairy farmers across the Northeast region, as well as extension educators, industry stakeholders (e.g., organic milk processors, nutritionists, veterinarians), and the scientific and academic communities (e.g., graduate and undergraduate students, post-docs, and fellow scientists). Our team disseminated project results through workshops, webinars, pasture walks, farmer-oriented conferences, and national and international scientific conferences.

Changes/Problems: Nothing Reported

What opportunities for training and professional development has the project provided? The project outreach and research components are advancing as planned. Workshops and outreach activities such as presentations, dairy farm meetings, field days, farm tours, and webinars featuring project results have been delivered. Specifically, PI Brito and co-PI Smith presented project materials at the University of New Hampshire Cooperative Extension Fall Forage Webinar Series, New England Dairy Nutrition Conference, University of New Hampshire Cooperative Extension Dairy and Livestock Crops Virtual Field Day, Northeast Organic Dairy Producers Alliance (NODPA) Field Days and Conference, University of Vermont 2021 Online Dairy Education Series, and 2021 American Dairy Science Association Annual Meeting. Allen Wilder (co-PI Bosworth graduate student) presented project data during University of New Hampshire Cooperative

Extension Fall Forage Webinar Series. Altogether, these presentations were delivered to over 300 participants, thus engaging organic dairy farmers, industry stakeholders, and the scientific community. How have the results been disseminated to communities of interest? Project results have been disseminated to dairy farmers, dairy nutritionists, extension educators, dairy industry personnel, students, and the scientific community through field days, professional meetings, farmer conferences, webinars, and workshops. Over the lifespan of the project, our team delivered 9 webinars during extension and conference events. We also delivered 3 field days/pasture walks in collaboration with the Wolfe's Neck Center Agriculture & the Environment (Freeport, ME), University of Vermont-Extension, and Choiniere Family Farm, (Highgate, VT.). Several in-person presentations were delivered during conferences in the region such as Northeast Pasture Consortium Annual Meeting, Northeast Organic Dairy Farmers Association New York (NOFA-NY), Vermont Organic Dairy Producers Conference, Granite State Graziers Association, New England Ag Service Providers In-Service Annual Meeting, and American Dairy Science Association Annual Meeting amounting to a total of 10 presentations. We published project results in conference proceeding papers (total = 7), dissertation theses (total = 3), popular-press articles (NODPA News; total = 3), and a booklet (2021 University of New Hampshire Agricultural Experimental Station Dairy Report). Our team is currently working to submit several peer-reviewed manuscripts to publication, and we anticipated that 10 articles will be published between 2022 and 2024. Throughout the duration of the project, 3 Ph.D. students and 1 MS student directly used data generated in the project as part of their theses. We also trained 3 post-doctorate students who actively participated in data collection and analyses, multiple undergraduate students (n = 10), and 2 international research scholars. We will continue to deliver data regionally and nationally beyond the lifespan of the project to keep organic dairy farmers and allied industry engaged and informed. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported **Impacts** What was accomplished under these goals? Agronomic Small-Plot Study at the University of New Hampshire: As described in previous progress reports, we reestablished the experimental plots in August 2018 due to poor establishment of the previous iteration of the experiment. Each plot was seeded to 1 of 4 forage legumes (alfalfa, white clover, red clover, and birdsfoot trefoil) and orchardgrass at a 70:30 (legume:grass) ratio. In addition, we also included 2 legume mixture treatments (all 4 legumes sown together with orchardgrass in either a 70:30 or 30:70 ratio). The intermediate intensity cutting (3X) frequency treatment was aimed at a relatively long interval and recovery time between each harvest and involved harvesting each plot a total of 3 times over the growing season, beginning in early June and ending in October each year. In contrast, the high intensity cutting (5X) frequency treatment involved harvesting each plot a total of 5 times over the season, creating a shorter interval and recovery period (30 d) between cuts. Plots were also assigned to a cutting height treatment of either 5 or 10 cm residual forage height. Despite the severity and duration of the 2020 drought, all 4 legume species persisted over the subsequent winter and were present (~ 5% to ~10% of total forage, depending on species) in harvest samples collected at the beginning of the 2021 growing season. White clover total abundance and proportion of total forage mass remained relatively low by the second harvest of 2021 (<5% of total forage mass); however, abundance of red clover increased in the second harvest, especially in the 5X harvest intensity treatments (~30% of total forage mass). We also compared the nutritive value of 4 binary legume-grass (LG) mixtures, and 2 complex LG mixtures under different seeding strategies over 2 years following a 3-cutting schedule. A randomized complete block design with a 6 × 3 factorial arrangement of treatments and 4 replicates for each treatment was used. Legumes selected were alfalfa (ALF), red clover (RC), birdsfoot trefoil (BFT), and white clover (WC) in binary mixtures with orchardgrass at 70:30 LG seeding rate, a high legume mixture (HI) with 70% of all 4 legumes and 30% orchardgrass, and 30:70 LG seeding rate, a low legume mixture (LO) with 30% of all 4 legumes and 70% orchardgrass. Crude protein increased in HI compared with ALF and BFT, with HI and LO showing reduced NDF concentration relative to ALF and BFT. Starch was greater in LO vs. WC but it did not differ compared with the other treatments. RC, HI, and LO resulted in greatest sugar content and ALF the lowest. In vitro fiber digestibility was lower for HI and LO than the binary LG mixtures. In general, second and third cuttings improved nutritive value. Feeding Trial at the University of New Hampshire: Red clover (*Trifolium pratense* L.) is one of the most used legumes in the Northeast United States, with the advantage to produce milk with lower milk urea-N than alfalfa (*Medicago sativa* L.) due to the presence of the enzyme polyphenol oxidase in red clover tissues that acts to reduce protein degradation during ensiling. Previous research demonstrated that red clover silage was comparable to alfalfa silage in terms of dry matter intake, milk production, and percentage of milk fat. However, some studies conducted in the United States showed that cows fed alfalfa silage produced more milk than those fed red clover silage. White clover (*Trifolium repens* L.) silage has been shown to produce more milk than red clover silage at the same dry matter intake, thus resulting in better feed efficiency. Therefore, partially replacing red clover silage with alfalfa-white clover mixture in the diet dry matter may maintain the positive effect of red clover on dietary N utilization while improving milk production. It is important to emphasize that there is limited data comparing the effects of red clover-grass mixture harvested as baleage on dry matter intake, milk production and composition, nutrient digestibility, and energy utilization in dairy cows. Two fields were planted as reported above with forages were harvested as baleage. Diets were fed as total mixed ration and contained (dry matter basis): (1) 60% second and third cut red clover-grass baleage (30% of each cut) and 40% concentrate (high red

clover-grass mixture diet = HRC-M), and (2) 30% second and third cut red clover-grass baleage (15% of each cut), 30% second cut alfalfa/white clover-grass baleage, and 40% concentrate (low red clover-grass mixture diet = LRC-M). The experiment was done as a crossover design with 24-d periods. Cows fed the HRC-M diet had greater intake than those receiving the LRC-M diet, but milk production did not differ between diets. Milk fat percentage increased, and milk protein tended to increase in cows fed the LRC-M diet. Milk fat and protein yield, and milk urea-N were not affected by diets. Conversely, plasma urea-N concentration was lower with feeding HRC-M than LRC-M. Total-tract digestibility of dry matter, organic matter, and neutral detergent increased, and that of crude protein tended to increase in cows fed HRC-M versus LRC-M. Modeling and Economic Analysis: We compared the economic and environmental performance of traditional (ORG-T) vs. grass-fed (ORG-GF) organic dairy farms using the Integrated Farm System Model. The ORG-T diet was characterized by pasture, grass-legume and corn silage, and grain during the grazing season, and conserved feed and grain during the winter season. The ORG-GF was characterized by an all pasture diet during the grazing season, and all conserved feed diet except corn silage during the winter season. Milk price and annual milk production used in the simulations averaged 71.50 vs. \$81.70/100L and 6,590 vs. 4,879 kg/cow for ORG-T vs. ORG-GF, respectively. Net return/cow was 35% greater in the ORG-GF (\$2,766) than ORG-T (\$2,051) due to additional premiums paid by milk processors to ORG-GF. Average greenhouse gas (GHG) emission was 87% greater in ORG-GF (0.56 kg of CO₂ eq/kg of energy-corrected milk production) than ORG-T (0.30 kg of CO₂ eq/kg of energy-corrected milk production).

****Publications**** - Type: Conference Papers and Presentations Status: Published Year Published: 2021 Citation: Sacramento, J. P., L. H. P. Silva, D. C. Reyes, Y. Geng, and A. F. Brito. 2021. Feeding legume-based forages: Effects on milk yield, nutrient digestibility, and methane emissions in dairy cows. *J. Dairy Sci. (Suppl. 1)* 104:307. - Type: Conference Papers and Presentations Status: Published Year Published: 2021 Citation: Sacramento, J. P., L. H. P. Silva, D. C. Reyes, Y. Geng, and A. F. Brito. 2021. Feeding legume-based forages: Effects on N utilization in dairy cows. *J. Dairy Sci. (Suppl. 1)* 104:306307. - Type: Conference Papers and Presentations Status: Published Year Published: 2021 Citation: Almeida, K. V., L. H. P. Silva, J. P. Sacramento, D. C. Reyes, R. G. Smith, N. Warren, and A. F. Brito. 2021. Effects of seeding intensity and cutting on the nutritional quality of grass-legume mixtures. *J. Dairy Sci. (Suppl. 1)* 104:249. - Type: Conference Papers and Presentations Status: Published Year Published: 2021 Citation: Lange, M. J., L. H. P. Silva, M. Ghelichkhan, M. A. Zambom, and A. F. Brito. 2021. Feeding alfalfa- or red clover-grass mixtures: Effects on methane emissions and plasma amino acids in dairy cows. *J. Dairy Sci. (Suppl. 1)* 104:101. - Type: Conference Papers and Presentations Status: Published Year Published: 2021 Citation: Lange, M. J., L. H. P. Silva, M. Ghelichkhan, M. A. Zambom, and A. F. Brito. 2021. Feeding alfalfa- or red clover-grass mixtures: Effects on production and milk fatty acids in dairy cows. *J. Dairy Sci. (Suppl. 1)* 104:101. - Type: Other Status: Published Year Published: 2021 Citation: Brito, A.F., M. J. Lange, J. P. Sacramento, L. H. P. Silva, M. Ghelichkhan, Y. Geng, D. C. Reyes, and M. A. Zambom. 2021. Alfalfa-grass or red clover-grass: Effects on milk production, composition, nitrogen and energy utilization. 2021 Dairy Research Report (Joint publication by NH Agricultural Experiment Station and UNH Cooperative Extension). <https://colsa.unh.edu/nhaes/dairyreport2021> - Type: Theses/Dissertations Status: Published Year Published: 2021 Citation: Sacramento, J. P. 2021. Energy nutritional requirements and dietary strategies for lactating dairy cows under different production and climatic conditions. Federal University of São João del-Rei, São João del-Rei, Minas Gerais, Brazil (Ph.D. Dissertation).

****Progress**** 09/01/19 to 08/31/20

****Outputs**** Target Audience: We directly served organic and conventional dairy farmers across the Northeast region, as well as extension educators, industry stakeholders (e.g., organic milk processors, nutritionists, veterinarians), and the scientific and academic community (e.g., graduate and undergraduate students, post-docs, and fellow scientists). Our team disseminated project results through workshops, webinars, pasture walks, farmer oriented conferences, and national and international scientific conferences. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Project results have been disseminated to dairy farmers, dairy nutritionists, extension educators, dairy industry personnel, students, and the scientific community through field days, professional meetings, farmer conferences, webinars, and workshops. Specifically, we delivered project results during farm tours and local and regional producer conferences. How have the results been disseminated to communities of interest? Project results have been disseminated to dairy farmers, dairy nutritionists, extension educators, dairy industry personnel, students, and the scientific community through field days, professional meetings, farmer conferences, webinars, and workshops. What do you plan to do during the next reporting period to accomplish the goals? We planned to report data from a second feeding trial done at the University of New Hampshire Organic Dairy Research Farm, modeling and economic analyses, and results of the ongoing legume-grass mixtures agronomic plots.

****Impacts**** What was accomplished under these goals? Agronomic Small-Plot Study at the University of New Hampshire: As described in previous progress reports, we reestablished the experimental plots in August 2018 due to poor establishment of the previous iteration of the experiment. Each plot was seeded to 1 of 4 forage legumes (alfalfa, white clover, red clover, and birdsfoot trefoil) and orchardgrass at a 70:30 (legume:grass) ratio. In addition, we also included 2 legume mixture treatments (all 4 legumes sown together with orchardgrass in either a 70:30 or 30:70 ratio). We observed good germination and overwinter survival in 2018/19 despite region-wide issues with winterkill. We

initiated the cutting frequency and height treatments in the spring of 2019 using a plot-scale forage harvester. The intermediate intensity cutting (3X) frequency treatment was aimed at a relatively long interval and recovery time between each harvest and involved harvesting each plot a total of 3 times over the growing season, beginning in early June and ending in October each year. In contrast, the high intensity cutting (5X) frequency treatment involved harvesting each plot a total of 5 times over the season, creating a shorter interval and recovery period (30 d) between cuts. Plots were also assigned to a cutting height treatment of either 5 or 10 cm residual forage height. These treatments have been maintained in the same plots for the duration of the study. At the time of each harvest, we sort herbage to species and dry and weigh the biomass. Similar to the 2019 growing season, total forage (legume + orchardgrass) production over the 2020 growing season was greatest in the red clover treatments compared to the other three legume treatments. Unlike 2019, however, total production in the white clover plots was higher compared to the alfalfa and birdsfoot trefoil plots, which both had similar production. The differences in total production among the four legumes treatments were due primarily to differences in the productivity of the legumes rather than orchardgrass, the abundance of which was relatively similar across legume treatments. Total forage production across all treatments was strongly influenced by the forage available at the first cut, which was much greater than in subsequent harvests due to the severe drought conditions that set in soon after the first harvest. Second harvests in both the 5X and 3X treatments produced on average 75% lower total forage dry matter than the first harvest. Total forage production continued to decline over the growing season in all treatments due to lack of rainfall. Among legume species, white clover appeared to be most negatively affected by the drought. Cutting height and intensity treatments appeared to have little influence over how each legume species responded to the drought conditions. Agronomic Small-Plot Study at the University of Vermont: Field work at the University of Vermont was completed. Feeding Trail at the University of New Hampshire: Twenty mid-lactation organic certified Jersey cows were assigned to 1 of 2 diets in a crossover design with 2 periods. Each experimental period lasted 24 days, with 14 days for diet adaptation and 10 days for sample collection. Two fields were planted with alfalfa- or red clover-grass mixture with a 79:14:7 legume:meadow fescue:timothy seeding rate (% total). Second- and third-cut legume-grass mixture used in this study were harvested as baleage in 2019. The botanical composition (dry matter basis) of fields from which the second and third cut red clover-grass averaged: 75 vs. 62% red clover, 4 vs. 11% grasses, and 21 vs. 10% weeds, respectively. Note that 17% (dry matter basis) of white clover was present in the red clover-grass field from the third cut. The botanical composition of the second cut alfalfa-grass field harvested as baleage averaged (dry matter basis): 40% alfalfa, 2% red clover, 26% white clover, 9% grass, and 23% weeds. Compared with 2018, the botanical composition of the alfalfa-grass field changed, with some alfalfa being replaced by white clover due to alfalfa winter kill. Diets were fed as total mixed ration and contained (DM basis): (1) 60% second and third cut red clover-grass baleage (30% of each cut) and 40% of a ground corn-soybean meal-based mash concentrate (high red clover-grass mixture diet = HRC-M), and (2) 30% second and third cut red clover-grass baleage (15% of each cut), 30% second cut alfalfa/white clover-grass baleage, and 40% of a ground corn-soybean meal-based mash concentrate (low red clover-grass mixture diet = LRC-M) Diets averaged 17.8 vs. 17.2% crude protein and 31.7 vs. 31.3% neutral detergent fiber (NDF) for HRC-M vs. LRC-M, respectively. Cows were fed and milked twice daily, with feed offered and refused weighed daily to compute dry matter intake throughout the study. Milk volume was recorded daily, and milk samples were collected for 4 consecutive milkings during the first 3 days of each experimental period. Milk was analyzed for fat, protein, and milk urea-N (Dairy One; Ithaca, NY). Blood samples were collected approximately 4 h after the morning feeding once in the last day both experimental periods and analyzed for urea N. Fecal samples were collected and analyzed for indigestible NDF to determine apparent total-tract digestibility of nutrients. Enteric methane emissions were measured using the GreenFeed system (C-Lock Inc., Rapid City, SD). The GreenFeed operates by automatically releasing a bait pellet every 30 seconds for up to 5-min measurements several times throughout the day triggered by a RFID ear tag wear by each cow. Built-in sensors are used to measure methane fluxes near real-time. Data are currently being analyzed statistically. **Publications** **Progress** 09/01/18 to 08/31/19 **Outputs** **Target Audience:** We directly served organic and conventional dairy farmers across the Northeast region, as well as extension educators, industry stakeholders (e.g., organic milk processors, nutritionists, veterinarians), and the scientific and academic communities (e.g., graduate and undergraduate students, post-docs, and fellow scientists). Our team disseminated project results through workshops, webinars, pasture walks, farmer-oriented conferences, and national and international scientific conferences. **Changes/Problems:** Nothing Reported **What opportunities for training and professional development has the project provided?** Project results have been disseminated to dairy farmers, dairy nutritionists, extension educators, dairy industry personnel, students, and the scientific community through field days, professional meetings, farmer conferences, webinars, and workshops. Specifically, we delivered project results during the American Dairy Science Association Annual Meeting, farm tours, and local and regional producer conferences. **How have the results been disseminated to communities of interest?** Project results have been disseminated to dairy farmers, dairy nutritionists, extension educators, dairy industry personnel, students, and the scientific community through field days, professional meetings, farmer conferences, webinars, and workshops. **What do you plan to do during the next reporting period to accomplish**

the goals? We planned to report data from a second feeding trial done at the University of New Hampshire Organic Dairy Research Farm, modeling and economic analyses, and results of the ongoing legume-grass mixtures agronomic plots. ****Impacts**** What was accomplished under these goals? Agronomic Small-Plot Study at the University of New Hampshire: As described in previous progress reports, we reestablished the experimental plots in August 2018 due to poor establishment of the previous iteration of the experiment. Each plot was seeded to 1 of 4 forage legumes (alfalfa, white clover, red clover, and birdsfoot trefoil) and orchardgrass at a 70:30 (legume:grass) ratio. In addition, we also included 2 legume mixture treatments (all 4 legumes sown together with orchardgrass in either a 70:30 or 30:70 ratio). We observed good germination and overwinter survival in 2018/19 despite region-wide issues with winterkill. We initiated the cutting frequency and height treatments in the spring of 2019 using a plot-scale forage harvester. The intermediate intensity cutting (3X) frequency treatment was aimed at a relatively long interval and recovery time between each harvest and involved harvesting each plot a total of 3 times over the growing season, beginning in early June and ending in October each year. In contrast, the high intensity cutting (5X) frequency treatment involved harvesting each plot a total of 5 times over the season, creating a shorter interval and recovery period (30 d) between cuts. Plots were also assigned to a cutting height treatment of either 5 or 10 cm residual forage height. These treatments have been maintained in the same plots for the duration of the study. At the time of each harvest, we sort herbage to species and dry and weigh the biomass. Similar to the 2019 growing season, total forage (legume + orchardgrass) production over the 2020 growing season was greatest in the red clover treatments compared to the other three legume treatments. Unlike 2019, however, total production in the white clover plots was higher compared to the alfalfa and birdsfoot trefoil plots, which both had similar production. The differences in total production among the four legumes treatments were due primarily to differences in the productivity of the legumes rather than orchardgrass, the abundance of which was relatively similar across legume treatments. Total forage production across all treatments was strongly influenced by the forage available at the first cut, which was much greater than in subsequent harvests due to the severe drought conditions that set in soon after the first harvest. Second harvests in both the 5X and 3X treatments produced on average 75% lower total forage dry matter than the first harvest. Total forage production continued to decline over the growing season in all treatments due to lack of rainfall. Among legume species, white clover appeared to be most negatively affected by the drought. Cutting height and intensity treatments appeared to have little influence over how each legume species responded to the drought conditions.

Feeding Trial at the University of New Hampshire: Alfalfa (*Medicago sativa* L.) has become the "gold standard" for production of silage, baleage, and hay in the United States, but a large proportion of alfalfa protein is broken down to non-protein N (i.e., ammonia, amino acids, and peptides) during ensiling, thus reducing the efficiency of protein utilization when cows are fed alfalfa silage. In contrast, protein from red clover (*Trifolium pratense* L.) is protected against degradation in the silo due to the presence of the enzyme polyphenol oxidase in red clover tissues. Previous research demonstrated that red clover silage was comparable to alfalfa silage in terms of dry matter intake, milk production, and percentage of milk fat (Johansen et al., 2018). However, cows fed red clover silage had lower concentration of milk urea N and excreted less N to the environment than those fed alfalfa silage (Broderick et al., 2007), thus showing improved use of dietary protein with red clover. However, there have been limited research comparing the effects of alfalfa- vs. red clover-grass mixtures on feed intake, milk production and composition, and dietary utilization of N and energy in dairy cows. Feed intake, milk production and composition, and N utilization were reported previously. Two fields were planted with alfalfa- or red clover-grass mixture with a 79:14:7 legume:meadow fescue:timothy seeding rate (% total), with forages harvested as baleage. Twenty mid-lactation organic certified Jersey cows were assigned to 1 of 2 diets in a randomized complete block design: alfalfa-grass (ALF-GR) or red clover-grass (RC-GR). A diet by week interaction was observed for the concentration of ammonia-N in the rumen fluid. Specifically, rumen ammonia-N concentration decreased with feeding RC-GR during week 4 (3.99 vs. 8.73 mg/dL) but no change during week 7. Rumen concentration of total volatile fatty acids was not affected by diets. In contrast, the molar proportion of rumen acetate was greater in cows fed RC-GR than ALF-GR. Diet by week interactions were found for the rumen molar proportions of propionate, butyrate, valerate, and isobutyrate. While the molar proportion of propionate decreased in RC-GR during week 4 (12.7 vs. 13.6 mol/100 mol), diets did not affect propionate in week 7. The rumen molar proportion of butyrate did not change in week 4, but it was reduced in cows fed RC-GR during week 7 (9.67 vs. 10.6 mol/100 mol). Rumen valerate (0.98 vs. 1.32 mol/100 mol) and isobutyrate (0.61 vs. 0.92 mol/100 mol) were lower in week 4 for cows offered RC-GR versus ALF-GR, with isobutyrate also been lower in the RC-GR diet in week 7. Rumen isovalerate was reduced with feeding RC-GR than ALF-GR. Cows fed RC-GR had increased total-tract digestibilities of dry matter, organic matter, and neutral detergent fiber compared with those fed ALF-GR. Diets did not affect intake of gross energy, digestible energy, metabolizable energy, and net energy of lactation. In contrast, diet by week interactions were observed for urinary energy and methane energy outputs, with these 2 variables decreasing in cows offered RC-GR during week 4, but no changes detected between diets during week 7. An interaction was also observed for the efficiency of converting metabolizable energy into milk energy. Specifically, cows fed RC-GR was less efficiency in converting metabolizable energy into milk energy during week 4 with no change detected in week 7. ****Publications**** - Type: Conference Papers and

Presentations Status: Published Year Published: 2020 Citation: Wilder, A., and S. Bosworth. 2020. Fermentation and protein evaluation of 12 binary legume-grass mixtures ensiled during multiple small plot harvests using vacuum-bag mini-silos. *J. Dairy Sci.* 103 (Suppl. 1):229-230.

PROGRESS

2017/09 TO 2018/08 Target Audience: We directly served organic and conventional dairy farmers across the Northeast region, as well as extension educators, industry stakeholders (e.g., organic milk processors, nutritionists, veterinarians), and the scientific and academic community (e.g., graduate and undergraduate students, post-docs, and fellow scientists). Our team disseminated project results through workshops, webinars, pasture walks, farmer-oriented conferences, and national and international scientific conferences.

Changes/Problems: At the University of Vermont, we were able to accomplish our goal in 2018 having 4 harvests of the intensive cutting management strategy and 3 harvests of the delayed strategy. However, due to spotty winter kill and injury in the winter of 2019, which eliminated about half our plots, we were limited to only 1 cutting strategy in 2019. Therefore, we only evaluated the 12 legume-grass mixtures plus legume monocultures within the intensive cutting strategy because that is the approach used by most dairy farms in the region.

What opportunities for training and professional development has the project provided? The project outreach and research components are advancing as planned. Workshops and outreach activities such as presentations, dairy farm meetings, field days, farm tours, and webinars featuring project results have been delivered. Specifically, presentations to extension educators done by our team during the New England Ag Service Providers In-Service Annual Meeting (Portsmouth, NH; January 29, 2020; 55 participants) and the University of New Hampshire Cooperative Extension Twilight Meeting (online presentation; June 24, 2020; 15 participants) were delivered and highlighted the importance of incorporating legumes in forage mixtures to improve milk production and feed efficiency in organic dairy farmers. Our team also presented at the 10th Vermont Organic Dairy Producers (Randolph, VT; March 11, 2020) and educate approximately 100 organic dairy farmers, extension educators, and industry personnel about forage-legume mixtures for silage production. Two webinars about forage quality and best forage-grass mixtures to boost milk production in cows fed high-forage diets were delivered during the Penn State Dairy Grazing Management Series (February 12, 2020 and March 11, 2020). Our team also presented project results in local, regional, national, and international conferences.

How have the results been disseminated to communities of interest? Project results have been disseminated to dairy farmers, dairy nutritionists, extension educators, dairy industry personnel, students, and the scientific community through field days, professional meetings, farmer conferences, webinars, and workshops.

What do you plan to do during the next reporting period to accomplish the goals? For the next report (final report), our team will present results of 2 feeding trials and the third growing season (UNH site). We will also plan to deliver e-organic webinars and continue to present project results in local, regional, national, and international conferences. Greenhouse gas modeling and economic analyses will be finalized as well.

IMPACT

2017/09 TO 2018/08 -2019?? What was accomplished under these goals? Agronomic Small-Plot Study at the University of Vermont: The small plot legume-grass study established in 2017 was continued and completed in 2019. The goal was to evaluate the effect of intensive and delayed management strategies on the yield and quality of 12 legume-grass mixtures created by combining alfalfa, red clover, or birdsfoot trefoil with timothy, tall fescue, meadow fescue, or perennial ryegrass. We also included monocultures of the 3 legumes for a total of 15 treatments. Field measurements were taken for yield and botanical composition and samples were analyzed by near infrared spectroscopy (NIRS) to determine crude protein (CP), non-fiber carbohydrates (NFC), non-structural carbohydrates (NSC), neutral detergent fiber (NDF), 30-h and 240-h NDF digestibility, relative forage quality (RFQ), and estimated milk/ha. The results of an analysis of covariance (ANCOVA) test showed that using a delayed cutting strategy increased NDF% and decreased CP, NFC, NSC, 30-h and 240-h NDF digestibility, and RFQ. Reductions in quality combined with lower average dry matter (DM) yields resulted in losses of 3,310 kg of milk/ha. Mixtures containing alfalfa significantly outperformed red clover-grass mixtures and birdsfoot trefoil-grass mixtures in plot yield and milk/ha during 2018. Birdsfoot trefoil-grass mixtures showed exceptional quality but failed to produce significantly higher milk/ha than alfalfa-grass mixtures, even when alfalfa and red clover suffered from severe winter injury in the second year. Red clover-grass mixtures were consistently lower in quality than mixtures containing the other legumes and showed the highest yield reduction when delayed cutting management was used. Binary mixtures that included perennial ryegrass were high in quality but were significantly lower in yield in most cases. Thus, yield differences were not offset by higher quality in terms of milk/ha. The opposite was true for legume-timothy mixtures. One hypothesis from our study was that different legume-grass mixtures would influence silage fermentation and the degree of proteolysis of these mixtures. To

test this, binary mixtures of legumes (alfalfa, red clover, and birdsfoot trefoil) and grasses (timothy, tall fescue, meadow fescue, and perennial ryegrass) were artificially wilted to 45% DM and ensiled across 6 cuttings over 2 years. Measurements were taken on vacuum-bag mini-silos to determine volumetric fermentation expansion and silage pH. NIRS was used to determine CP, soluble protein, insoluble degradable protein, and degradable protein. An analysis of covariance was conducted, and results indicated that legume-grass mixtures containing birdsfoot trefoil or red clover had more CP as insoluble degradable protein and less CP as rapidly degradable soluble protein compared to alfalfa mixtures. While grass species generally had little effect on silage protein fractions, tall fescue inclusion resulted in higher soluble protein and lower insoluble degradable protein in some cuttings. The fermentation of alfalfa and alfalfa-grass mixtures generated more gas expansion in the vacuum bag minisilos than red clover and birdsfoot trefoil mixtures along with reduced silage pH in non-inoculated birdsfoot trefoil mixtures and occasionally in red clover mixtures (delayed cuttings) compared to alfalfa mixtures.

Agronomic Small-Plot Study at the University of New Hampshire: As described in the previous progress report, we reestablished the experimental plots in August 2018 due to poor establishment of the previous iteration of the experiment. Each plot was seeded to 1 of 4 forage legumes (alfalfa, white clover, red clover, and birdsfoot trefoil) and orchardgrass at a 70:30 (legume:grass) ratio. In addition, we also included 2 legume mixture treatments (all 4 legumes sown together with orchardgrass in either a 70:30 or 30:70 ratio). We observed good germination and overwinter survival in 2018/19 despite region-wide issues with winterkill. We initiated the cutting frequency and height treatments in the spring of 2019 using a plot-scale forage harvester. The haying (3X) frequency treatment was aimed at a relatively long interval and recovery time between each harvest and involved harvesting each plot a total of 3 times over the growing season, beginning June 3 and ending October 15, 2019. In contrast, the grazing (5X) frequency treatment involved harvesting each plot a total of 5 times over the season creating a shorter interval and recovery period (30 d) between cuts. Plots were also assigned to a cutting height treatment of either 9 or 10 cm. For each harvest we sorted herbage to species and dried and weighed the biomass. Red clover was much more productive compared to the other 3 legumes. The second emerging trend is that harvest frequency has a greater impact on total forage production (total amount of forage DM produced over the season) than does cutting height. We observed greater total forage yield in the 5X compared to the 3X treatment and this was apparent regardless of which legume was included in the mixture. Importantly, most of this difference in total DM production was due to the abundance of the orchardgrass component of the mixture, which was on average 40% greater in the 5X treatment. In other words, the orchardgrass was much more responsive to the cutting frequency than were any of the four legume species. Finally, we observed that the proportion of legumes in each mixture varied over the course of the season and the trends were species-specific. This was particularly apparent in the 5X cutting treatment. For example, the proportion of red clover was nearly 70% of the total DM at the first harvest, just over 40% at the fourth harvest, and a little higher than that at the fifth and final harvest of the season. In contrast, both alfalfa and birdsfoot trefoil made up just over 35% of the total DM at the first harvest but not more than 5% by the final harvest. White clover exhibited a different trend; it made up just 20% of the total DM at the first harvest, but by the final harvest it had increased to over 30%.

Feeding Trial at the University of New Hampshire: Twenty mid-lactation organic Jersey cows were used to investigate the effects of different legume-grass mixtures on production, milk fatty acids (FA) profile, CH₄ emissions and plasma amino acids (AA) concentration. Two fields were planted with alfalfa (ALF)- or red clover (RC)-grass mixture with a 79:14:7 legume:meadow fescue:timothy seeding rate (% total). Forages were harvested as baleage, with second- and third-cut legume-grass mixtures used in the study. Diets were formulated to contain 65% second- and third-cut ALF or RC-grass (32.5% of each cut) and 35% concentrate. The study lasted 9 wk (2-wk covariate) with sample collection done at wk 4 and 7. Production and milk composition were reported previously. Significant diet by wk interactions were found for the milk proportions of total ω -3 FA and 16-carbon FA, with ω -3 FA and 16-carbon FA increasing more noticeably in cows fed RC- or ALF-grass in wk 7 than wk 4, respectively. No differences were detected for total ω -16-carbon FA in milk fat but feeding RC-grass increased total ω -6 FA and 18-carbon FA. A significant diet by wk interaction was observed for CH₄ production, with cows fed RC-grass showing lower CH₄ in wk 4 but no change in wk 7. Diets did not affect the plasma concentrations of Lys and Met. However, plasma Leu increased with feeding RC-grass. Significant diet by wk interactions were found for the plasma concentrations of Arg, His, Phe, Trp, Val, and total EAA. Feeding RC-grass increased plasma Arg, Phe, Val, and total EAA in wk 7 but not in wk 4. Further, RC-grass enhanced plasma His more noticeably in wk 7 than wk 4. Compared with ALF-grass, plasma Trp decreased in cows fed RC-grass in wk 4 and increased in wk 7.

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

- 2017/09 TO 2018/08 1. Type: Other Status: Published Year Published: 2020 Citation: Brito, A. F., M. J. Lange, and L. H. P. Silva. 2020. The key role of forage legumes in organic dairy diets: Effects on your bottom line. Northeast Organic Dairy Producers Alliance Online Newsletter. <https://nodpa.com/n/945/The-Key-Role-of-Forage-Legumes-in-Organic-Dairy-Diets-Effects-on-Your-Bottom-Line> 2. Type: Other Status: Awaiting Publication Year Published: 2020 Citation: Smith, R. G., and N. D. Warren. 2020. Managing forage legumes for improved productivity and persistence. Northeast Organic Dairy Producers Alliance Online Newsletter. (In Press).
3. Type: Conference Papers and Presentations Status: Published Year Published: 2020 Citation: Wilder, A. and S. Bosworth. 2020. Artificial wilting in a forced-air oven has minimal effects on silage

fermentation and quality in both inoculated and untreated vacuum-bag mini-silos. J. Dairy Sci. 103 (Suppl. 1):64.
4. Type: Theses/Dissertations Status: Published Year Published: 2020 Citation: Wilder, A M. 2020. The agronomics of organically managed legume-grass mixtures for ensiled forage production. MS Thesis. Department of Plant and Soil Science, University of Vermont, Burlington. 5. Type: Conference Papers and Presentations Status: Published Year Published: 2020 Citation: Wilder, A. and S. Bosworth. 2020. Fermentation and protein evaluation of 12 binary legume-grass mixtures ensiled during multiple small-plot harvests using vacuum-bag mini-silos. J. Dairy Sci. 103 (Suppl. 1):229.

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Ensuring the Best Practical Use of Microbe-containing Crop Biostimulants/biofertilizers Among (transitional)-organic Vegetable Growers

Accession No.	1010588
Project No.	OHO03009-CG
Agency	NIFA OHO\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2016-51106-25714
Proposal No.	2016-06197
Start Date	01 SEP 2016
Term Date	31 AUG 2019
Grant Amount	\$499,415
Grant Year	2016
Investigator(s)	Kleinhenz, M. D.
Performing Institution	OHIO STATE UNIVERSITY, 1680 MADISON AVENUE, WOOSTER, OHIO 44691

NON-TECHNICAL SUMMARY

Microbe-containing biostimulants and biofertilizers (MC BSs/BFs) are many things. First, they are advertised to enhance soil and crop health, accelerate soil nutrient cycling, and improve crop quality, among other benefits. Second, they are popular among ever-greater numbers of (transitional)-organic vegetable farmers. Third, they are numerous, diverse, frequently ineffective, often costly and minimally labeled, and essentially absent in research-based resources meant to help (transitional)-organic farmers. Finally, they represent a large and increasing, but, currently, entirely unregulated business. Collectively, these deficiencies have clear and significant undesirable effects on (transitional)-organic farmers and their advisors. Least among these effects is that farmers' profits decline and advisors underserve growers. Our long-term goal is to create resources, tangible and human, ensuring the best practical use of MC BSs/BFs among (transitional)-organic vegetable growers. Next, we will: a) complete stakeholder-focused experiments on farms and research stations, b) expand and strengthen a growing network of farmers and other professionals while evaluating and reporting on product performance, and c) establish, share, and help stakeholders implement core components of practical guidelines for using MC BSs/BFs during (transitional)-organic vegetable production. Engaging farmers, regional-national organizations, manufacturers, and students, we will demonstrate a replicable process for evaluating MC BSs/BFs on farms, thereby minimizing farmer and advisor guess-work in selecting, using, and evaluating MC BSs/BFs. We will improve farmers' immediate capacities to sensibly and reliably integrate MC BSs/BFs into their toolboxes. We will also foster durable gains in farmers' on-farm research skills and in resources educators can apply in serving (transitional)-organic farmers.

OBJECTIVES

Biostimulants and biofertilizers are types of microbe-containing bioproducts (MCBPs) advertised to enhance crop growth. These promising MCBPs are very popular among certified-organic growers and, presumably, many transitional growers, also. Unfortunately, these MCBPs are also very numerous and diverse, frequently ineffective, entirely unregulated, often costly and minimally labeled, and essentially absent in research-based guides and other resources upon which (transitional)-organic growers look to rely. These deficiencies frustrate

users and lower their profits, limit the ability of advisors to serve growers, and erode grower confidence in microbe-containing biostimulants and biofertilizers (MC BSs/BFs). Our long-term goal is to create resources, tangible and human, allowing current and aspiring organic growers to gain more reliably from using MC BSs/BFs. Our specific objectives in this three-year workplan are to: 1. Evaluate selected MC BSs/BFs on farms and research stations using crop and financial metrics; 2. Expand and strengthen a growing network of farmers, MC BS/BF manufacturers, scientists, educators, and consultants engaged in evaluating and reporting on the performance of MC BSs/BFs; and 3. Establish, share, and help stakeholders implement core components of user-centered guidelines for the best practical use of MC BSs/BFs during (transitional-)organic vegetable production.

APPROACH

Objective 1: Evaluate selected MC BSs/BFs on farms and research stations using crop and financial metrics. Evaluation will begin with recruiting stakeholder input on key aspects of the process. (Transitional-)organic growers will be invited to participate in web-based and in-person information sessions prior to initiating on-station and on-farm experiments and evaluations. Each session will have three major sections: 1) a "primer" on MC BS/BF selection, use, and effects, 2) an assessment of grower attitudes toward and experience with MC BSs/BFs and suggestions for product evaluation, and 3) an invitation to participate in the project as a grower-cooperator and host of on-farm research, along with a summary of the roles, expectations, and expected challenges and rewards. In Year 1, evaluation will continue with the recruitment of 5-10 grower-cooperators in OH and TN. In addition to experience with or a clear interest in MC BSs/BFs, grower-cooperators will: 1) have experience with one or more project crops (butternut squash, carrot, lettuce, spinach, tomato; see Table 3); 2) be prepared to participate in on-farm research, with team support; and 3) have the potential to share their experiences effectively with growers and others. Evaluations documenting the effects of inoculants on crops will be completed in Years 1-3 in experiments located in open-field and semi-protected (high, mid, and low tunnel) settings including transitional- and certifiable-organic parcels managed by The OSU and UT. Individual studies to be completed each year are expected to involve six products applied to one-two crops (five crops total - butternut squash, carrot, lettuce, spinach, and tomato), treatments based on application timing or rate, and data collection focused on changes in crop productivity and product quality. Evaluations will also include economic analysis. The role of MC BSs/BFs in (transitional-)organic production will be further studied by estimating their contribution to yield-based crop outputs and evaluating their contribution to farm profits. Several methods (enterprise budgets, partial budgets, and production function estimation) will be used to identify inoculant effects on crops and the value of MC BSs/BFs to (transitional-)organic operations.

Objective 2: Expand and strengthen a growing network of farmers, MC BS/BF manufacturers, scientists, educators, and consultants engaged in evaluating and reporting on the performance of MC BSs/BFs. Our workplan is well integrated in that distinctions between research and extension will rarely be absolute. Stakeholder-project team interaction will be inclusive, extensive, and outcome-oriented. Participation in evaluations and information dissemination, the network facilitating them, and opportunities for even more robust stakeholder-based, MC BS/BF-related projects are likely to grow. Our tangible and intangible products, resources, and events (e.g., articles, webpages, field days, workshops, presentations, in-services, listserv) will reach many and they are important. However, the collaborative framework and process that will be built through planned activities may be the most significant output. The collaborative network initiated in Fall 2014 will be expanded and strengthened.

Objective 3: Establish, share, and help stakeholders to implement core components of user-centered guidelines for the best practical use of MC BSs/BFs, during (transitional-)organic vegetable production. Guidance in selecting, using, and evaluating MC BSs/BFs (including in on-farm research) will be provided from grower-cooperator recruitment through project completion in numerous formats: in-person, guided on-farm experiments, publications, moderated discussions, field days, and static and dynamic online resources and events (e.g., webinars). Active guidance using these approaches and involving all project PDs will occur throughout the project, although many resources and platforms are expected to remain viable for much longer. Online resources, and contacts and firsthand experience gained through project participation are examples of resources that will contribute to stakeholder success long after project completion. Consensus, core components of user-center guidelines for MC BS/BF use will emerge beginning with manufacturer-project team-grower engagement early in Year 1. These baseline components will be shared in updatable articles, presentations, online resources, and educational items provided to growers before and during on-farm research. Testing protocols will also be reviewed grower and industry advisors and modified accordingly. Technical reports, articles (university, grower organization, trade), website postings, and presentations at grower meetings will be used to share annual research summaries and help develop follow-on research and extension activities, including recruiting additional growers, if needed. MC BS/BF manufacturers, and universities and professional organizations will be invited to co-host field days, farm tours and educational programs, issue newsletters, and offer webpages. The ORFN website will also be useful in tracking and reporting on project activities and sharing protocols, experimental results, and program announcements. An MC BS/BF-specific YouTube channel will also be created to host recorded presentations

(e.g., Camtasia, Mediasite) prepared by project team members. Moderated project- and MC BS/BF-related workshops held during annual conferences will also allow growers, MC BS/BF industry representatives, and university researchers and educators to share their experiences with and recommendations for MC BS/BF selection, use, and evaluation, including using approaches we employ as a project team. This dialogue and information gleaned from participant questionnaires will help to further refine best-use protocols prepared, distributed, and implemented by the team and its cooperators. Workshop summaries will be posted at the ORFN website using an approach we have employed successfully to help advance the best-use of grafted vegetable plants, including among organic growers. A searchable MC BS/BF database will also be refined and expanded in Years 2 and 3. Traditional print and online resources containing fundamental information on MC BSs/BFs will remain relevant for years. Likewise, with modest follow-up funding (i.e. industry-derived), this online searchable database could be updated continuously and house evaluation summaries from many investigators. Our connecting experienced mentors with less experienced learners will also establish deeper and more self-perpetuating foundations for expanding and improving (transitional-)organic farming. Inclusive development of the ORFN network focused on MC BSs/BFs will foster these connections. A novel online decision tool that incorporates production functions observed in experiments is also planned. ****Progress**** 09/01/17 to 08/31/18 ****Outputs**** Target Audience: The target audience included: 1. Specialty crop growers, emphasizing vegetable producers utilizing transitional- and/or certified-organic approaches and ones interested in learning more about selecting, using, and evaluating the performance of microbe-containing crop biostimulants; 2. Private- and public-sector advisors to the target audience of specialty crop growers, with advisors including county- and state-level cooperative extension personnel, consultants, educators, and members of grower and trade organizations and the agricultural/trade media offering technical content via programs, publications, and other resources; and 3. Scientists and other technical professionals involved in developing, evaluating, distributing, and/or marketing microbe-containing crop biostimulants, emphasizing the community of scientists and other professionals specifically engaged in these activities as they target specialty crop growers. Membership in this audience was not restricted by the size, geography, age, or other factors of the operation or to the background of its proprietors or members. Efforts reached historically disadvantaged populations. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? 1. For project leaders and personnel, an opportunity to engage with stakeholders in research and extension activities on increasingly important topics. Very important, the project topic is not only increasingly important to stakeholders but also one with which many research-extension personnel, including project members, had comparatively little experience prior to undertaking the project. Therefore, activities in 2018 represented opportunities for project personnel to develop critical experience and expertise and assist others in doing the same. This expertise represents multiple areas of interest including the handling, application, and evaluation of microbe-containing crop biostimulants and stakeholder-focused and data-driven discussion of their potential roles on farms. 2. For stakeholders, an opportunity to participate as co-learners and instructors in developing and disseminating novel, timely, and in-demand research-based information. Much excitement exists around the potential value of microbe crop biostimulants, especially on (transitional-)organic (vegetable) farms. Still, greater levels of confusion surround the individual, unavoidable processes of product selection, use, and evaluation. Activities in 2018 provided a structure through which stakeholders were able to set a personalized research and/or outreach/dissemination agenda, apply and enhance their core research and/or outreach skills, and assess the outcomes of their activities. Hundreds of microbe-containing crop biostimulants are commercially available. That, coupled with the large number of crops to which they can be applied, large number of environments under which they can be applied, and large number of application factors (e.g., rate, timing) that can be used, makes any attempt to identify "the best product" for any particular crop-environment extremely difficult. Therefore, instead of direct product comparison, activities in 2018 emphasized the development of durable and reliable on-farm and on-station evaluation methodology. So, stakeholders were engaged in developing information leading to methods they can rely on going forward. How have the results been disseminated to communities of interest? Results were disseminated in multiple formats (print, digital, oral/audio) and settings (on-farm and program, individual and group level consultation, instruction, demonstration, collaboration) using approaches known to be effective at addressing the needs of large and diverse communities of stakeholders with regard to selecting, using, and evaluating the effects of microbe-containing crop biostimulants. Dissemination included: (a) collaboration in on-farm and on-station research; (b) press, extension, and technical articles and newsletters; (c) presentations during industry and technical conferences, conventions, and similar programs; (d) interactive workshops; (e) databases and viewable and downloadable resources at webpages and blogs; (f) field days; (g) individual and small group consultations; and (i) responses to spontaneous requests for information by phone and email. In total, we engaged more than seven farmers in five states directly in research, published more than three trade and technical articles, delivered more than ten presentations at industry, extension, and technical programs, hosted and/or participated in three workshops and field days, created and renewed content at one project website, and responded to more than twenty-five spontaneous requests for project-related information from across the U.S. and Canada. We reached hundreds of growers and dozens of extension and industry advisors

and researchers directly and/or indirectly through our dissemination activities. What do you plan to do during the next reporting period to accomplish the goals? Our integrated, collaborative, and stakeholder-focused activities are beginning to achieve the expected and desired outcomes. Significant changes in fundamental approach appear to be unwarranted. For the next reporting period, we plan to maintain our core goals and methodologies while examining individual steps and techniques in order to identify how effectiveness and/or efficiency can be improved.

****Impacts**** What was accomplished under these goals? Goal 1. Evaluate selected MC BSs/BFs on farms and research stations using crop and financial metrics Six MC BSs/BFs representing major classes of this product category were included in experiments completed on two research stations and seven farms across four states. Individual on-station experiments involved three product timing or three rate application treatments and up to six crops grown in field and high tunnel settings whereas individual on-farm experiments involved fewer products, crops, treatments, and settings. Evaluation of product effects included ratings and measures of crop development, total and marketable yield, and quality using physical and chemical criteria scored or measured in the field, postharvest evaluation area, or laboratory. Goal 2. Expand and strengthen a growing network of farmers, MC BS/BF manufacturers, scientists, educators, and consultants engaged in evaluating and reporting on the performance of MC BSs/BFs. Project research and outreach/dissemination activities took place directly in nine U.S. states and one Canadian province, although the extension and industry programs hosted in those locations included participants representing other states, provinces, and countries. Similarly, research and outreach/dissemination also engaged a wide range of academic and industry professionals representing the research and development, MC BS/BF distribution, marketing, and use and extension/education and outreach sectors. Effort in 2018 reached, engaged, and joined stakeholders representing a significant cross-section of people interested in developing, marketing, using, or evaluating MC BSs/BFs or advising or educating people about those processes. Also, critically, deliberate steps were taken to include stakeholders representing different sectors and expertise in individual research or extension/dissemination activities. Goal 3. Establish, share, and help stakeholders implement core components of user-centered guidelines for the best practical use of MC BSs/BFs during (transitional-)organic vegetable production. Achieving Goal 3 will require the entire project period. Integrated research-extension activities in 2018 achieved a measure of progress toward Goal 3 as evidenced by the number of invited presentations, workshops, and on-farm and other programs to which project personnel were asked by stakeholders to contribute. We are confident our continued focus on "user-centered" and "best practical" guidelines and commitment to active engagement of stakeholders will lead to success with Goal 3.

****Publications**** - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Crop microbial biostimulants: What, why, and how? Invited presentation given at the 37th Annual Long Island Agricultural Forum in Riverhead, New York - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbials overview and next steps. Invited presentation given at the 2018 Indiana Horticultural Congress in Indianapolis, Indiana. - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbe-containing crop biostimulants: What we know, what is important to learn. Workshop held at the 2018 OEFFA Conference in Dayton, Ohio. - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbials summary and discussion. Presented at the 2018 OEFFA Conference in Dayton, Ohio. - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbial biostimulants overview. Invited presentation given at the Ontario Fruit and Vegetable Growers Conference in Niagara Falls, Ontario, Canada. - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbes in your toolbox? Let's talk. Invited presentation given at the 2018 SARE FarmersForum in Danville, Indiana. - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Biostimulants: What are they and how can I make them work for me? Invited presentation given at 2018 BioControls West in Carlsbad, California. - Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Big claims, big questions. Published in the Spring 2018 OEFFA Newsletter. <http://u.osu.edu/dist/9/24091/files/2016/12/oeffa-spr18-nwsltr-mcrbls-1-2-q81mq1.pdf> - Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Researchers Share Five Fast Facts to Help Growers Understand Biofertilizers. Published by MOSES Organic Broadcaster, July/August 2018 issue <<https://mosesorganic.org/biofertilizers/>>. - Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Progress through private-public sector partnerships: issues and approaches. Invited presentation given at the New Ag International Biostimulant Summit in Chicago, IL. - Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Key steps, including on-farm evaluation, in getting the most from biostimulants. Workshop/field-day and crop walk on Wayne County, Ohio farm. (100 attendees) - Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Improving labels: an important step in advancing the use of crop biostimulants. Invited panelist and panel moderator for Crops and Chemicals Biostimulant/Biofertilizer Conference in Raleigh, North Carolina. - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Assessing the Influence of Microbe-containing Crop Biostimulants on Vegetable Crops and Farms through On-station and On-

farm Study. Oral presentation during the Annual Meetings of the American Society for Horticultural Science (Washington, D.C.) to an audience of extension-research colleagues from the U.S. and other countries. Recordings of the presentation are available at <https://ashs.confex.com/ashs/2018/meetingapp.cgi/Paper/29281>. - Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. OSUE Wayne County IPM scout training. Presentation and field walk at OARDC, Wooster, OH. (6 attendees) - Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Fruit Yield and Quality in a Strip Till Tomato Systems as Influenced by Grafted Plants and Crop Biostimulants. Published in the VegNet Newsletter at <<https://u.osu.edu/vegnetnews/2018/09/01/fruit-yield-and-quality-in-a-strip-till-tomato-system-as-influenced-by-grafted-plants-and-crop-biostimulants/>>. - Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbe-containing crop biostimulants in the farming toolbox. Invited presentation given at the 2018 Acres USA Conference in Louisville, Kentucky. - Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Biostimulant science and application. Invited, 45-minute presentation to and fielding questions during follow-up discussion with the Board of Directors of the Soil Health Institute (Raleigh, North Carolina).

PROGRESS

2016/09 TO 2020/08 Target Audience: The leading target audience for this effort includes transitional- and certified-organic vegetable growers, their private- and public-sector advisors and information providers, and developers and manufacturers of microbe-containing crop biostimulants (MCCBs), which are the focus of our experimentation and extension/outreach. Effort during the reporting period demonstrated: 1) that outcomes from inoculating vegetable crops with MCCBs differ by crop, product, application rate, application timing, season, and variable studied; and 2) that care must be taken in selecting, using, and evaluating the performance of MCCBs. Changes/Problems: The pandemic has had two major effects on the project. First, beginning in early March-2020, it altered the timeline of various activities, with various key ones needing to be temporarily delayed, at minimum. Second, while all attempts have been made to maintain all planned activities, some needed to be canceled or replaced. Developing and completing suitable alternatives consistent with project goals and resources has been and will remain our focus through project end and we look forward to reporting on success in that regard. What opportunities for training and professional development has the project provided? The project provided substantive opportunities for training and professional development to a large range and number of rising and experienced professionals. Examples include: Dr. Zheng Wang; former post-doctoral researcher with the project and currently, Area Vegetable and Irrigation Advisor (Stanislaus County) with Univ. of California Cooperative Extension. Dr. Wang joined the project team with knowledge of cropping system effects on plant-microbe dynamics. While with the project team, Dr. Wang gained experience in experimental design, extension/outreach, microbe-containing crop biostimulant (MCCB) development, use, and evaluation, and other topics. He applies this new knowledge in his current role. Nicole Wright, MPH; currently, Program Coordinator with The OSU Vegetable Production Systems Laboratory (VPSL) and lead technical contributor to the project. Ms. Wright joined the project team with extensive experience in extension/outreach, but none focused on MCCBs. While with the project team, Ms. Wright has gained additional experience in extension/outreach and in MCCB-related experimental design and other research methodology, microbe-containing crop biostimulant development, use, and evaluation, and related topics. She continues to both increase and apply her knowledge and skills through engaging in project activities. Sonia Walker, B.S.; currently, Research Associate with The OSU Vegetable Production Systems Laboratory (VPSL) and technical contributor to the project. Ms. Walker joined the project team with extensive experience in the conduct of field and high tunnel research, but very little focused on MCCBs. While with the project team, Ms. Walker has gained additional experience in MCCB-related research methodology (principally product handling and application and data analysis). She continues to both increase and apply her knowledge and skills through engaging in project activities. Mark Spigos, B.S.; currently, Agricultural Technician with The OSU Vegetable Production Systems Laboratory (VPSL) and technical contributor to the project. Mr. Spigos joined the project team with little experience in the conduct of field and high tunnel research and none focused on MCCBs. While with the project team, Mr. Spigos has gained valuable experience in multiple aspects of MCCB-related research methodology (seeding through sample analysis). He continues to both increase and apply his knowledge and skills through engaging in project activities. Dana Hilfinger, M.S.; formerly, technical contributor to the project team and currently, Program Coordinator with The OSU Initiative for Food and Agricultural Transformation (InFACT Program). Ms. Hilfinger joined the project team with private sector experience in extension/outreach, high tunnel use, and on-farm research but none involving MCCBs. While with the project team, Ms. Hilfinger gained additional experience in all these areas specifically as MCCB evaluation and potential grower success are at stake. She applies knowledge and skills gained while with the VPSL in her current role. In addition to these specific examples, members of the following groups benefitted from engaging in project-based training and professional development activities and/or direct consultation with project team members: 1) County Extension Educators and Specialists; 2) Industry Research and Development and

Outreach/Communications Professionals; and 3) Undergraduate Research Aides who participated in project activities. How have the results been disseminated to communities of interest? Overall, to-date, OH-based personnel have: a) published a total of 14 articles in public, trade, and extension outlets; b) delivered 23 talks and presentations; c) hosted 3 field days; and d) provided several radio interviews, blog posts, and calendar listings. Print, online articles: Articles addressed grower questions regarding how to better select, use, and evaluate microbial biostimulants in vegetable crop production, understand their place in a grower's toolbox, and discuss some of the claims and questions this group of crop inputs present. Outlets included those with regional and national reach and estimated distribution of more than 1,000 (OEFFA newsletter, MOSES Broadcaster, Growing Produce, and Agribusiness Global) along with more local and state-centered outlets with estimated distribution of 500 or less (OSU's VegNet, Hightunnels.org, and Tilth as examples). Invited and volunteered talks and presentations: A unique series of six call-in conversations (3 in 2017, 3 in 2018) aimed at increasing grower success with microbial biostimulants were coordinated by the project team. The series attracted 192 registrants from 28 U.S. cities, plus D.C and five international countries (Canada, Spain, Germany, and Angola). These calls were opportunities for growers, researchers, Extension, and industry to dialogue and ask questions for ninety minutes each and dig deeper into the selection, use, and evaluation of microbial biostimulants in vegetable crop production. Eleven University faculty and Extension, 10 company representatives, and 1 organic certifier served as expert panelists throughout the series. Presentations have been delivered at annual conferences, summits, forums, and meetings with a focus on grower audiences (ACRES USA, Indiana Hort Congress, Ohio Ecological Food and Farming Association Conference, Ohio Produce Network, SE Regional Fruit and Vegetable Conference, Long Island Ag Forum, Great Lakes Expo, SARE Farmer's Forum, and Ontario Fruit and Vegetable Growers Conference). Interactive sessions covered the role these inputs have in organic systems and grower's toolboxes, their best practical use, and the "whys" and "hows" of selecting, using, and evaluating their performance. A subset of professional, academic, and industry audiences were also addressed (World Congress on Biostimulants, Crops and Chemicals Biostimulant/Biofertilizer Conference, New Ag International Biostimulant Summit, American Society for Horticultural Science, and NAICC Annual Meeting). Field days: Four opportunities were provided for overviews of field and high tunnel research projects in progress, 2017-2019, at the Ohio Agricultural Research and Development Center in Wooster, Ohio. One targeted at a general grower audience, covered research in progress, examined fields, discussed experimental process and goals, and opened discussion about the role of microbial biostimulant inputs in vegetable crop production and methods to evaluate success (from the need for comparison/control plots to identifying observable outcomes). Other field days were annual requests from Wayne County Extension IPM scouts to learn about in-progress research. What do you plan to do during the next reporting period to accomplish the goals? Current activities will continue. Data collection will continue on a select subset of experiments alongside data analysis focused on identifying project-wide impacts and stakeholder-facing messages. Extension/outreach will also continue at full pace (as adjusted for pandemic-based restrictions) with the inclusion of research-based, project-wide messages.

IMPACT

2016/09 TO 2020/08 What was accomplished under these goals? Dozens, if not hundreds, of microbe-containing crop biostimulants (MCCBs) are available to growers; however, few, if any, research-based guidelines for selecting, using, or evaluating their effectiveness are available, especially to organic vegetable growers. This gap between information needed and information available leads to loss, waste, inefficiency, and confusion as crops, farms, balance sheets, farmer-farmer advisor relationships are all sub-optimal. This gap can be closed only by combining on-station and on-farm research, and continual, focused engagement of growers, industry, and academia, including the extension community. We used this approach to develop unique, stakeholder-facing datasets, collaborations, and resources holding crucial information regarding the performance of various MCCBs when applied to five high value crops in various settings at different times or rates. The process of collecting and actively sharing this information, and information provided by others, resulted in our catalyzing and contributing to new conversations that will lead to growers receiving more adequate returns on their investments in these complex, enigmatic products. Our approach has included on-station and on-farm experiments (expts) completed at the OSU-OARDC in Wooster, OH and Univ. of Tennessee-Knoxville. To date (Spring-2017 through Fall-2019), a total of thirty-nine runs of eleven individual on-station expts have been completed in OH with each exptl run containing 32-72 inoculated plots (2550 inoculated plots total 2017-2019). OH expts included butternut squash and tomato plots in open fields (OF) and carrot, lettuce, and spinach plots in high tunnels (HTs) at transitional-organic (T) and certified-organic (O) sites. Plots were established in spring (SP), summer (SU), and fall (FA), all managed using O practices. Individual expts were comprised of one crop seeded or transplanted in the SP, SU, or FA, at a T or O site in an OF or HT, and applying up to six products at either one of three crop development stages (timing) or percents of recommended rate (rate). 2017 SP, HT, timing: T carrot, spinach; O lettuce SU, OF, rate and timing; T and O: butternut squash, tomato FA, HT, timing: T lettuce, spinach 2018 SP, HT, timing: T carrot, spinach; O lettuce SU, OF, rate and timing; T and O: butternut squash, tomato FA, HT, timing: T; carrot,

lettuce, spinach 2019 SP, HT, timing: T carrot, spinach; O lettuce; SU, OF, rate and timing; T and O: butternut squash, tomato Fa, HT, timing: T carrot List of treatments in expts by expt type; all expts included controls. Timing Direct seeded carrot, spinach: 1. After seeding, before emergence 2. One week after 50% emergence 3. Three weeks after 50% emergence Transplanted lettuce, butternut squash, tomato: 4. At transplant 5. Two weeks after transplant (WAT) 6. 4 WAT Rate (relative to recommended rate) Butternut squash and tomato only: 1. 50% 2. 100% 3. 150% Products Used BioGenesis, EcoFungi, Environoc 401, MycoApply All Purpose, MycoApply EndoMaxx, and MycoGenesis were selected for use in the expts. All products included in all expts, except: a) carrots lacked Environoc 401, b) spinach lacked MycoApply EndoMaxx and EcoFungi, and c) lettuce lacked MycoApply All Purpose (except SP 2017) and EcoFungi (SP 2018 and 2019). Omissions were based on expected product-crop compatibility, product availability, or space limitations. MycoApply Soluble Maxx was used in FA 2019 carrot expt due to discontinuation of MycoApply All Purpose by manufacturer. Crop total and marketable yield and quality were recorded in all expts in a manner consistent with the scientific literature and grower practice and interest specific to each crop. On-farm evaluations were conducted in 2017, 2018, and 2019 by new and repeat grower-cooperators. Transitional and certified-organic growers were invited to participate if they grew: 1. one of the five project crops (butternut squash, carrot, lettuce, spinach, tomato), 2. in field or high tunnel settings, 3. in the Northcentral and Great Lakes States. Growers recruited through direct outreach and collaboration with the Ohio Ecological Food and Farming Association via 300 postcards sent to potentially qualified growers in 2018 and articles in 2017-2018 newsletters. A webpage (<https://u.osu.edu/vegprolab/microbe-containing-products/microbial-biostimulantsbiofertilizers-research-and-evaluation/>), announcements on the Organic Farming Research Network website, and in-person and web-based information sessions were also used in recruitment. Project staff worked with growers to decide crop, product, treatments, experimental design, and set expectations for return of observations and yield data. Product (if one of the six pre-selected for study; was donated by manufacturers), storage information, and application rates were sent to growers prior to planting. Project team continually assessed strategies to best assist growers to successfully set-up and complete evaluations using input from product manufacturers and feedback from growers. Project staff and growers stayed in contact during seasons by phone, email, and/or mail. Planting size and management (irrigation, mulch, amendments, pest/disease control), crop observations (written and/or photos comparing treated to untreated), perceived product/application ease of use, and data (predominantly yield) were collected by growers and provided to project team. Growers completing an evaluation received a \$250 stipend. Data collection and analysis continue. So far, based on standard analytical approaches, results from on-station expts in OH suggest that product application rarely led to significant changes in yield or quality on a field or HT basis (regardless of crop, season, timing, or rate); i.e., the average yield and quality of individual entire treated (inoculated) and untreated (control) plantings were similar. However, we also found large variation in responses to inoculation among plots within each expt run. Yield was greater following inoculation in fifty-four percent of all HT and fifty percent of all OF plots, with percentages differing by expt run (crop, season, rate of timing expt). This result has major implications for farmers, product suppliers, and farmer advisors. For example, to farmers, it signals that they may observe yield increases after product use but to levels providing unclear returns on investment. To product suppliers and farmer advisors, it signals that product formulation, application conditions, and evaluation protocols must be reconsidered and, probably, not approached like those of other major inputs (e.g., irrigation, fertilizer, crop protectants). Our results signal to all that much remains to be discovered (research) and taught/learned (extension/outreach) regarding selecting, using, and evaluating MCCBs more effectively. Articles, presentations, recordings, facilitated discussions, field days, webpages, and other resources and learning opportunities we developed and coordinated have helped ignite and facilitate this reconsideration across farming product supplier, and farmer-advisor communities. We identified and described key aspects of the thought process leading growers to use MCCBs, then focused on delivering key baseline information on MCCBs and their selection, use, performance, and evaluation. Anecdotally, the extension-outreach program has helped: a) foster greater awareness of major issues around these aspects of MCCBs and b) set a way forward for farmers, product suppliers, researchers, and farmer advisors interested in improving the reliability of these very popular but misunderstood and under-performing inputs. ****PUBLICATIONS (not previously reported):**** 2016/09 TO 2017/08 1. Type: Other Status: Published Year Published: 2016 Citation: Kleinhenz, M.D. 2016. Considering crop biostimulants, biofertilizers? Holmes County Hub Shopper. 2. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Call-in conversations offered on microbe-containing biostimulants and biofertilizers. <https://attra.ncat.org/calendar/brnews.php/call-in-conversations-offered-on>. 3. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. New resources available on microbe-containing biostimulants and biofertilizers (MCBSFs). <http://blog.nacaa.com/2017/01/new-resources-available-on-microbe.html>. 4. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Biostimulants and biofertilizers: Their role in organic production. Invited presentation given at the Southeast Regional Fruit and Vegetable Conference in Savannah, GA (1/6/17). 5. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Get your money's worth from crop biostimulants/biofertilizers that contain microbes. <https://www.ccof.org/blog/get-your-money%E2%80%99s-worth->

crop-biostimulants/biofertilizers-contain-microbes. 6. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Larger, better, and more stress-tolerated crops with microbial biostimulants? <https://u.osu.edu/vegnetnews/2017/05/11/larger-better-and-more-stress-tolerant-crops-with-microbial-biostimulants/> 7. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Microbials, grafting, strip tillage, and soil balancing. Workshop and field day held at the Ohio Agricultural Research and Development Center, The Ohio State University in Wooster, Ohio. 8. Type: Other Status: Published Year Published: 2017 Citation: Wang, Z., J. Laudick, and M. Kleinhenz. 2017. Microbial biostimulants in grower toolboxes. *Tilth Producers Quarterly* Vol. 27 No. 2 Summer 2017. <https://cpb-us-w2.wpmucdn.com/u.osu.edu/dist/9/24091/files/2016/12/Microbial-Biostimulants-in-Grower-Toolboxes-1dfwztj.pdf> 9. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. VegNet Newsletter at <http://u.osu.edu/vegnetnews/2017/07/22/can-microbial-inoculants-biostimulants-enhance-vegetable-yield-and-quality/>. 10. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Wang, Z. and M. Kleinhenz. 2017. Grafting and microbial crop biostimulants on early growth of greenhouse tomato. *HortSci* 52(9):S289. 11. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Getting the most from microbe-containing crop biostimulants. Autumn 2017 OEFFA Newsletter. <https://indd.adobe.com/view/644516f4-7eff-4fa4-9c27-ee7fc522034e> 12. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Microbial-based biostimulants: Grower, supplier, and researcher perspectives on their use in vegetable production. Invited presentation given at the BioControls USA East 2017 in Orlando, Florida. 13. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. U.S growers cautiously optimistic about biostimulants. Published in *Agribusiness Global* at <http://www.agribusinessglobal.com/markets/africa-middle-east/u-s-growers-cautiously-optimistic-about-biostimulants/> 14. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Towards the best practical use of microbial-based biostimulants in vegetable production. Presented by Matt Kleinhenz at the 3rd World Congress on Biostimulants in Agriculture in Miami, Florida. 15. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. What is in your microbial-based crop fertilizer? Published in the Winter 2017 OEFFA Newsletter. <https://indd.adobe.com/view/05e30fe4-dbd1-4309-9a73-2b82f073a1b4> 16. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Microbial biostimulants: Their place in the toolbox. Invited presentation given at the 2017 Great Lakes Expo in Grand Rapids, Michigan. 17. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Big questions about microscopic crop (and grower?) partners. Invited presentation given at the Acres U.S.A. 2017 Eco-Ag Conference & Trade Show. 18. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Crop microbial biostimulants: What, why, and how? Invited presentation given at the 37th Annual Long Island Agricultural Forum in Riverhead, New York 19. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbials overview and next steps. Invited presentation given at the 2018 Indiana Horticultural Congress in Indianapolis, Indiana. 20. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbe-containing crop biostimulants: What we know, what is important to learn. Workshop held at the 2018 OEFFA Conference in Dayton, Ohio. 21. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbials summary and discussion. Presented at the 2018 OEFFA Conference in Dayton, Ohio. 22. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbial biostimulants overview. Invited presentation given at the Ontario Fruit and Vegetable Growers Conference in Niagara Falls, Ontario, Canada. 23. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbes in your toolbox? Let's talk. Invited presentation given at the 2018 SARE Farmers Forum in Danville, Indiana. 24. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Biostimulants: What are they and how can I make them work for me? Invited presentation given at 2018 BioControls West in Carlsbad, California. 25. Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Big claims, big questions. Published in the Spring 2018 OEFFA Newsletter. <http://u.osu.edu/dist/9/24091/files/2016/12/oeffa-spr18-nwsltr-mcrbls-1-2-q81mq1.pdf> 26. Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Researchers Share Five Fast Facts to Help Growers Understand Biofertilizers. Published by MOSES Organic Broadcaster, July/August 2018 issue <https://mosesorganic.org/biofertilizers/> 27. Type: Other Status: Published Year Published: 2017 Citation: Kleinhenz, M.D. 2017. Microbial-based biostimulants: Big potential in small packages. Published by Meister Media at <http://www.growingproduce.com/vegetables/microbial-based-biostimulants-should-you-use-them-in-your-production/> 28. Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Progress through private-public sector partnerships: issues and approaches. Invited presentation given at the New Ag International Biostimulant Summit in Chicago, IL. 29. Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Key steps, including on-farm evaluation, in getting the most from biostimulants. Workshop/field-day and crop walk on on Wayne County, Ohio farm. 30. Type: Other Status:

Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Improving labels: an important step in advancing the use of crop biostimulants. Invited panelist and panel moderator for Crops and Chemicals Biostimulant/Biofertilizer Conference in Raleigh, North Carolina. 31. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Assessing the Influence of Microbe-containing Crop Biostimulants on Vegetable Crops and Farms through On-station and On-farm Study. Oral presentation during the Annual Meetings of the American Society for Horticultural Science (Washington, D.C.) to an audience of extension-research colleagues from the U.S. and other countries. Recordings of the presentation are available at <https://ashs.confex.com/ashs/2018/meetingapp.cgi/Paper/29281>. 32. Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. OSUE Wayne County IPM scout training. Presentation and field walk at OARDC, Wooster, OH. 33. Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Fruit Yield and Quality in a Strip Till Tomato Systems as Influenced by Grafted Plants and Crop Biostimulants. Published in the VegNet Newsletter at <https://u.osu.edu/vegnetnews/2018/09/01/fruit-yield-and-quality-in-a-strip-till-tomato-system-as-influenced-by-grafted-plants-and-crop-biostimulants/> 34. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Microbe-containing crop biostimulants in the farming toolbox. Invited presentation given at the 2018 Acres USA Conference in Louisville, Kentucky. 35. Type: Other Status: Published Year Published: 2018 Citation: Kleinhenz, M.D. 2018. Biostimulant science and application. Invited, 45-minute presentation to and fielding questions during follow-up discussion with the Board of Directors of the Soil Health Institute (Raleigh, North Carolina). 36. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. Development and utilization of microbe-containing biostimulants for vegetables. Invited presentation given at the 2019 National Association for Independent Crop Consultants Meeting in Savannah, GA. 37. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. Microbe-containing crop biostimulants in organic vegetable production: lessons and messages from farmers, researchers, and manufacturers. Poster presented at the 2019 Organic Agriculture Research Forum in Portland, OR. 38. Type: Other Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. Research newly completed and started. Published in the VegNet Newsletter at <http://u.osu.edu/vegnetnews/2019/05/25/research-newly-completed-and-started/> 39. Type: Other Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. Muck Crops Research-Extension Breakfast Meeting. Monthly meeting to discuss current ag topics and research including on microbial biostimulants. 40. Type: Other Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. Muck Crops Research-Extension Breakfast Meeting (June 2019). Monthly meeting to discuss current ag topics and research including on microbial biostimulants. 41. Type: Other Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. Making up lost ground (actually, for lost plants or leaves). Published in the VegNet Newsletter at <http://u.osu.edu/vegnetnews/2019/07/06/making-up-lost-ground-actually-for-lost-plants-or-leaves/> 42. Type: Other Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. Harvests of data hopefully increase harvests of money. Published in the VegNet Newsletter at <http://u.osu.edu/vegnetnews/2019/08/24/harvests-of-data-hopefully-increase-harvests-of-money/> 43. Type: Other Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. From new and unusual to common (or maybe not): the dynamic world of specialty varieties. Published in the VegNet Newsletter at <http://u.osu.edu/vegnetnews/2019/09/28/from-new-and-unusual-to-common-or-maybe-not-the-dynamic-world-of-specialty-varieties/> 44. Type: Other Status: Published Year Published: 2019 Citation: Kleinhenz, M.D. 2019. What are biostimulants? OSU/VPSL Microbe-containing bioproducts database referenced as resource in October 2019 UMASS Extension Vegetable Notes Newsletter available at [https://ag.umass.edu/sites/ag.umass.edu/files/newsletters/october 17 2019 vegetable notes.pdf](https://ag.umass.edu/sites/ag.umass.edu/files/newsletters/october%2019%20vegetable%20notes.pdf)

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Going Underground: Digging up the Dirt on Metarhizium-plant-pest Interactions in an Organic Cropping System

Accession No.	1010492
Project No.	PENW-2016-06198
Agency	NIFA PENW\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2016-51106-25715
Proposal No.	2016-06198
Start Date	01 SEP 2016
Term Date	31 AUG 2019
Grant Amount	\$463,947
Grant Year	2016
Investigator(s)	Barbercheck, M. E.
Performing Institution	PENNSYLVANIA STATE UNIVERSITY, 408 Old Main, UNIVERSITY PARK, PENNSYLVANIA 16802-1505

NON-TECHNICAL SUMMARY

Demand for organic feed exceeds supply, resulting in the need to facilitate production while maintaining environmental quality, beneficial processes and natural cycles. Overwintering cover crops in annual crop rotations promote soil conservation and natural enemies of pests, but little is known about cover crop effects on an often over-looked natural enemy - insect pathogens. We are investigating the effects of cover crops and soil characteristics on the novel interactions among the fungus, *Metarhizium*, an endemic disease-causing organisms of insects and plant-protective plant-associate, with crops and cover crops in an organic corn-soybean-wheat cropping system. Our objectives include: 1) characterize *Metarhizium* isolates from on-going organic research-station and on-farm experiments; 2) determine the ability of naturally-occurring isolates to form a relationships with cash crops and selected cover crops; 3) determine effects of *Metarhizium* infection of plants in a model system of corn, *Zea mays*, black cutworm, *Agrotis ipsilon*; and *Cochliobolus heterostrophus*, the causal agent of southern corn leaf blight; and 4) determine the effect of plant-associated *Metarhizium* on the expression of key defense genes that protect plants from crop pests and diseases. Information from this research will be incorporated into evaluated Extension materials and activities to strengthen the capacity of Extension and other agricultural professionals to serve organic growers, and into undergraduate curricula. This project seeks to improve the efficiency and competitiveness of organic crop producers and those transitioning to organic practices, and to understand the effects of soil management and characteristics, crop rotation and cover crops on biodiversity and plant protection in organic feed-grain rotations.

OBJECTIVES

Our long-term goal is to understand how to exploit the multiple benefits of the endemic soil fungus, *Metarhizium*, as an insect pathogen and as a plant symbiont in organic production systems. Our immediate research objectives are to: 1) characterize isolates of *Metarhizium* from the on-going research-station and on-farm field experiments associated with a USDA OREI-funded project; 2) determine the ability of endemic isolates to form endophytic relationships with cash crops and selected cover crops; 3) determine the effects of endophytic *Metarhizium* on the performance of corn, *Zea mays*, and two corn pests, the black cutworm, *Agrotis ipsilon*, and *Cochliobolus*

heterostrophus, the causative agent of southern corn leaf blight; and4) determine the effect of endophytic *Metarhizium* on the expression of key defense genes that protect plants from crop pests.

APPROACH

A field trial on certified organic land includes 12 cover crop treatments to compare ecosystem services associated with cover crop monocultures with cover crop mixtures designed to target particular services in an organic corn-soybean-wheat rotation. The experiment is a full-entry stripped plot design with 4 replicates, for a total of 144 treatment plots. Replicated experiments on 8 organic farms in the Mid-Atlantic will compare the effects of a standard and location-adjusted 5-cover crop mixture on the following corn crop. Isolates of *Metarhizium* from all treatments plots and sites will be cultured and identified using standard molecular techniques for this fungus to determine the effects of cover crop species, species diversity, and soil characteristics on the species and diversity of *Metarhizium*. The ability of selected isolates of *Metarhizium* to form an endophytic relationship in corn will be conducted as a greenhouse trial. Endophytic growth will be determined by reisolation of *Metarhizium* from exposed plants. We will conduct greenhouse assays to compare the effects of colonization with *Metarhizium* compared to no colonization on performance indicators on corn, including corn growth, relative growth rate of larval black cutworm, and infection by southern corn leaf blight. The effects of *Metarhizium* infection on plant defense gene expression in corn will be examined using realtime-PCR to obtain relative quantification of gene expression. ****Progress**** 09/01/16 to 08/31/21 ****Outputs**** Target Audience: Farmers, Extension specialists and educators, other agricultural professionals, undergraduate and graduate students **Changes/Problems:** Nothing Reported **What opportunities for training and professional development has the project provided?** This project provided training in the ecology and biology of tri-trophic interactions (microbe-plant-plant pest) to project personnel. Opportunities for scientific communication, presentations and networking were also provided to the post-doctoral scientist and graduate student associated with the project. The post-doctoral scientist mentored the graduate student on microbiological and molecular techniques. **How have the results been disseminated to communities of interest?** Results of the project were disseminated in academic seminars, in oral presentations at scientific and technical meetings, in undergraduate courses, and in extension programs. **What do you plan to do during the next reporting period to accomplish the goals?** Nothing Reported ****Impacts**** **What was accomplished under these goals?** Objective 1, we recovered more than 500 isolates from *Metarhizium*-infected cadavers of *Galleria mellonella*. Sanger sequencing of translation elongation factor 1 alpha (TEF 1-alpha) of representative isolates from our research site and collaborating commercial farms showed that all the selected isolates were *M. robertsii*. We submitted the translation elongation factor 1-alpha (TEF1-alpha) sequence of *M. robertsii* to the NCBI GenBank under accession number MK988559 and the single spore isolated culture to The Agricultural Research Service Collection of Entomopathogenic Fungal Cultures (ARSEF) under the accession number 14325. Objective 2. In assays with maize, we recovered *M. robertsii* from 70 - 91% of plants grown from *M. robertsii*-treated seed. We detected *M. robertsii* more frequently in roots compared with leaves. Colonized plants were greater in plant height and above-ground biomass compared to control plants. The chlorophyll content (SPAD) of the 4th true leaf of maize plants grown from *M. robertsii*-treated seed was not significantly different from control plants. We tested the effects of *M. robertsii* inoculation of seeds of three cover crop species in three plant functional groups that were associated with different levels of detection of *M. robertsii* in the field: Austrian winter pea (*Pisum sativum* L. 'Arvika'), cereal rye (*Secale cereale* L. 'Aroostook'), and winter canola (*Brassica napus* L. 'Wichita'). We recovered *M. robertsii* from AWP (58.72 \pm 0.62%; n = 52), cereal rye (46.45 \pm 3.91%; n = 68), and canola (39.05 \pm 3.74%; n = 51) plants grown from inoculated seeds. When we compared among cover crop species, we found greater endophytic colonization in Austrian winter pea than cereal rye and canola. There was no difference in endophytic colonization between canola and cereal rye (p < 0.03, F_{2,91} = 3.8, n = 94). Endophytic colonization of root tissue was greater than colonization of leaf tissue in Austrian winter pea (p = 0.007, F_{1,28} = 8.23, n = 30) and canola (p = 0.02, F_{1,24} = 6.72, n = 26), and was not different in cereal rye (p = 0.43, F_{1,36} = 0.64, n = 38). Endophytic *M. robertsii* significantly increased height and above-ground biomass of Austrian winter pea and cereal rye, but did not affect chlorophyll content of any of the cover crop species compared with non-inoculated control plants. The ability of *M. robertsii* to systemically colonize plants commonly grown as winter cover crops suggests that an additional benefit of cover crops may help to conserve *Metarhizium* in annual cropping systems. Objective 3. The mean relative growth rate (RGR) of 2nd instar black cutworm fed for 96 hours on maize grown from *M. robertsii*-treated seed was significantly lower than BCW fed on control plants (F_{2, 11} = 16.11; P = 0.006). The RGR for black cutworm was weakly negatively correlated with the proportion of endophytic leaf (r₂ = 0.02; P = 0.03) and root tissue (r₂ = 0.02; P = 0.03). We conducted greenhouse assays to determine the effects of endophytic *M. robertsii* on the growth and severity of Southern Corn Leaf Blight (SCLB) disease caused by *Cochliobolus heterostrophus* in maize. The severity of SCLB in *C. heterostrophus*-inoculated plants was lower in *M. robertsii*-endophytic maize compared to non-endophytic plants. Objective 4. Maize leaf tissue from *M. robertsii*-colonized plants showed changes in the expression of genes involved in plant defense. In the jasmonic acid (JA) biosynthesis pathway, lipoxygenase 1

(lox1) ($P = 0.0001$; $F_{1,22} = 29.5$) and 12-oxo-phytodienoate reductase 7 (opr7) ($P = 0.02$; $F_{1,22} = 6.56$) in V4 leaf tissue from plants grown from *M. robertsii*-inoculated plants were up-regulated compared to control plants. In the JA response pathway, maize protease inhibitor (mpi) ($P = 0.002$; $F_{1,22} = 13.23$) in leaf tissue from plants grown from *M. robertsii*-inoculated plants was down-regulated compared to control plants. In the salicylic acid (SA) response pathway, pathogenesis-related protein 5 (pr5) ($P = 0.0001$; $F_{1,22} = 24$) in V4 leaf tissue from *M. robertsii*-inoculated plants was up-regulated compared with control plants. The chitinase gene, endochitinase A ($P = 0.0036$; $F_{1,22} = 10.63$) was up-regulated in V4 leaf tissue from *M. robertsii*-inoculated plants whereas pathogenesis-related protein 4 (pr4) ($P = 0.006$; $F_{1,22} = 16.11$) was down-regulated compared to control plants. In assays that compared selected gene expression and phytohormone content of maize sequentially inoculated with *M. robertsii* followed by *C. heterostrophus*, both defense gene expression and phytohormone content were different compared with control plants. *lox1*, *lox3*, and *lox6* were upregulated in maize leaf tissue inoculated with *C. heterostrophus* compared to control, *M. robertsii*-inoculated, and plants inoculated sequentially with both microbes. Endochitinase A was upregulated in plants in *C. heterostrophus* compared to plants in the control and *M. robertsii* treatment. Pathogenesis-related genes (*pr4* and *pr5*) were upregulated in plants in the *C. heterostrophus* treatment compared to the control and *M. robertsii* and *M. robertsii* + *C. heterostrophus* treatments. Among the measured phytohormones in maize leaf tissue, cis-zeatin was greater in the *C. heterostrophus* treatment compared with the control and *M. robertsii* treatments. Gibberellin 19 was lower in treatments with *C. heterostrophus* compared to the *M. robertsii* treatment. The salicylic acid content of maize leaf tissue was greater in the *M. robertsii* + *C. heterostrophus* treatment compared to the control and *M. robertsii* treatment. **Publications** - Type: Journal Articles Status: Published Year Published: 2021 Citation: Flonc, B., Barbercheck, M., Ahmad, I. 2021. Observations on the relationships between endophytic *Metarhizium robertsii* and Spodoptera frugiperda (Lepidoptera: Noctuidae) on maize. *Pathogens* 10(6), 713. <https://doi.org/10.3390/pathogens10060713>. Special Issue Plant-Microbe-Invertebrate Pest Interactions. <https://www.mdpi.com/2076-0817/10/6/713> - Type: Journal Articles Status: Published Year Published: 2021 Citation: Wallace, J.M., Barbercheck, M.E., Curran, W., Keene, C.L., Mirsky, S.B., Ryan, M. and VanGessel, M. 2021. Cover crop-based, rotational no-till (CCORNT) management tactics influence crop performance in organic transition within the Mid-Atlantic U.S. *Agron. J.* 00:1-13, <https://doi.org/10.1002/agj2.20822> - Type: Conference Papers and Presentations Status: Submitted Year Published: 2022 Citation: Peterson, H., Barbercheck, M. 2022. Impact of Water Stress on the Establishment and Persistence of Endophytic and Entomopathogenic *Metarhizium robertsii*. Eastern Branch ESA Meeting, Feb. 19-21, Philadelphia, PA - Type: Journal Articles Status: Other Year Published: 2022 Citation: Ahmad, I. M. d. M. Jimenez-Gasco, D. S. Luthe. and M. E. Barbercheck. Antagonistic effects of endophytic *Metarhizium robertsii* on *Cochliobolus heterostrophus* and its role in modulation of maize defense. In prep. to be submitted to *PLoS Biology* in 2022 - Type: Other Status: Published Year Published: 2021 Citation: Barbercheck, M., Borrelli, K. (Eds). 2021. Penn State Organic Crop Production Guide. AGRS 124-G. <https://extension.psu.edu/penn-state-organic-crop-production-guide>

PROGRESS

2019/09 TO 2020/08 Target Audience: Scientists, undergraduate and graduate students, farmers, agricultural professionals Changes/Problems: We will complete the project under a no-cost extension because our progress was delayed due to restrictions associated with COVID-19. What opportunities for training and professional development has the project provided? Five undergraduate students conducted internships associated with this project. One graduate student completed a Master's Degree. How have the results been disseminated to communities of interest? Results from this project were disseminated in two courses: AGECO144 Principles and Practices of Organic Agriculture, Fall Semester 2019, 3 credits, 25 undergraduate students; and FOR 597 Global Agricultural Systems, delivered lecture, Arthropod Management and IPM. Fall semester 2019; 3 hrs; 12 graduate students. Information from this project was included in Extension presentations: Barbercheck, M. (organizer and presenter) 2020. Organic Research Flash Talks & Discussion Session. PASA Farming for the Future Conference, 8 Feb. 2020. 80-min workshop. Lancaster, PA; and Barbercheck, M. (panelist with J. Wallace, K. Borrelli, J. Cook). 2020. Organic Crop Production Q & A. Virtual Ag Progress Days Session. 34 attendees. 11 August 2020. What do you plan to do during the next reporting period to accomplish the goals? Because of restrictions associated with COVID-19, we were unable to finish experiments associated with Objective 3) determine the effects of endophytic *Metarhizium* on the performance of corn, Zea mays, and two model corn pests, the black cutworm, *Agrotis ipsilon*, and *Cochliobolus heterostrophus*, the causative agent of southern corn leaf blight. Expected outcome: The effect of endophytic *Metarhizium* on corn growth and on growth and survival of black cutworm and on the development of southern corn leaf blight will vary according to *Metarhizium* species and isolate. One replicate has been completed. We have requested and received a no-cost extension so that we may complete experiments associated with this objective. Upon completion of the experiment and data analysis, we will write up the results for publication in scientific journals.

2017/09 TO 2018/08 Target Audience: Agricultural scientists, agricultural professionals, extension specialists, undergraduate and graduate students, farmers
Changes/Problems: Nothing Reported
What opportunities for training and professional development has the project provided? The project team delivered 19 presentations at scientific and agricultural industry conferences. How have the results been disseminated to communities of interest? The project team participated in and presented project-related information at four Extension/Outreach events. What do you plan to do during the next reporting period to accomplish the goals? In coming year, we will process samples and data from experiments to assess naturally-occurring infections of corn by *Metarhizium*. We will identify the *Metarhizium* isolates from on-going research station experiment and on-farm experiments using molecular techniques to determine effects of cover crops and soil properties on *Metarhizium* prevalence. We will initiate experiments to determine the study the effects of endophytic *M. robertsii* on *Cochliobolus heterostrophus*, the causative agent of southern corn leaf blight to expand our understanding of the role of *Metarhizium* in crop plants. We will also initiate experiments to determine the role of *Metarhizium*-plant interactions on plant defense and growth-related gene expression regulation. We will present project information at conferences and educational events as the opportunity arises.

2016/09 TO 2017/08 Target Audience: Farmers, Extension educators and other agricultural professionals, scientists. We participate in extension events and scientific meetings. We hold an annual advisory board meeting in the spring to engage with our grower and extension collaborators. Ahmad, I., Mary Barbercheck, Brianna Flonc, Christina Mullen, Maria Jimenez-Gasco, Dawn Luthe. 2017. "Farming for Success 2017" by Penn State Extension, Manheim, PA, USA, 29th June 2017. (Extension Meeting) Ahmad, I., Christina Mullen, Mary Barbercheck, Dawn S. Luthe, Maria Jimenez-Gasco. 2017. *Metarhizium*: A Multifunctional Fungal Bodyguard of Plants. Post-Doctoral Research Exhibition, Penn State, PA, USA, 22nd Sep. 2017. (Poster Presentation) Barbercheck, M., Leslie Pillen, Jermaine Hinds, Brianna Flonc. 2016. Student Farm Field Trip for AGECO 144: Principles and Practices of Organic Agriculture, The Pennsylvania State University, State College, PA, Sept. 21, 2016. (Student field trip) Barbercheck, M., Regan, K., Murrell, E. 2017. Crop Management and Soil Health: Is Your Soil Alive? Agronomy Team Diagnostic Clinic workshop, Russell E Larson Research and Education Center, Rock Springs, PA Barbercheck, M., K Regan 2017. Pest and beneficial insects and soil health workshop. The Student Farm at Penn State, University Park, PA Barbercheck, M. 2017. No pesticides? No problem! Insect management in organic crops. 2017 Mid-Atlantic Crop Management School. Ocean City MD. Barbercheck, M. 2017. Fungal Endophytes: Fungi that Facilitate Farming. Penn State Extension Sustainable Agriculture Webinar Series focused on Cropping Strategies for Managing Soil Health. February 6, 2017. 56 attendees Curran, W., Esbenshade, W. 2017. Managing Cover Crops with reduced tillage for soil health. Organizer. PASA conference. 3 Feb. 2017. 75 attendees. Kaye, J, Ebony Murrell, Dave Mortensen, Mary Barbercheck. 2017. Mixing your cover crop cocktail. 3 Feb. 2017. PASA Conference. University Park, PA. 100 attendees. Extension Education Program Kaye, J., Barbara Baraibar, Mary Barbercheck, Brosi Bradley, Sarah Cornelisse, Katie Ellis, Denise Finney, Brianna Flonc, Scott Harkcom, Jermaine Hinds, Mitch Hunter, Shan Jin, Dawn Luthe, Dave Mortensen, Christina Mullen, Ebony Murrell, Imtiaz Ahmad, Puneet Randhawa, Dayton Spackman, Charlie White. 2017. Annual Cover Crop Cocktails Field Day, Russell E. Larson Agricultural Research Station, Rock Springs, PA, May 24, 2017. (Field day) Kaye, J., Barbara Baraibar, Mary Barbercheck, Brosi Bradley, Sarah Cornelisse, Katie Ellis, Denise Finney, Brianna Flonc, Scott Harkcom, Jermaine Hinds, Mitch Hunter, Shan Jin, Dawn Luthe, Dave Mortensen, Christina Mullen, Ebony Murrell, Imtiaz Ahmad, Puneet Randhawa, Dayton Spackman, Charlie White. 2017. Field Day for Argentinian Delegation of Organic Farmers for the Cover Crop Cocktails Project, Russell E. Larson Agricultural Research Station, Rock Springs, PA, June 13, 2017. (Field day) Barbercheck, M. (Fall 2017). AGECO144 Principles and Practices of Organic Agriculture (Co-instructor). 35 students. Barbercheck, M. (Fall 2017). Introduction to Organic Agriculture. Guest lecture, AGRO 28. Principles of Crop Management. 40 students. Changes/Problems: Nothing Reported
What opportunities for training and professional development has the project provided? Ahmad, I. 2017. Internship training awarded by National Pest Management Association Pestworld2017, Baltimore, Maryland. 24-27 Oct. 2017 Ahmad, I., Christina Mullen, Mary Barbercheck, Dawn S. Luthe, Maria Jimenez-Gasco. 2017. Natural Nurture: Plant Growth Promotion by Multifunctional Fungi. National Pest Management Association, Pestworld2017, Baltimore, Maryland, USA, 24-27th Oct. 2017. (Oral Presentation) Ahmad, I., Christina Mullen, Mary Barbercheck, Dawn S. Luthe, Maria Jimenez-Gasco. 2017. *Metarhizium*: A Multifunctional Fungal Bodyguard of Plants. Bioinformatics & Genomics Retreat 2017, Huck Institutes of Life Sciences, Penn State, PA, USA, 22-23rd Sep 2017. (Poster Presentation) Barbercheck, M., J. Hinds, A. Rivers, C. Mullen. 2017. Effects of cover crops on insect pests and their natural enemies. Northeast Cover Crops Council Annual Meeting, Cornell University, Ithaca, NY, Nov. 8, 2017. (Invited oral presentation) Barbercheck, M., I. Ahmad, B. Flonc, M. Jimenez-Gasco, D. Luthe, Christina Mullen. 2017. Going underground: The role of a multifunctional fungus in organic cropping systems. Northeast Cover Crops Council Annual Meeting, Cornell University, Ithaca, NY, Nov. 8, 2017. (Poster presentation) Barbercheck, M., I. Ahmed, M. Jimenez-Gasco, D. Luthe. 2017. Going underground: Conserving Insect-Pathogenic Fungi for Biological Control?. 3rd Annual

NEIPMC Online Conference, 23 October 2017 (5-minute flash talk). Barbercheck, M., I. Ahmed, M. Jimenez-Gasco, D. Luthe. 2017. Going underground: Conserving Insect-Pathogenic Fungi for Biological Control?. NEIPMC Annual Advisory Council Meeting, 31 October 2017 (invited 30-minute presentation) Flonc, B., Mary Barbercheck, Mary Ann Bruns, Nina Jenkins. 2016. Committee meeting: Effect of agricultural practices on *Metarhizium* in an organic system. The Pennsylvania State University, State College, PA, Feb. 22, 2017. (Committee meeting) Flonc, B., Mary Barbercheck, Christina Mullen. 2017. Does endophytic *Metarhizium* make insects picky eaters? 7th Annual Sustainable Cropping Systems Symposium, The Pennsylvania State University, State College, PA, March 31, 2017. (Poster presentation) Hinds, J., Barbercheck, M.E., Hagler, J. 2017. Impacts of cover crop diversification on attraction, dispersal, and pest suppression by generalist predators. Newport, RI. Invited Speaker for Mark Recapture Symposium, Annual Meeting of the Entomological Society of America, Eastern Branch, Newport RI, March 17 - 21, 2017. Hinds, J and Barbercheck, M. 2017. Impacts of cover crop diversification on attraction, dispersal, and pest suppression by generalist predators. USDA Arid Land Agricultural Research Center. Maricopa, AZ. How have the results been disseminated to communities of interest? Participation in extension, outreach, and publication of a project newsletter. Ahmad, I., Mary Barbercheck, Brianna Flonc, Christina Mullen, Maria Jimenez-Gasco, Dawn Luthe. 2017. "Farming for Success 2017" by Penn State Extension, Manheim, PA, USA, 29th June 2017. (Extension Meeting) Ahmad, I., Christina Mullen, Mary Barbercheck, Dawn S. Luthe, Maria Jimenez-Gasco. 2017. *Metarhizium*: A Multifunctional Fungal Bodyguard of Plants. Post-Doctoral Research Exhibition, Penn State, PA, USA, 22nd Sep. 2017. (Poster Presentation) Barbercheck, M., Leslie Pillen, Jermaine Hinds, Brianna Flonc. 2016. Student Farm Field Trip for AGECO 144: Principles and Practices of Organic Agriculture, The Pennsylvania State University, State College, PA, Sept. 21, 2016. (Student field trip) Barbercheck, M., Regan, K., Murrell, E. 2017. Crop Management and Soil Health: Is Your Soil Alive? Agronomy Team Diagnostic Clinic workshop, Russell E Larson Research and Education Center, Rock Springs, PA Barbercheck, M., K Regan 2017. Pest and beneficial insects and soil health workshop. The Student Farm at Penn State, University Park, PA Barbercheck, M. 2017. No pesticides? No problem! Insect management in organic crops. 2017 Mid-Atlantic Crop Management School. Ocean City MD. Barbercheck, M. 2017. Fungal Endophytes: Fungi that Facilitate Farming. Penn State Extension Sustainable Agriculture Webinar Series focused on Cropping Strategies for Managing Soil Health. February 6, 2017. 56 attendees Curran, W., Esbenshade, W. 2017. Managing Cover Crops with reduced tillage for soil health. Organizer. PASA conference. 3 Feb. 2017. 75 attendees. Kaye, J, Ebony Murrell, Dave Mortensen, Mary Barbercheck. 2017. Mixing your cover crop cocktail. 3 Feb. 2017. PASA Conference. University Park, PA. 100 attendees. Extension Education Program Kaye, J., Barbara Baraibar, Mary Barbercheck, Brosi Bradley, Sarah Cornelisse, Katie Ellis, Denise Finney, Brianna Flonc, Scott Harkcom, Jermaine Hinds, Mitch Hunter, Shan Jin, Dawn Luthe, Dave Mortensen, Christina Mullen, Ebony Murrell, Imtiaz Ahmad, Puneet Randhawa, Dayton Spackman, Charlie White. 2017. Annual Cover Crop Cocktails Field Day, Russell E. Larson Agricultural Research Station, Rock Springs, PA, May 24, 2017. (Field day) Kaye, J., Barbara Baraibar, Mary Barbercheck, Brosi Bradley, Sarah Cornelisse, Katie Ellis, Denise Finney, Brianna Flonc, Scott Harkcom, Jermaine Hinds, Mitch Hunter, Shan Jin, Dawn Luthe, Dave Mortensen, Christina Mullen, Ebony Murrell, Imtiaz Ahmad, Puneet Randhawa, Dayton Spackman, Charlie White. 2017. Field Day for Argentinian Delegation of Organic Farmers for the Cover Crop Cocktails Project, Russell E. Larson Agricultural Research Station, Rock Springs, PA, June 13, 2017. (Field day) What do you plan to do during the next reporting period to accomplish the goals? In coming year, we identify the *Metarhizium* isolates from on-going research station experiment and on-farm experiments using molecular techniques to determine effects of cover crop treatments and soil properties on *Metarhizium* abundance and diversity. We will continue feeding assays with Black Cutworm and FAW, as well as conduct virulence assays with selected isolates of *Metarhizium* against Black Cutworm and Fall armyworm larvae and pupae. We will initiate experiments to determine the effects of endophytic *Metarhizium* on *Cochliobolus heterostrophus*, the causative agent of southern corn leaf blight to expand our understanding of the role of *Metarhizium* in crop plants. We will also initiate experiments to determine the role of *Metarhizium*-plant interactions on plant defense and growth-related gene expression regulation. We will participate in extension and outreach events, including a workshop at the annual Pennsylvania Association for Sustainable Agriculture's Farming for the Future conference in February 2018. We will also present research results at the 8th Annual Sustainable Cropping Systems Symposium at Penn State, The Annual Meeting of The Entomological Society of America (ESA) Eastern Branch 2018, and Annual Meeting of the Society for Invertebrate Pathology Meeting 2018.

IMPACT

2019/09 TO 2020/08 What was accomplished under these goals? We recovered more than 420 isolates from *Metarhizium*-infected cadavers of *Galleria mellonella*. Sanger sequencing of TEF 1-alpha of representative

isolates from our research site. All the selected isolates were *M. robertsii*. We inoculated seeds of maize (*Zea mays* L.) with spores of *Metarhizium robertsii* and evaluated V4 maize for endophytic colonization of leaves and roots, measured plant height, chlorophyll content and above-ground biomass, and relative growth rate of black cutworm, *Agrotis ipsilon* (Hufnagel), and expression of selected plant defense genes. We recovered *M. robertsii* from 91% of plants grown from inoculated seeds. We detected *M. robertsii* more frequently in roots compared with leaves. Colonized plants were greater in plant height and above-ground biomass compared to control plants suggesting a beneficial effect on plant growth. Leaf tissue from colonized plants showed changes in the expression of genes involved in plant defense. Phytohormone analyses of leaf tissues showed that the levels of jasmonic acid and salicylic acid were not different between control and *M. robertsii*-treated plants. Phytohormone gibberellin 19 was greater in leaf tissue of *M. robertsii*-treated plants compared with control plants. There was no difference in the level of gibberellin 24 in the leaf tissue of control and *M. robertsii*-treated plants. In feeding bioassays, the relative growth rate of black cutworm was lower on leaves from endophytic plants compared to control plants. We evaluated the effects of seed inoculation of maize with *M. robertsii* on southern corn leaf blight caused by *Cochliobolus heterostrophus* at V4-V5 growth stage. Seeds were either treated with 0.1% triton x-100 (control) or with *M. robertsii* spore suspension in 0.1 % triton x-100 solution (*M. robertsii* treated). At V3 growth stage, half of the plants from each treatment were sprayed with 0.1 % triton x-100 solution and half were treated with *C. heterostrophus* spore suspension in 0.1 % triton x-100 solution (1×10^4 spores/ml). We evaluated plants at V4-V5 stage after 96 hours of *C. heterostrophus* inoculation. Biomass ($p < 0.05$; $F_{3,46} = 3.01$) and chlorophyll content ($p < 0.068$; $F_{3,46} = 2.56$) were not different among treatments. There was significant difference in plant height among treatments ($p < 0.036$; $F_{3,46} = 3.09$). Height of *M. robertsii*+ / *C. heterostrophus*+ plants (82.49 ± 1.55 cm) was greater than control (*M. robertsii*- / *C. heterostrophus*-) plants (76.0 ± 1.55 cm) but was not different than *M. robertsii*+ (77.99 ± 1.5 cm) or *C. heterostrophus*+ (78.11 ± 1.7 cm) plants. There was no difference among the heights of *C. heterostrophus*+ (78.11 ± 1.7 cm), *M. robertsii*+ (77.99 ± 1.5 cm) and control (*M. robertsii*- / *C. heterostrophus*-) plants (76.0 ± 1.55 cm). We evaluated the effects of treatment on the concentration of different defense and growth related phytohormones in maize leaf at V4-V5 stage. There was significant difference in the concentration of gibberellin 19 among treatments ($p < 0.0001$; $F_{1,11} = 41.83$). *M. robertsii*+ plants (12.37 ± 0.57 ng/g FW) had greater level of gibberellin 19 than control (*M. robertsii*- / *C. heterostrophus*-) (7.56 ± 0.56 ng/g FW), *C. heterostrophus*+ (4.90 ± 0.56 ng/g FW) and *M. robertsii*+ / *C. heterostrophus*+ (4.36 ± 0.56 ng/g FW). The level of gibberellin 19 in control (*M. robertsii*- / *C. heterostrophus*-) (7.56 ± 0.56 ng/g FW) plants was greater than *C. heterostrophus*+ (4.90 ± 0.56 ng/g FW) and *M. robertsii*+ / *C. heterostrophus*+ (4.36 ± 0.56 ng/g FW). There was no difference in the level of gibberellin 19 in *C. heterostrophus*+ (4.90 ± 0.56 ng/g FW) and *M. robertsii*+ / *C. heterostrophus*+ (4.36 ± 0.56 ng/g FW). There was significant difference in the concentration of gibberellin 24 among treatments ($p < 0.0001$; $F_{1,11} = 30$). *M. robertsii*+ plants (8.72 ± 0.74 ng/g FW) had greater level of gibberellin 24 than *C. heterostrophus*+ (0.00 ± 0.74 ng/g FW) and *M. robertsii*+ / *C. heterostrophus*+ (2.12 ± 0.74 ng/g FW). The level of gibberellin 24 in control (*M. robertsii*- / *C. heterostrophus*-) (6.97 ± 0.74 ng/g FW) plants was greater than *C. heterostrophus*+ (0.00 ± 0.74 ng/g FW) and *M. robertsii*+ / *C. heterostrophus*+ (2.12 ± 0.74 ng/g FW). There was no difference in the level of gibberellin 24 in *C. heterostrophus*+ (0.00 ± 0.74 ng/g FW) and *M. robertsii*+ / *C. heterostrophus*+ (2.12 ± 0.74 ng/g FW). There was no difference in the level of gibberellin 24 in leaves from *M. robertsii*+ plants (8.72 ± 0.74 ng/g FW) and control (*M. robertsii*- / *C. heterostrophus*-) (6.97 ± 0.74 ng/g FW) plants. There was significant difference in the concentration of salicylic acid (SA) among treatments ($p < 0.0045$; $F_{1,11} = 9.94$). The level of SA in *C. heterostrophus*+ plants (15.42 ± 1.72 ng/g FW) was greater than in control (*M. robertsii*- / *C. heterostrophus*-) (3.18 ± 1.72 ng/g FW), *C. M. robertsii*+ / *C. heterostrophus*+ (6.42 ± 1.72 ng/g FW) and *M. robertsii*+ (5.15 ± 1.72 ng/g FW) plants. There was no difference in the levels of SA in control (*M. robertsii*- / *C. heterostrophus*-) (3.18 ± 1.72 ng/g FW), *C. M. robertsii*+ / *C. heterostrophus*+ (6.42 ± 1.72 ng/g FW) and *M. robertsii*+ (5.15 ± 1.72 ng/g FW) plants. SA induction is the marker of defense response by in diseased plants. There was no difference in the levels of jasmonic acid among treatments ($p < 0.36$; $F_{1,11} = 9.94$) suggesting the absence of herbivory defense response due to no herbivory stress. Endophytic colonization of maize plants by *M. robertsii* promoted plant growth and altered defense gene expression in maize, and suppressed growth rate of black cutworm larvae. We will repeat the experiment three times on the evaluation of effects of *M. robertsii* on *C. heterostrophus*. **PUBLICATIONS (not previously reported):** 2019/09 TO 2020/08 1. Type: Theses/Dissertations Status: Published Year Published: 2019 Citation: Flonc, B. 2019. do Fungi Make Caterpillars Picky Eaters? Effects of Endophytic *Metarhizium robertsii* on Corn, *Zea mays*, Growth and Fall Armyworm, *Spodoptera frugiperda*. 2. Type: Other Status: Published Year Published: 2020 Citation: Barbercheck, M., Borrelli, K. 2020. Terminating Winter Cover Crops in Organic Feed and Forage Crops Field Crop News, July 8, 2020. <https://extension.psu.edu/terminating-winter-cover-crops-in-organic-feed-and-forage-crops> 3. Type: Other Status: Published Year Published: 2020 Citation: Barbercheck, M. 2020. 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campaign=FAFC-2020-MAY-13-GN-EM-Field+Cr op+News&utm content=FAFC-2020-MAY-13-GN-EM-Field+Crop+News&subscriberkey=0030W0 0003P0ySiQAJ 4. Type: Other Status: Published Year Published: 2020 Citation: Barbercheck, M. 2020. Predators control pests and crop damage during transition to organic. Research highlight. Field Crop News 15 April 2020. <https://extension.psu.edu/predators-control-pests-and-crop-damage-during-transition-to-organic?j=531624&sfmc sub=35519620&l=159 HTML&u=10500004&mid=7234940&jb =9&utm medium=email&utm source=MarketingCloud&utm campaign=FAFC-2020-APR-16-GN- EM-Field+Crop+News&utm content=FAFC-2020-APR-16-GN-EM-Field+Crop+News&subscribe rkey=0030W00003P0ySiQAJ> 5. Type: Other Status: Published Year Published: 2020 Citation: Borelli, K. Busch, A., Barbercheck, M. 2020. Is organic certification right for your operation? Field Crop News 27 May 2020 <https://extension.psu.edu/is-organic-certification-right-for-your-operation?j=538536&sfmc sub=35519620&l=159 HTML&u=10818935&mid=7234940&jb=9&utm medium=email &utm source=MarketingCloud&utm campaign=FAFC-2020-MAY-28-GN-EM-Field+Crop+News&utm content=FAFC-2020-MAY-28-GN-EM-Field+Crop+News&subscriberkey=0030W00003P0ySiQAJ> 6. Type: Journal Articles Status: Published Year Published: 2020 Citation: Ahmad, I., M. del M. Jiménez-Gasco, D. S. Luthe, M. E. Barbercheck. 2020. Systemic colonization by *Metarhizium robertsii* enhances cover crop growth. Journal of Fungi 62(2):64 <https://doi.org/10.3390/jof6020064> 7. Type: Book Chapters Status: Published Year Published: 2020 Citation: Ahmad I., Zaib S. 2020. Mighty Microbes: Plant Growth Promoting Microbes in Soil Health and Sustainable Agriculture. In: Giri B., Varma A. (eds) Soil Health. Soil Biology, vol 59. Springer, Cham. http://doi-org-443.webvpn.fjmu.edu.cn/10.1007/978-3-030-44364-1_14 8. Type: Journal Articles Status: Published Year Published: 2020 Citation: Ahmad, I., M. Jiménez-Gasco, D. S. Luthe, S.N. Shakee, M.E. Barbercheck. 2020. Endophytic *Metarhizium robertsii* promotes maize growth and suppresses insect growth by eliciting plant defense. Biological Control 144: <https://doi.org/10.1016/j.biocontrol.2019.104167> 9. Type: Journal Articles Status: Published Year Published: 2020 Citation: Cloutier, M., E. Murrell; M. Barbercheck; J. Kaye; D. Finney; I. Garcia-Gonzalez; M. A. Bruns. 2020. Fungal community shifts in soils with varied cover crop treatments and edaphic properties. Scientific Reports 10: 6198. <https://doi.org/10.1038/s41598-020-63173-7> 10. Type: Journal Articles Status: Published Year Published: 2019 Citation: Neher, D.A. and Barbercheck, M.E. 2019. Soil microarthropods and soil health: Intersection of decomposition and pest suppression. Insects 10(12): 414.[doi: 10.3390/insects10120414](https://doi.org/10.3390/insects10120414)

2017/09 TO 2018/08 What was accomplished under these goals? In greenhouse assays to determine rates of colonization of maize by *M. robertsii* by inoculation of seed, we recovered *M. robertsii* from 91.06 ± 4.05 % of plants grown from treated seed. We detected *M. robertsii* more frequently in roots (49.66 ± 2.33 %) compared with leaves (33.33 ± 2.43 %). Endophytically colonized plants were significantly greater in plant height ($P = 0.03$; $F_{2,227} = 3.73$) and above-ground biomass ($P = 0.002$; $F_{2,211} = 6.37$) compared to control plants. Chlorophyll content did not differ ($P = 0.35$; $F_{2,227} = 1.05$) among treated and control plants. In assays with *Agrotis ipsilon*, the Black cutworm (BCW), the relative growth rate of 2nd instar black cutworm was lower ($P = 0.01$; $F_{2,211} = 4.66$) when fed on maize leaves from endophytic plants compared to control plants. In assays with the *Spodoptera frugiperda*, the Fall Armyworm (FAW), there was no difference in relative growth rate (RGR) of fall armyworm larvae fed a diet of *M. robertsii*-exposed corn leaf tissue and the RGR of fall armyworm larvae fed untreated control leaf tissue. FAW exhibited no preference between *M. robertsii*-infected corn leaf tissue and untreated corn leaf tissue in choice assays. In summary, in greenhouse assays, infection of corn with *M. robertsii*, had growth promotive effects on maize plants and growth suppressive effects on black cutworm larvae, but no effect of fall armyworm larvae. **PUBLICATIONS (not previously reported):** 2017/09 TO 2018/08 1. Type: Journal Articles Status: Published Year Published: 2018 Citation: Randhawa, P. K., Mullen, C., Barbercheck, M. 2018. Plant identity, but not diversity, and agroecosystem characteristics affect the occurrence of *M. robertsii* in an organic cropping system. Biological Control 124:18-29. <https://doi.org/10.1016/j.biocontrol.2018.06.001> 2. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Ahmad I., Brianna Flonc, Christina Mullen, Maria Jimenez-Gasco, Dawn Luthe, Mary Barbercheck. 2018. Going underground: The ecology of a beneficial fungus in an organic agroecosystem. North-East Cover Crop Council Meeting, State College, PA, USA. Nov. 15th, 2018. (Poster presentation) 3. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Ahmad I., Christina Mullen, Mary Barbercheck, Dawn S. Luthe, Maria Jimenez-Gasco. 2018. Harnessing nature: Role of beneficial soil-borne fungi in an agroecosystem. Pestworld2018, Orlando, FL, USA, 23-27th Oct. 2018. (Oral presentation) 4. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Ahmad I., Christina Mullen, Maria Jimenez-Gasco, Dawn Luthe, Mary Barbercheck. 2018. Going underground: The ecology of a beneficial fungus in an organic agroecosystem. Plant Sciences Symposium, University of Illinois, Urbana-Champaign, IL, USA. Sep. 6th, 2018. (Poster presentation) 5. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Ahmad I., Christina Mullen, Maria Jimenez-Gasco, Dawn Luthe, Mary Barbercheck. 2018. Going underground: The ecology of a beneficial fungus in an organic agroecosystem. Plant Biology Symposium, Penn State, PA, USA, 19-22 June 2018. (Poster presentation) 6. Type: Conference Papers and Presentations Status:

Other Year Published: 2018 Citation: Ahmad I., Brianna Flonc, Christina Mullen, Maria Jimenez-Gasco, Dawn Luthe, Mary Barbercheck. 2018. Going underground: The ecology of a beneficial fungus in an organic agroecosystem. 8th Annual PSU Sustainable Cropping Systems Symposium, Penn State, PA, USA. April 6th, 2018. (Poster presentation) 7. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Ahmad I., Brianna Flonc, Christina Mullen, Maria Jimenez-Gasco, Dawn Luthe, Mary Barbercheck. 2018. Going underground: The ecology of a beneficial fungus in an organic agroecosystem. Farming for the future, organized by Pennsylvania Sustainable Agriculture (PASA), Penn State, PA, USA, 7-10 Feb. 2018. (Poster presentation) 8. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Ahmad, I., Christina Mullen, Mary Barbercheck, Dawn S. Luthe, Maria Jimenez-Gasco. 2017. Metarhizium: A Multifunctional Fungal Bodyguard of Plants. Post-Doctoral Research Exhibition, Penn State, PA, USA, 22nd Sep. 2017. (Poster Presentation) 9. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Ahmad, I., Christina Mullen, Mary Barbercheck, Dawn S. Luthe, Maria Jimenez-Gasco. 2017. Metarhizium: A Multifunctional Fungal Bodyguard of Plants. Bioinformatics & Genomics Retreat 2017, Huck Institutes of Life Sciences, Penn State, PA, USA, 22-23rd Sep. 2017. (Poster Presentation) 10. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Ahmad, I., Christina Mullen, Mary Barbercheck, Dawn S. Luthe, Maria Jimenez-Gasco. 2017. Natural Nurture: Plant Growth Promotion by Multifunctional Fungi. National Pest Management Association, Pestworld2017, Baltimore, Maryland, USA, 24-27th Oct. 2017. (Oral Presentation). 11. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Barbercheck, M. 2018. Soil health and pest management. Mid-Atlantic Fruit and Vegetable Convention. Hershey, PA. 31 January 2018. 200 people. 12. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Barbercheck, M.E., P. Randhawa, C. Mullen. 2018. Cover Crop Identity, not Diversity, & Agroecosystem Characteristics Affect the Occurrence of a Beneficial Soil Fungus. Northeast Cover Crops Council Annual Conference, State College, PA. 15 November 2018 (Invited). 13. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Barbercheck, M. 2018. Restructuring plant-associated arthropod composition. Workshop on "Manipulating phytobiomes: challenges and opportunities," Wild and Tamed Phytobiomes: 21st Penn State Plant Biology Symposium, June 19-22, 2018. University Park, PA. (Invited oral presentation) 14. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Barbercheck, M. 2018. Effects of cover crops on invertebrate pests and their natural enemies in conservation tillage systems. 2018 North Central Branch ESA Meeting, March 18-21, 2018, Madison, WI. Invited Symposium (Influence of Cover Crops on Crop Insect Management) 15. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Barbercheck, M. 2018. Farming and fungi: Agroecosystem impacts on a multifunctional fungus in an organic cropping system. Wild and Tamed Phytobiomes: 21st Penn State Plant Biology Symposium, June 19-22, 2018. University Park, PA. (Invited plenary presentation) 16. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Barbercheck, M., T. Gareau, R. Smith, D. Mortensen. 2018. Using spider plots to understand multifunctionality of agroecosystems. Workshop on teaching organic agriculture. June 10 ? 12, 2018. Ames, Iowa. Invited oral presentation. 17. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Flonc, B., Ahmad, I., Mullen, C., Barbercheck, M. 2018. Can fungi make caterpillars picky eaters? Effect of endophytic *Metarhizium* in corn on fall armyworm (*Spodoptera frugiperda*) feeding behavior. 21st Penn State Plant Biology Symposium: Wild and Tamed Phytobiomes. 19-22 June 2018. 18. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Flonc, B., Ahmad, I., Mullen, C., Barbercheck, M. 2018. Can fungi make caterpillars picky eaters? Effect of endophytic *Metarhizium* in corn on fall armyworm (*Spodoptera frugiperda*) feeding behavior. Eastern Branch Entomological Society of America (EB-ESA) Conference. 17-19 March 2018 19. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Regan, K. and Flonc, B. 2018. Who's in our crop fields? Penn State University Cover Crop/Reduced Tillage Field Day for Argentinian Farmers. 17 May 2018. 20. Type: Conference Papers and Presentations Status: Other Year Published: 2018 Citation: Flonc, B., Ahmad, I., Mullen, C., Barbercheck, M. 2018. Can fungi make caterpillars picky eaters? Effect of endophytic *Metarhizium* in corn on fall armyworm (*Spodoptera frugiperda*) feeding behavior. Penn State Life Science Symposium. 18 May 2018.

2016/09 TO 2017/08 What was accomplished under these goals? To address the research objective 1, we conducted sentinel insect assays of soil from the field experiment at the Russell E. Larson Agricultural Research and Education Center at Rock Springs from the cover crop treatments that varied in diversity. There was no effect of cover crop mixture diversity on detection of *Metarhizium*. Mean infection rates of the sentinel insect, *Galleria mellonella*, in cover crop treatments were, from least to greatest: 3 spp. mix (6.8%), Canola (9.2%), Fallow (12.8%), Forage radish (13.6%), Triticale (13.9%), Crimson clover (13.9%), Austrian winter pea (14.2%), 5 spp. mix (15.5%), 3 spp. N (15.8%), Oat (15.8%), 6 spp. mix (20.8%), and 2 spp. mix (21.7%). We have established approximately 400 *Metarhizium* isolates via sentinel insect assay from soil collected from research station and on-farm experiments. We are continuing to collect isolates of *Metarhizium* isolates with the goal of identifying them via molecular methods to determine the effects of cover crop treatments and soil properties on the diversity

and abundance of *Metarhizium*. To address objective 2, we are conducting experiments to assess the ability of *Metarhizium* to infect corn, canola, cereal rye and Austrian winter pea (AWP). 100% of corn plants germinated from seeds exposed to *Metarhizium* spores showed endophytic colonization by *Metarhizium* with varying degree of colonization among different plant tissues. At V4, we recovered *Metarhizium* from 65% of corn root samples and 56% of 4th true leaf samples grown from plants grown from exposed seed, respectively. Corn height, biomass, and leaf greenness in plants grown from seed exposed to *Metarhizium* were not different from untreated control plants. Cereal rye plants germinated from *Metarhizium*-treated seeds showed 26.7% and 33% endophytic colonization in leaves and roots, respectively. The *Metarhizium* treated plants had greater leaf greenness, plant height and biomass compared to control (non-inoculated) plants. We did not recover *Metarhizium* from the roots or leaves of canola plants grown from seeds exposed to *Metarhizium*. However, canola plants grown from seed exposed to *Metarhizium* treated had greater leaf greenness, plant height and biomass compared with control plants. We recovered *Metarhizium* from 37% of root samples from AWP plants germinated from seeds exposed to *Metarhizium* spores, but none from leaf tissue samples. The *Metarhizium* treated AWP plants had greater leaf greenness, plant height and biomass compared with control plants. These experiments confirmed that there is varying degree of endophytic relationship of *Metarhizium* associated with corn and selected cover crops. There also appears to be variability in the locality of *Metarhizium* in different tissues among the different crops. To address objective 3, we are currently conducting detached-leaf feeding assays to determine the effects of endophytic *Metarhizium* in corn on growth of the Fall Armyworm (FAW), *Spodoptera frugiperda*, and the Black Cutworm, *Agrotis ipsilon*. We are also conducting choice assays to determine the effect of endophytic *Metarhizium* on host choice by FAW. There were 85 instances of leaf feeding in the choice assay, out of which 52 feeding events (61.2%) were on leaves from plants infected with *Metarhizium*. *Metarhizium* was expressed in leaf and root tissue in 57.1% experimental plants used in the choice assay. These assays are currently being repeated. A teleconference was held in November 2017 with participants from Penn State, Delaware State, and the University of Maryland Eastern Shore, and Ursinus College to initiate the development of curriculum focused on ecosystem services and disservices associated with cover crop diversity in organic cropping systems. This will help undergraduate students at participating institutions learn about practices central to the management of organic systems and gain a broader perspective of ecosystem services, such as biological control and plant protection, provided by organic systems. This achievement will accomplish our educational goal.

****PUBLICATIONS (not previously reported):**** 2016/09 TO 2017/08 1. Type: Other Status: Published Year Published: 2017 Citation: Baraibar, B., editor. 2017. The cover crop cocktails hour: The cover crop cocktails newsletter. The Pennsylvania State University, State College, PA, Nov. 18, 2017. 2. Type: Theses/Dissertations Status: Accepted Year Published: 2017 Citation: Randhawa, P.K. 2017. Effect of cover crops and soil characteristics on the occurrence of *Metarhizium robertsii* in an organic cropping system. M.S. Thesis, Department of Entomology, Penn State University. 3. Type: Journal Articles Status: Published Year Published: 2017 Citation: Finney, D. M. Ebony G. Murrell, Charles M. White, Barbara Baraibar, Mary E. Barbercheck, Brosi A. Bradley, Sarah Cornelisse, Mitchell C. Hunter, Jason P. Kaye, David A. Mortensen, Christina A. Mullen, and Meagan E. Schipanski. 2017. Ecosystem services and disservices are bundled in simple and diverse cover cropping systems. 2017. *Agricultural & Environmental Letters* 2:170033. doi:10.2134/ael2017.09.0033 4. Type: Journal Articles Status: Published Year Published: 2017 Citation: Schipanski, M. E., Mary E. Barbercheck, Ebony G. Murrell, Jayson Harper, Denise M. Finney, Jason P. Kaye, David A. Mortensen, Richard G. Smith. 2017. Balancing multiple objectives in organic feed and forage cropping Systems. *Agric. Ecosyst. Env.* 239: 219-227.

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Pathway to Organic: a Research, Extension, and Education Project in the Southeast Us on Transitioning Cropping Systems

Accession No.	1010355
Project No.	TEX09663
Agency	NIFA TEX\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2016-51106-25710
Proposal No.	2016-06174
Start Date	01 SEP 2016
Term Date	31 AUG 2019
Grant Amount	\$475,000
Grant Year	2016
Investigator(s)	Rajan, N.
Performing Institution	TEXAS A&M UNIVERSITY, 750 AGRONOMY RD STE 2701, COLLEGE STATION, TEXAS 77843-0001

NON-TECHNICAL SUMMARY

Texas ranks first in number of farms and third in total agricultural production in the U.S. However, the state lags behind in organic crop production. The low rate of adoption of organic farming for grain crops such as corn and sorghum has been a major bottleneck for expansion of the organic livestock sector in this state. The specific goals of this study are based on our interactions with farmers and other stakeholders in the region. Collectively, these discussions have shaped the goals and objectives of the project. Our goals are: (1) Conduct research and on-farm demonstrations in a partnership between scientists and stakeholders for greater understanding of the influence of tillage and cover cropping on greenhouse gas emissions, weed dynamics, water-yield relations, and soil health, (2) Develop best management practices that optimize both agricultural profitability and ecosystem services in transitioning cropping systems (corn, grain sorghum, and soybeans), (3) Determine the current level of cognitive understanding and related beliefs, attitudes, and opinions on transitioning to organic systems and create a model for educational and outreach activities, and (4) Develop an educational and outreach program for efficient transfer of project results to the various stakeholders and organize training efforts on the certification process, farm plan development, environmental benefits, and best management strategies while transitioning to organic production. Through this project, we will address some of the critical needs of farmers and other stakeholders in Texas who plan to adopt organic farming.

OBJECTIVES

The long-term goal of this proposed project is the expansion of organic cropping systems (corn, sorghum, and soybeans) production in Texas. The specific goals of this study are based on our interaction with farmers and other stakeholders in the region. Our specific objectives of this project are to: Conduct research and on-farm demonstrations in a partnership between scientists and stakeholders for greater understanding of the influence of tillage and cover cropping on greenhouse gas emissions, weed dynamics, water-yield relations, and soil health, and develop best management practices that optimize both agricultural profitability and ecosystem services in transitioning cropping systems (corn, grain sorghum, and soybean). Determine the current level of cognitive understanding and related beliefs, attitudes, and opinions on transitioning to organic systems and create a model for educational and outreach activities. Develop an educational and outreach program for efficient transfer of

project results to the various stakeholders and organize training efforts on the certification process, farm plan development, environmental benefits, and best management strategies while transitioning to organic production.

APPROACH

Objective 1: A three-year transitional organic systems experiment will be established at the beginning of 2017 at College Station, TX. This experiment will be managed according to NOP-guidelines. The experimental design will be a randomized split-plot design with four replications. Cropping systems will focus on three major crops: corn, soybeans and grain sorghum. Yield goals for system development will be 125 bu/acre for corn, 40 bu/acre soybeans and 100 bu/acre grain sorghum. The rotation for main crops will be soybeans-corn-sorghum. All three main crops will be in rotation each year. We will impose three experimental production systems plus the current organic practice for each main crop to evaluate: (a) greenhouse gas (GHG) mitigation potential, (b) weed suppression potential, (c) nutrient balance (d) water use (e) yield and economic return, and (d) soil health benefits. The experimental production systems will be as follows:(1)Current Practice: Primary and secondary tillage operations will be used for pre-plant weed control, incorporation of manure and seedbed preparation. (2)Summer Cover Crop-No Till grain/soybean: A sixty-day cowpea (*Vigna unguiculata* L.) cover crop will be planted late summer after the main crop. The crop will be allowed to stand over winter with grain or legume crops in no-till planted the following spring. (3)Summer Cover Crop - Fall Cover Mulch - No Till grain/soybean: A sixty-day cowpea cover crop will be planted late summer after the main crop and incorporated after 60 days. A cover crop mixture of winter rye and hairy vetch (*Vicia villosa* Roth) will be planted as a cover mulch following incorporation of cowpea. The cover mulch will be roller-crimped to provide weed control. Grain or soybean crops will be no-till planted into the residue. (4)Double Cover Crop - Conventional Tillage: This system will utilize the same crop sequence as system #3. Main Crop-Cow Pea-Rye/Vetch-Main Crop. However this treatment will utilize tillage to incorporate all cover crops and will utilize raised beds for main crops. Cultivation will be used for weed control as needed. A demonstration site will be established on a commercial certified organic farm near Rosenberg, TX during Year 2 and 3 of the project. The site will serve as a living demonstration of an organic system (farm) plan. Information obtained from field and demonstration sites will be used in an economic analysis of the organic management systems. The data from experimental and demonstration fields will be used to build enterprise budgets for each crop in transitional organic management to understand the associated costs, revenues, and enterprise profits. Life cycle analysis will be used to compare the carbon footprint of production under transitioning organic systems. Objective 2: To determine the current level of understanding and related beliefs, attitudes, and opinions on organic in general, and on transitioning to organic system in particular, we will employ an online survey questionnaire in Year 1 of the project. There are two target populations for the survey: (1) established organic producers in the East and Central regions of Texas; and (2) conventional producers who are interested in transitioning to organics in these same regions. The survey will also address specific issues based on anecdotal evidence reported to project staff by transitioning producers interviewed in preparation for this research proposal, such as (1) the NOP certification process, (2) improving soil fertility and crop yield, (3) tillage and cover cropping; (4) lack of extension resources for organic farming of field crops, (5) long-term commitment, (6) awareness of environmental benefits, and (7) marketing Objective 3: Guided by the survey research results, we will develop appropriate educational materials to meet the needs of Texas crop producers interested in transitioning to organics in Year 2 and 3 of the project. It is our hope that producers will embrace the organic grain cropping systems and information derived through the research of this project. To attempt to achieve high degree of adoption, a high-impact, multifaceted education and outreach program will be conducted. In addition to the Texas A&M ArgiLife Extension program, we will utilize the ATTRA (also called the National Sustainable Agriculture Information Service) program of the National Center for Appropriate Technology (NCAT) to further reach interested stakeholders. Findings from this project will be incorporated into the courses at TAMU and SHSU by team members. Project team members at Texas A&M will recruit and supervise Undergraduate Research Scholars and engage them in a two-semester (summer semesters) research effort in the current study. Their research results will be presented at the Summer Undergraduate Research Poster Session at Texas A&M.

PROGRESS

2016/09 TO 2020/08 Target Audience: Targeted audience of this project during the reporting period included agricultural producers, agricultural scientists, graduate students, undergraduate students, extension personnel, policy makers, and general public. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Two Ph. D. students (Diana Zapata and Spencer Samuelson) and one M.S. student (Jonathan Moreno) worked in the project. Diana Zapata had graduated in Spring 2019 and worked in the project as a post-doctoral research associate until March 2020. Jonathan Moreno had graduated in Spring 2019. Spencer Samuelson had graduated in Spring 2020. A non-thesis M.S. student (Andrea Fonseca)

had joined the project in summer 2019 to assist with outreach activities (at no cost to NIFA). All personnel working in the project have received training in various activities related to organic management and equipment use for establishing and maintaining the project site. Undergraduate students from TAMU were hired to assist with plot maintenance and field data collection. Instrumentation used for measuring GHG emissions at the field project site was demonstrated to several visiting scientists. Graduate students working in the project attended the annual meeting of ASA-CSSA-SSSA, the Southern ASA meeting, and the Weed Science Society meeting and participated in graduate student presentation competitions. Graduate student Spencer Samuelson won second prize in poster competition at the Southern Weed Science Society meeting and second prize in poster competition at the 2019 ASA-CSSA-SSSA annual meeting in San Antonio, TX. An undergraduate student (Walker Crane) conducted research in the project in 2020. He has presented his research findings at the 2020 ASA-CSSA-SSSA annual meeting and won second prize in a poster competition. Overall, the project has provided multiple opportunities for professional development. How have the results been disseminated to communities of interest? The project team has been active in communicating results to various stakeholder groups through participation in scientific conferences, grower meetings and online meetings. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

2017/09 TO 2018/08 Target Audience: Targeted audience of this project during the reporting period included agricultural producers, agricultural scientists, graduate students, undergraduate students, extension personnel, policy makers, and general public. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Two Ph. D. students (Diana Zapata and Spencer Samuelson) and one M.S. student (Jonathan Moreno) are currently working in the project. They have received training in various activities related to organic management and equipment use for establishing and maintaining the project site. Four undergraduate students from TAMU were hired to assist with plot maintenance and field data collection. Instrumentation used for measuring GHG emissions at the field project site was demonstrated to a class of 7 graduate students in the course SCSC 618 (Analysis of Environmental Systems) offered in the Department of Soil and Crop Sciences at TAMU. Graduate students working in the project attended the annual meeting of ASA-CSSA-SSSA and participated in graduate student presentation competitions. Overall, the project has provided multiple opportunities for professional development. How have the results been disseminated to communities of interest? The project team has been active in communicating results to various stakeholder groups. Four presentations showcasing project results were made at the 2017 ASA-CSSA-SSSA Annual Meeting in Tampa, FL. One presentation was made at the Southern American Society of Agronomy Meeting in Jacksonville, FL. Dr. Schnell made a plenary keynote presentation at the annual meeting of the Texas Organic Farmers and Gardeners Association Conference in Georgetown, TX. Dr. Schnell also presented organic cropping information at the Bell County Crops Conference with approximately 250 participants. One popular article targeting organic producers was also published. What do you plan to do during the next reporting period to accomplish the goals? We will continue the field research, survey, and outreach activities as outlined in the proposal. Field research data from past two years will be analyzed to publish project results in peer-reviewed journals. Tentative graduation date of M.S. student, Mr. Jonathan Moreno, is May, 2019. Ph. D. student, Ms. Diana Zapata, is also scheduled to graduate in May, 2018. A second organic transitions grain project site will be established at the Texas A&M Research Farm in the third year with the same set of treatments at no-cost to the existing NIFA project. This new site was under conventional management until August 2017. Grain yield from this site (year 2019) will be compared to grain yields from our ongoing site which was under fallow for several years prior to establishing this project.

2016/09 TO 2017/08 Target Audience: Targeted audience include agricultural producers, agricultural scientists (soil scientists, agronomists, and environmental scientists), extension personnel, policy makers, and general public. Changes/Problems: After the first year of field investigations, our conclusion is that cereal rye/vetch is not ideal as a winter cover crop for the grain and soybean cropping systems in Texas. When it began to grow and put on biomass, it was too late to plant grain crops and the ability to mechanically terminate the crop was reduced. We typically plant corn near the first week of March, and sorghum and soybeans in late March. The rye and vetch didn't mature until April, which ended up being competitive with the grain crops and became more like a weed. This has resulted in severe yield reduction in no-till cover crop treatment plots. We will change the winter cover treatment to spring wheat-Australian winter pea mix as it would mature early for timely planting of grain crops in March. No-till systems also had severe weed pressure especially Johnsongrass. Because they are perennial, inclusion of more strategic tillage in the summer and fall is important for effective management of this species. Hence, we would like to change the no-till systems to reduced till systems. What opportunities for training and professional development has the project provided? Our project has provided training for two Ph.D. students and one M.S. student. These students will be presenting their research at the ASA-CSSA-SSSA Annual Meetings in Tampa, FL. How have the results been disseminated to communities of interest? Results will be disseminated

through popular articles, extension publications, peer-reviewed journal papers, dissertations, thesis, presentations, and conference abstracts. We have published one popular article, and have three abstracts accepted for presentation at the 2017 ASA-CSSA-SSSA Annual Meeting in Tampa, FL. What do you plan to do during the next reporting period to accomplish the goals? We will continue the field research activities. In addition, we will initiate our survey experiment and extension activities.

IMPACT

2016/09 TO 2020/08 What was accomplished under these goals? Objective 1: Two field studies were conducted to accomplish specific objective 1. We established the first field study in September 2016 at the Texas A&M Research Farm. The land was previously left fallow for several years (2006-2016). The experimental design was a randomized strip-split plot design with three replications. The rotation for main crops is soybeans-corn-sorghum. The treatments under each main crop include: (1) Current practice, which uses primary and secondary tillage operations for preplant weed control, incorporation of manure and seedbed preparation; (2) Summer Cover Crop-No Till grain/soybean; (3) Summer Cover Crop - Fall Cover Mulch - No Till grain/soybean; and (4) Summer Cover Crop - Fall Cover Mulch - Conventional Till grain/soybean. Cowpea was planted as the summer cover crop in treatments 2, 3 and 4. For fall cover mulch, we planted a cover crop mixture of winter rye and hairy vetch. In treatment # 4, cowpea residues were incorporated by plowing before planting Rye/Vetch. Manure was applied in all plots on using a manure spreader at a rate of approximately 4,450 kg ha⁻¹. After the first year of field investigations, our conclusion was that cereal rye/vetch is not ideal as a winter cover crop for the grain and soybean cropping systems in Texas. From second year onward, we changed the winter cover treatment to spring wheat-Australian winter pea mix as it would mature early for timely planting of grain crops in March. No-till systems also had severe weed pressure especially Johnsongrass. Hence, we changed the no-till systems to reduced till systems. A second transitioning experiment was established in fall 2018 to compare weed pressure and soil fertility issues associated with transitioning a previously conventionally farmed land as opposed to grassland. The land was previously planted to soybean and managed conventionally. The experiment was established in a split-plot design with three replications. Crop management was the main plot and included conventional and organic practices. Conventional and organically managed plots separated by a 15 m buffer zone. The crop rotation was the subplot and included corn and grain sorghum. We monitored soil temperature and volumetric water content continuously at both field sites. Crop management had an effect on soil moisture only in corn plots, with conventional management showing higher water content compared to organic. In sorghum, soil moisture and temperature were similar between management practices all depths. GHG emission data was collected by integrating two gas analyzers in parallel (The LI-8100A multi-chamber system with a PICARRO G2408 GHG analyzer. Soil CO₂ flux was the most dynamic contributor to GHG flux. The soil CO₂ flux reported in this study were generally higher than previously reported. Soil cracking was a significant factor for increased CO₂ emissions. Cover cropping and soil tillage influenced cumulative CO₂ emissions. Winter cover crop mixtures that were mechanically terminated before corn planting enhanced CO₂ emissions during the growing season, probably due to an increase in residue decomposition and root respiration from both crops. Cover crop biomass production showed wide variability among the three years of the study, but the highest biomass levels were observed in the third year, irrespective of the treatment. Grain yield was significantly affected in all treatments due to severe weed pressure. Soybeans performed poorly in every year of the study compared to other grain crops. Mean grain yield for corn was 1,546 kg ha⁻¹ in the first year. Substantial reduction in corn yield was observed in 2018 and 2019. For sorghum, mean sorghum grain yield was 640.6 kg ha⁻¹ during the first year with no differences between management practices. In 2018, sorghum grain yield improved significantly. Management under current practice resulted in a grain yield 2,930 kg ha⁻¹ in 2018. In the second study, 2019 corn yield in organic plots was 2610.5 kg ha⁻¹ and 6269.3 kg ha⁻¹ in conventional plots. The 56% decline in yield with organic production was due to a higher weed pressure on organic plots (mainly pigweed) and nitrogen limitation. Sorghum yield was not affected by crop management. The average organic sorghum yield was 4510.9 kg ha⁻¹ and in conventional plots yield was 5218.4 kg ha⁻¹. We are currently working on analyzing 2020 grain yield data. During the first year of the experiment, the highest winter annual weed biomass were mostly comprised of Italian ryegrass that had been abundant at the site before transitioning this land into row cropping. Among the treatments, conventional-till plots had significantly lower winter weed biomass compared to that of no-till treatments which in turn allowed the cover crops to be more competitive and accumulate higher biomass in each successive year. Percent coverage of summer weeds observed at 21 days after cash crop planting also decreased over time, mainly due to the interruption of weed lifecycles by the crop/weed management activities implemented in the experiment. A major weed challenge in the study site was johnsongrass, which proved to be very difficult to manage using organic methods. The treatment with conventional-till and double cover crop planting decreased johnsongrass densities. Shifts in weed species abundance were observed over the duration

of the experiment. The top five most abundant species in the above-ground weed population consisted of purple nutsedge (*Cyperus rotundus*L.), woolly croton, johnsongrass, Texas millet and Italian ryegrass. Overall, the conventional-till double cover crop treatment had the most impact on the population sizes of all dominant weeds studied here, when compared to all other treatments. The combined action of aggressive cover crop implementation followed by a clean seed bed prior to cash crop planting and inter-row cultivation helped in the this observed decrease. Species richness decreased over time with the highest species richness observed in the first year of the study in the no-till double cover crop mix treatment. By the concluding year of the study, species richness decreased significantly from year one with the lowest richness observed in the no-till double cover crop legume treatment. The seedbank densities for different weed species studied were comparable across the treatments.

Objective 2: Drs. Constance and Nair at Sam Houston State University administered an online survey instrument to the agricultural producers through the county extension agents following a systematic process. The survey results indicated that most of the producers (58.3%) had a bachelor's degree and 45.8% were in operation for greater than 20 years. Among the respondents, 70.8% managed conventional operations, 29.2% had non-certified organic, and 12.3% had both conventional and organic components. One-half of the agribusiness operations received less than \$50,000 in annual gross sales, while 25% received more than \$1,000,000 in annual gross revenue. One-third of the agribusinesses expect their operations to expand and 37.5% expect their operations to become more diversified in the next three years. Most of the respondents indicated that they have slight (20.8%), moderate (20.8%), or high (25%) interest in transitioning to organic production. Uncertainty in obtaining organic price premium, complexity of the certification process, and the large number of regulations were perceived by most of the respondents as barriers to entry to organic production.

Objective 3: Project team actively disseminated knowledge gained from the project through participation in scientific and grower-oriented meetings. A non-thesis master's student was appointed to develop organic training documents for county extension agents. A project website, www.organic.tamu.edu, showcasing various aspects organic grain production is scheduled for launching in Fall 2020. ****PUBLICATIONS (not previously reported):****

2016/09 TO 2020/08

1. Type: Other Status: Published Year Published: 2016 Citation: Texas A&M leading organic grain crop study. Popular article published in AgriLife Today. <https://today.agrilife.org/2016/10/21/texas-leading-organic-grain-crop-study/>
2. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Zapata, D., N. Rajan, K.D. Casey and R. W. Schnell. 2017. Diurnal greenhouse gas emissions under different carbon and nitrogen input from cover crops. Abstracts, ASA-CSSA-SSSA Annual Meeting, 22-25 Oct., Tampa, FL.
3. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Rajan, N., R. Schnell, M. Bagavathiannan, S. Nair, D. Constance, K.D. Casey, D. Zapata, J. Moreno and S. Samuelson. 2017. Transitioning organic grain and soybean cropping systems in Texas: Challenges and benefits. Abstracts, ASA-CSSA-SSSA Annual Meeting, 22-25 Oct., Tampa, FL
4. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Moreno, J., R. Schnell, M. Bagavathiannan, C. Neely and N. Rajan. 2017. Organic farming implementing cover cropping and varying tillage practices. Abstracts, ASA-CSSA-SSSA Annual Meeting, 22-25 Oct., Tampa, FL.
5. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Samuelson S. L., R. Schnell, N. Rajan and M. Bagavathiannan. 2018. Evaluation of weed seedling emergence and density in organic grain production systems under different management practices. Proc. Southern Weed Sci. Soc. 71:31.
6. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Rajan N., and D. Zapata. 2018. Greenhouse gas emissions from soils transitioning to organic. Abstracts, Southern American Society of Agronomy Annual Meeting, February 4-6, Jacksonville, FL
7. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Schnell, R. 2018. Opening Plenary - Updates from around the state. The Annual Texas Organic Farmers and Gardeners Association Conference, February 1-3, Georgetown, TX.
8. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Zapata, D., N. Rajan, K. D. Casey and R. Schnell. Carbon and nitrogen mineralization of cereal and legume cover crop residues in organic soils. Abstracts, ASA-CSSA-SSSA Annual Meeting, 4-7 November, Baltimore, MD.
9. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Pokhrel, P., N. Rajan, R. Schnell, and D. Zapata. Effect of cover crop residues on soil organic carbon mineralization in an organic soybean production system. 2018. Abstracts, ASA-CSSA-SSSA Annual Meeting, 4-7 November, Baltimore, MD.
10. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Zapata, D., N. Rajan and R. Schnell. Greenhouse gas emissions from organically managed cropping systems in Texas. 2018. Abstracts, ASA-CSSA-SSSA Annual Meeting, 4-7 November, Baltimore, MD.
11. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Moreno, J., R. Schnell, N. Rajan and M. Bagavathiannan. Impacts of tillage and cover cropping on organic systems. Abstracts, ASA-CSSA-SSSA Annual Meeting, 4-7 November, Baltimore, MD.
12. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Samuelson, S. L., N. Rajan, R.W. Schnell, and M. Bagavathiannan. 2019. Impact of non-chemical management practices on weed population dynamics in organic grain production. Abstracts, ASA-CSSA-SSSA Annual Meeting, November 10-13, San Antonio, TX. (Awarded 3rd Place in Poster Presentation, Organic Management Systems Section)
13. Type: Conference Papers and Presentations Status: Published Year Published: 2019

Citation: Samuelson, S. L., N. Rajan, R.W. Schnell, and M. Bagavathiannan. 2019. Non-chemical management practices and their impact on weed population dynamics in organic grain production. Proc. Southern Weed Sci. Soc. 59:145. (Awarded 2nd Place in Ph.D. Poster Presentation) 14. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Constance, D. H., S. Nair, N. Rajan, M. Bagavathiannan, and R. Schnell. 2019. Organic Texas row crops: Opportunities and barriers to increased adoption. Paper presented at the annual meeting of the Rural Sociological Society, Richmond, VA. August 9. 15. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Constance, D. H., S. Nair, N. Rajan, M. Bagavathiannan, and R. Schnell. 2019. Opportunities and barriers to the adoption of organic row crop agriculture in Texas. Paper presented at the annual meeting of the Agriculture, Food, and Human Values Society. Anchorage, AK. June 28. 16. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Zapata, D. M., N. Rajan, J. Moreno, R. Schnell, S. Nair, and K. D. Casey. 2019. Transitioning into organic grain production in Texas: Challenges and environmental impact. Abstracts, ASA-CSSA-SSSA Annual Meeting, November 10-13, San Antonio, TX. 17. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Zapata, D., N. Rajan, K. D. Casey, J. E. Mowrer, and R. W. Schnell. 2019. Linking carbon dioxide and nitrous oxide emissions from crop residue decomposition. Abstracts, ASA-CSSA-SSSA Annual Meeting, November 10-13, San Antonio, TX. 18. Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Zapata, D. M., N. Rajan, K. Casey, R. Schnell and J. Mowrer. 2019. Greenhouse gas emissions from cover crop decomposition in an organic corn field in Texas. Abstracts, Annual Meeting of the Southern Branch of the American Society of Agronomy, 3-5 February, Birmingham, AL. 19. Type: Conference Papers and Presentations Status: Published Year Published: 2020 Citation: Crane, W., N. Rajan, D. Zapata and R. Schnell. 2020. Cover cropping affects soil microclimate and soil CO₂ emissions. Abstracts, ASA-CSSA-SSSA Virtual Annual Meeting. 20. Type: Conference Papers and Presentations Status: Published Year Published: 2020 Citation: Crane, W., N. Rajan, D. Zapata and R. Schnell. 2020. Effect of cover cropping on soil CO₂ emissions and soil microclimate in sorghum cropping systems. Abstracts, ASA-CSSA-SSSA Virtual Annual Meeting. 21. Type: Conference Papers and Presentations Status: Published Year Published: 2020 Citation: Samuelson, S., L. Herndon and M. Bagavathiannan. 2020. Evaluation of non-chemical tactics for managing Johnsongrass (*Sorghum halepense*). Annual Meeting of the Weed Science Society of America. 2-5 March, Maui, HI. 22. Type: Journal Articles Status: Other Year Published: 2021 Citation: Zapata, D., N. Rajan, J. Mowrer, K. Casey and R. Schnell. Dynamics of soil properties and CO₂ emissions in a transitioning organic grain production system implementing cover crops. To be submitted to *Agrosystems, Geosciences & Environment*. 23. Type: Journal Articles Status: Other Year Published: 2021 Citation: Zapata, D., N. Rajan, J. Mowrer, K. Casey and R. Schnell. Impact of cereal and legume cover crop residues on carbon and nitrogen mineralization in organic systems. To be submitted to *Soil Science Society of America Journal*. 24. Type: Journal Articles Status: Other Year Published: 2021 Citation: Crane, W., N. Rajan, D. Zapata and R. Schnell. 2020. Effect of cover cropping on soil CO₂ emissions and soil microclimate in conventional and organic sorghum cropping systems. In Preparation. 25. Type: Journal Articles Status: Other Year Published: 2021 Citation: Rajan, N., D. Zapata, W. Crane and R. Schnell. Greenhouse gas emissions from organic and conventional sorghum in Texas. In Preparation. 26. Type: Journal Articles Status: Other Year Published: 2021 Citation: Samuelson, S. L., N. Rajan, R.W. Schnell, and M. Bagavathiannan. Impact of tillage and cover crops on weed management in organic grain production. To be submitted to *Weed Science*. 27. Type: Theses/Dissertations Status: Published Year Published: 2019 Citation: Moreno, J. A. 2019. Developing Cropping Systems for Organic Grain Production in Texas. Master's thesis, Texas A&M University. 28. Type: Theses/Dissertations Status: Published Year Published: 2019 Citation: Zapata, D. 2019. Impact of Cropping Practices and Tillage on Greenhouse Gas Emissions and Soil Properties Dynamics in South Central Texas. Doctoral dissertation, Texas A & M University. 29. Type: Theses/Dissertations Status: Published Year Published: 2020 Citation: Samuelson, S. 2020. Developing cover crop systems for weed management in Texas row crop production. Doctoral dissertation, Texas A & M University. PROGRESS: 2018/09 TO 2019/08 Target Audience: Targeted audience of this project during the reporting period included agricultural producers, agricultural scientists, graduate students, undergraduate students, extension personnel, policy makers, and general public. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Two Ph. D. students (Diana Zapata and Spencer Samuelson) and one M.S. student (Jonathan Moreno) worked in the project. Diana Zapata has graduated in Spring 2019 and continued working in the project as a post-doctoral research associate. Jonathan Moreno also graduated in Spring 2019. A non-thesis M.S. student (Andrea Fonseca) has joined the project in summer 2019 to assist with outreach activities (at no cost to NIFA). All personnel working in the project have received training in various activities related to organic management and equipment use for establishing and maintaining the project site. Undergraduate students from TAMU were hired to assist with plot maintenance and field data collection. Instrumentation used for measuring GHG emissions at the field project site was demonstrated to a group of approximately 25 scientists in summer 2019. Graduate students working in the project attended the annual meeting of ASA-CSSA-SSSA, the Southern ASA meeting, and the Southern Weed Science Society meeting and participated in graduate student presentation competitions. Graduate student Spencer Samuelson won second

prize in poster competition at the Southern Weed Science Society meeting and second prize in poster competition at the 2019 ASA-CSSA-SSSA annual meeting in San Antonio, TX. Overall, the project has provided multiple opportunities for professional development. How have the results been disseminated to communities of interest? The project team has been active in communicating results to various stakeholder groups. A total of nine presentations showcasing project results were made by team members. Dr. Schnell presented organic cropping information at several producer meetings. What do you plan to do during the next reporting period to accomplish the goals? We will continue the field research, survey, and outreach activities as outlined in the proposal. Field research data from past three years will be analyzed to publish project results in peer-reviewed journals. Tentative graduation date of Ph.D. student Mr. Spencer Samuelson is May 2020. IMPACT: 2018/09 TO 2019/08

What was accomplished under these goals? Objective 1: The field study established in 2016 was continued in the third year and the treatments were the same as previous years. Considering large contrasts in weed densities observed in previous years between the north and south sections of the experimental site, the plots were divided into two sections (high and low weed infested areas) and observations were carried out separately. Soil seedbank samples were collected during November 2019. Five random 20 cm x 5 cm soil cores were collected in each treatment. Samples will be washed to determine weed species present and their densities. Cover crop and weedy biomass at planting were collected from three one m² quadrats to record impact of cover crop on winter annual and early emerging summer annual weed species. Prior to the first inter-row cultivation in treatment 4, summer annual weed seedling emergence and any remaining winter annual weed species were counted within each plot. A reduction in the diversity of species infesting the field was observed between the study years, with 29 species in 2017, 19 species in 2018, and 14 species in 2019. However, specific species shifts have been observed, with johnsongrass density increasing between all treatments except for the double cover cropped and conventional tillage treatment. In an effort to shift the trend of increased johnsongrass density, the third and most highly infested block was transitioned to an organic johnsongrass management study. This experiment focuses on intensive management during the fallow season to combat johnsongrass rhizomes and seedbank, to decrease johnsongrass density to a manageable level in subsequent growing season. Additionally, a second transitioning experiment was established in fall 2018 to compare weed pressure and soil fertility issues associated with transitioning a previously conventionally farmed land as opposed to grassland. The land was previously planted to soybean and managed conventionally. The experiment was established in a strip-plot design arranged in a randomized complete block with three replications. Crop management was the main plot and included conventional and organic practices. Conventional and organically managed plots separated by a 15 m buffer zone. The crop rotation was the subplot and included corn and grain sorghum. Organic certified corn (Blue River hybrid 70A47) and untreated conventional grain sorghum (Blue River hybrid 63C5) were planted on 3/28/19 in 70 cm wide rows. Organically managed plots received an application of mushroom compost on 4/30/19 at a rate of 3 ton ha⁻¹. The soil was cultivated on 5/17/19 to reduce weed pressure. Conventionally managed plots received a pre-emergent herbicide application of Outlook herbicide (Dimethenamid-P) on 4/23/19 at a rate of 18 oz/A, 15 gal. A synthetic liquid fertilizer (Urea Ammonium Nitrate 32-0-0) was applied in conventional plots on 5/17/19 at a rate of 112 kg N ha⁻¹. We monitored soil temperature and volumetric water content (VWC) continuously at three depths (5, 15 and 25 cm) in conventional and organically managed plots. Soil CO₂ fluxes were monitored during the growing season using 11 soil chambers deployed in the field. Final crop and weed biomass were collected before harvest. Crop management had an effect on soil moisture only in corn plots, with conventional management showing approximately 16% higher water content compared to organic. In sorghum, soil moisture and temperature were similar between management practices all depths. Overall, conventionally managed plots showed lower soil CO₂ emissions compared to organic production and differences on CO₂ emissions were more prominent during dry-periods. The average soil CO₂ fluxes were 20% higher in organic corn compared to conventional. However, no significant differences in terms of carbon emissions were observed between management with organic releasing 4063.5 kg C ha⁻¹ and conventional 3570.9 kg C ha⁻¹. This could be due to a trade-off in biomass productivity in organic systems, in which weeds are a major contributor. Thus, higher crop biomass productivity in conventional plots was compensated with high weed pressure plus less crop biomass productivity in organic plots. Average soil CO₂ fluxes in grain sorghum were 47% higher in organic compared to conventional management. Significant differences in C emissions were found between organic grain sorghum (3857.1 kg C ha⁻¹) and conventional (2649.4 kg C ha⁻¹). Grain sorghum plots were harvested on 8/9/19 and corn plots on 8/14/19. Crop yield was calculated by harvesting the six middle rows. Corn yield in organic plots was 2610.5 kg ha⁻¹ and 6269.3 kg ha⁻¹ in conventional plots. The 56% decline in yield with organic production was due to a higher weed pressure on organic plots (mainly pigweed) and nitrogen limitation. Sorghum yield was not affected by crop management. The average organic sorghum yield was 4510.9 kg ha⁻¹ and in conventional plots yield was 5218.4 kg ha⁻¹. Final soil samples were collected on 8/17/19 using a Giddings probe and sectioned into 0-15, 15-30, and 30-60 cm depths for soil fertility analysis. Objective 2: Drs. Constance and Nair at Sam Houston State University administered an online survey instrument to the agricultural producers through the county extension agents following a systematic process. First, an email was sent to the producers (on 1/23/2019) that described the purpose of the survey and informed them to watch out for the survey. The survey was then sent out

to the producers on 1/28/2019, which was followed by two weekly reminders. We received 24 usable responses to the survey, which were analyzed to identify the characteristics of the agricultural producers of the region and their perception of the barriers to adoption. The survey results indicated that most of the producers (58.3%) had a bachelor's degree and 45.8% were in operation for greater than 20 years. Among the respondents, 70.8% managed conventional operations, 29.2% had non-certified organic, and 12.3% had both conventional and organic components. One-half of the agribusiness operations received less than \$50,000 in annual gross sales, while 25% received more than \$1,000,000 in annual gross revenue. One-third of the agribusinesses expect their operations to expand and 37.5% expect their operations to become more diversified in the next three years. Most of the respondents indicated that they have slight (20.8%), moderate (20.8%), or high (25%) interest in transitioning to organic production. Uncertainty in obtaining organic price premium, complexity of the certification process, and the large number of regulations were perceived by most of the respondents as barriers to entry to organic production. The results of the analysis were presented in two national conferences (Constance et al., 2019a; 2019b). We are working on administering a paper-based survey during various producers meeting to collect convenience samples with a larger sample size. This will enable us to conduct more detailed statistical analysis of the survey data. The cost of production data from the field experiments were used to conduct initial scenario analysis to find the breakeven price and yield combinations of organic production for corn and sorghum. We are currently working on developing enterprise budgets, partial budgets, and price sensitivity analysis for transitioning to organic. Objective 3: A non-thesis master's student has joined the project to assist with the education and outreach activities. A number of training events are planned for Spring 2019. Topics that will be covered in these training events will include certification process, organic systems plan development, seed, soil and fertility management, pest/disease management, organic integrity, and harvest/handling. A project website, www.organic.tamu.edu, showcasing various aspects organic grain production is scheduled for launching in Spring 2019. PUBLICATIONS (not previously reported): 2018/09 TO 2019/08 1\ Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Samuelson, S. L., N. Rajan, R.W. Schnell, and M. Bagavathiannan. 2019. Impact of non-chemical management practices on weed population dynamics in organic grain production. Abstracts, ASA-CSSA-SSSA Annual Meeting, November 10-13, San Antonio, TX. (Awarded 3rd Place in Poster Presentation, Organic Management Systems Section) 2\ Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Samuelson, S. L., N. Rajan, R.W. Schnell, and M. Bagavathiannan. 2019. Non-chemical management practices and their impact on weed population dynamics in organic grain production. Proc. Southern Weed Sci. Soc. 59:145. (Awarded 2nd Place in Ph.D. Poster Presentation) 3\ Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Constance, D. H., S. Nair, N. Rajan, M. Bagavathiannan, and R. Schnell. 2019a. Organic Texas Rowcrops: Opportunities and Barriers to Increased Adoption. Paper presented at the annual meeting of the Rural Sociological Society. Richmond, VA. August 9. 2019. 4\ Type: Conference Papers and Presentations Status: Accepted Year Published: 2019 Citation: Constance, D. H., S. Nair, N. Rajan, M. Bagavathiannan, and R. Schnell. 2019b. Opportunities and Barriers to the Adoption of Organic Row Crop Agriculture in Texas. Paper presented at the annual meeting of the Agriculture, Food, and Human Values Society. Anchorage, AK. June 28. 2019. 5\ Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Zapata. D. M., N. Rajan, J. Moreno, R. Schnell, S. Nair, and K. D. Casey. 2019. Transitioning into Organic Grain Production in Texas: Challenges and Environmental Impact. Abstracts, ASA-CSSA-SSSA Annual Meeting, November 10-13, San Antonio, TX. 6\ Type: Conference Papers and Presentations Status: Published Year Published: 2019 Citation: Zapata, D., N. Rajan, K. D. Casey, J. E. Mowrer, and R. W. Schnell. 2019. Linking Carbon Dioxide and Nitrous Oxide Emissions from Crop Residue Decomposition. Abstracts, ASA-CSSA-SSSA Annual Meeting, November 10-13, San Antonio, TX. 7\ Type: Conference Papers and Presentations Status: Accepted Year Published: 2019 Citation: Zapata. D. M., N. Rajan, K. Casey, R. Schnell and J. Mowrer. 2019. Greenhouse Gas Emissions from Cover Crop Decomposition in an Organic Corn Field in Texas. Abstracts, Annual Meeting of the Southern Branch of the American Society of Agronomy, 3-5 February, Birmingham, AL. 8\ Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Zapata. D. M., N. Rajan, K. Casey, J. Mowrer, and R. Schnell. 2018. Carbon and Nitrogen Mineralization of Cereal and Legume Cover Crop Residues in Organic Soils. Abstracts, ASA-CSSA-SSSA International Annual Meetings, November 4-7, Baltimore, MD. 9\ Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Zapata. D. M., N. Rajan, J. Moreno, K. Casey, and R. Schnell. 2018. Greenhouse Gas Emissions from Organically Managed Cropping Systems in Texas. Abstracts, ASA-CSSA-SSSA International Annual Meetings, November 4-7, Baltimore, MD. 10\ Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Moreno, J., R. W. Schnell, N. Rajan, and M. Bagavathiannan. 2018. Effect of Cover Crop Residues on Soil Organic Carbon Mineralization in an Organic Soybean Production System. Abstracts, ASA-CSSA-SSSA International Annual Meetings, November 4-7, Baltimore, MD.

2017/09 TO 2018/08 What was accomplished under these goals? Objective 1: Year 1 field results showed that the popular cover crop mixture of rye and vetch was not ideal for the grain and soybean cropping systems in

Texas due to maturity issues. As crimping was done in February to allow timely planting of main crops, it was less effective in terminating the cover crops. This has resulted in yield reductions in year 1 of the project in no-till rye-vetch treatment plots. In year 2 of the project, we have made the following changes in treatments to address these challenges. Treatment 2 'summer cowpea-no till grain/soybean' was changed to 'summer cowpea- winter Austrian pea - reduced till grain and soybean'. Treatment 3 'summer cowpea - rye and vetch winter cover - no till grain and soybean' was changed to 'summer cowpea - spring wheat, barley and Austrian winter pea mix - reduced till grain and soybean'. Treatment 4 'summer cowpea- rye and vetch winter cover - conventional tillage' was changed to 'summer cowpea - spring wheat, barley and Austrian winter pea mix - conventional till grain and soybean'. We planted cowpea on 7 September 2017 at a seeding rate of 40 kg/ha at 7 inch spacing. Organic N-Dure inoculant was added to ensure inoculation. As planting of cowpea was done after receiving over twenty inches of rain from hurricane Harvey, there was plenty of moisture at the beginning, but no significant rain was received after planting. Cowpeas were incorporated on 7 November 2017 and plots were planted with winter cover crops. The treatment 2 was planted with Austrian pea at a rate of 55 kg/ha. Treatments 3 and 4 were planted with a mixture of spring wheat (72 kg/ha), barley (25 kg/ha), and Austrian winter pea (42 kg/ha). Approximately 70% of the mixture was wheat and barley and 30% was Austrian winter pea. Plots were rolled and crimped on 21 March 2018. Corn was planted on 22 March 2018 and population was set at 28,000 plants/acre. Aqua Power from Grow Organic was used as an organically approved pop-up fertilizer at a rate of 6 gal/acre. On 13 April 2018, corn was replanted following a plant count revealing subpar emergence numbers. The second planting was made at a population of 32,000 plants/acre. Seed maggots and wireworms played a major role in the need to replant. Sorghum was planted on 16 April 2018 at a population of 80,000 seeds/acre and soybean was planted on 18 April 2018 at a rate of 140,000 seeds/acre. Aqua Power was once again applied as a pop-up fertilizer. Chilean Nitrate was added as an in-season side dress fertilizer at a rate of 25 pounds of N/acre. All fertilizer applications were done the same throughout all blocks and crops, except for soybeans, which had no additional inputs after the manure application. Data collection was continued in second year as proposed in the project. Continuous GHG emission data was collected by integrating two gas analyzers in parallel (The LI-8100A multi-chamber system with a PICARRO G2408 GHG analyzer). The system allowed automated measurements at 60-minute intervals. Each chamber was programmed to close for 10-minute and the increase in gas concentration over that period was used to calculate GHG fluxes using the SoilFluxPro software (version 4.0.1, Li-COR Biosciences., Lincoln, NE). Hourly measurements were made from all four treatments of a main crop for 7-10 consecutive days. After that, chambers were moved to the next main crop. This data is being analyzed now. Considering large contrasts in weed densities observed in 2017 between the north and south sections of the experimental site, the plots were divided into two sections (high and low weed infested areas) and observations were carried out separately. Soil seedbank samples were collected during October 2017. Eight random 20 cm x 5 cm soil cores were collected in each treatment from north and south sections of plots. Samples were washed to determine weed species present and their densities. Prior to the first inter-row cultivation in treatment 4, summer annual weed seedling emergence and any remaining winter annual weed species were counted within each plot. Three one m² quadrats were randomly placed in each plot and the most dominant species (3-4 species) within that quadrat were identified, counted, and an estimate of percent ground was made for each species. A reduction in the number of species infesting the field was observed between the two study years, with 29 species in 2017 and 19 species in 2018. However, an increase in Johnson grass seedlings and ground cover was observed, with 42 and 86% ground cover of Johnson grass in 2017 and 2018, respectively. Activities are planned to reduce the Johnson grass population in the area. Late summer annual weed emergence was also observed after the harvesting of the cash crop and the establishment of the late-summer cowpea cover. Objective 2: Drs. Constance and Nair at Sam Houston State University developed a survey instrument to acquire data from the agricultural producers on their demographic data, current agricultural practices, and perceived barriers to adoption of organic farming. The survey instrument was discussed and fine-tuned in a meeting at Texas A&M University on 15 May 2018 attended by the PI, all Co-PIs, and graduate students working in the project. The finalized survey was then converted to an on-line survey instrument using Google Forms. The project team is currently working on completing a mailing list of producers in the targeted region. We will randomly select a sample from the list and administer the survey by the second week of September. This initial survey administration will be followed by three biweekly reminders to ensure higher response rate. We are also working with County Extension Agents in the focus areas to distribute the survey to the targeted population groups. Objective 3: Dr. Schnell has developed educational and outreach materials for training purpose. Topics covered in these training materials include certification process, plan development, seed, soil and fertility management, pest/disease management, organic integrity, and harvest/handling. Drs. Schnell, Rajan and Bagavathiannan are developing an extension article for publication in Fall, 2018. A popular article titled "Organic grain, soybean study establishes early production recommendations" was published through AgriLife Today on 22 November 2017. A project website, www.organic.tamu.edu, is currently under construction. **PUBLICATIONS (not previously reported):** 2017/09 TO 2018/08 1. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Samuelson S. L., R. Schnell, N. Rajan and M. Bagavathiannan. 2018. Evaluation of weed seedling emergence

and density in organic grain production systems under different management practices. Proc. Southern Weed Sci. Soc. 71:31. 2. Type: Conference Papers and Presentations Status: Published Year Published: 2017 Citation: Zapata, D., N. Rajan, K. D. Casey and R. W. Schnell. 2017. Diurnal greenhouse gas emissions under different carbon and nitrogen input from cover crops. Abstracts, ASA-CSSA-SSSA International Annual Meetings, October 22-25, Tampa, FL. 3. Type: Journal Articles Status: Published Year Published: 2017 Citation: Rajan, N., R. Schnell, M. Bagavathiannan, S. Nair, D. Constance, K.D. Casey, D. Zapata, J. Moreno and S. Samuelson. 2017. Transitioning organic grain and soybean cropping systems in Texas: Challenges and benefits. Abstracts, ASA-CSSA-SSSA International Annual Meetings, October 22-25, Tampa, FL. 4. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Rajan N., and D. Zapata. 2018. Greenhouse Gas Emissions from Soils Transitioning to Organic. Abstracts, Southern American Society of Agronomy Annual Meeting, February 4-6, Jacksonville, FL. 5. Type: Conference Papers and Presentations Status: Published Year Published: 2018 Citation: Schnell, R. 2018. Opening Plenary - Updates from Around the State. The Annual Texas Organic Farmers and Gardeners Association Conference, February 1-3, Georgetown, TX. 6. Type: Conference Papers and Presentations Status: Accepted Year Published: 2018 Citation: Zapata, D., N. Rajan, K. D. Casey and R. Schnell. Carbon and Nitrogen Mineralization of Cereal and Legume Cover Crop Residues in Organic Soils. Abstract accepted for presentation at the 2018 ASA and CSSA Meeting, 4-7 November, Baltimore, MD. 7. Type: Conference Papers and Presentations Status: Accepted Year Published: 2018 Citation: Pokhrel, P., N. Rajan, R. Schnell, and D. Zapata. Effect of Cover Crop Residues on Soil Organic Carbon Mineralization in an Organic Soybean Production System. Abstract accepted for presentation at the 2018 ASA and CSSA Meeting, 4-7 November, Baltimore, MD. 8. Type: Conference Papers and Presentations Status: Accepted Year Published: 2018 Citation: Zapata, D., N. Rajan and R. Schnell. Greenhouse Gas Emissions from Organically Managed Cropping Systems in Texas. Abstract accepted for presentation at the 2018 ASA and CSSA Meeting, 4-7 November, Baltimore, MD. 9. Type: Conference Papers and Presentations Status: Accepted Year Published: 2018 Citation: Zapata, D., N. Rajan and R. Schnell. Greenhouse Gas Emissions from Organically Managed Cropping Systems in Texas. Abstract accepted for presentation at the 2018 ASA and CSSA Meeting, 4-7 November, Baltimore, MD. 10. Type: Conference Papers and Presentations Status: Accepted Year Published: 2018 Citation: Moreno, J., R. Schnell, N. Rajan and M. Bagavathiannan. Impacts of Tillage and Cover Cropping on Organic Systems. Abstract accepted for presentation at the 2018 ASA and CSSA Meeting, 4-7 November, Baltimore, MD.

2016/09 TO 2017/08 What was accomplished under these goals? IMPACT: We have established the first organic grain and soybean cropping systems experiment in East-Central Texas. Through this project, we will address some of the critical needs of farmers and other stakeholders in Texas who plan to adopt organic farming. ACCOMPLISHMENTS: Objective 1: Conduct research and on-farm demonstrations in a partnership between scientists and stakeholders for greater understanding of the influence of tillage and cover cropping on greenhouse gas emissions, weed dynamics, water-yield relations, and soil health, and develop best management practices that optimize both agricultural profitability and ecosystem services in transitioning cropping systems (corn, grain sorghum, and soybean): We established the field study in September 2016 at the Texas A&M Research Farm (30°33'7.34" N, 96°25'32.96" W). The land was previously left fallow for several years (2006-2016). The experimental design is a randomized strip-split plot design with three replications. The rotation for main crops is soybeans-corn-sorghum. All three main crops are in rotation each year. The treatments under each main crop include: (1) Current practice, which uses primary and secondary tillage operations for pre-plant weed control, incorporation of manure and seedbed preparation; (2) Summer Cover Crop-No Till grain/soybean; (3) Summer Cover Crop - Fall Cover Mulch - No Till grain/soybean; and (4) Summer Cover Crop - Fall Cover Mulch - Conventional Till grain/soybean. We started the experiment by collecting baseline soil samples (depth) for soil fertility and initial weed seed bank estimation. Cowpea was planted as the summer cover crop in treatments 2, 3 and 4 planted on 9/23/2016 at a seeding rate of 40 kg ha⁻¹. Seeds were inoculated with N-Dure inoculant. For fall cover mulch, we planted a cover crop mixture of winter rye and hairy vetch. Cowpea was shredded on 11/17/2016 and planted to Rye/Vetch mixture (2.5:1 ratio) at 7" row spacing the following day at a seeding rate of 146 kg ha⁻¹. In treatment # 4, cowpea residues were incorporated by plowing before planting Rye/Vetch. Manure was applied in all plots on 3/3/2017 using a manure spreader at a rate of approximately 4,450 kg ha⁻¹. We integrated two gas analyzers with different capabilities to simultaneously measure major greenhouse gas (GHG) fluxes at the soil surface. The LI-8100A (LI-COR Biosciences, Lincoln, NE) system has eight long-term chambers, a multiplexer and an infrared gas analyzer for measuring CO₂. We integrated LI-8100A with a PICARRO G2408 GHG analyzer (Picarro Inc, Santa Clara, CA) for measuring CH₄, NH₃, and N₂O concentrations in addition to CO₂. Both analyzers were connected in parallel. The system allowed automated measurements at 30-minute measurements. Each chamber was programmed to close for 3-minute and the increase in gas concentration over that period was used to calculate GHG fluxes using the SoilFluxPro software (version 4.0.1, Li-COR Biosciences., Lincoln, NE). Half-hourly measurements were made from all four treatments of a main crop for 7-10 consecutive days. After that, the chambers were moved to the next main crop. A total of

11 measurement campaigns were conducted which covered the early-, mid-, and late- growing season periods of corn, sorghum and soybean. Objective 2:Determine the current level of cognitive understanding and related beliefs, attitudes, and opinions on transitioning to organic systems and create a model for educational and outreach activities: This will be initiated in Year 2 of the project. Objective 3:Develop an educational and outreach program for efficient transfer of project results to the various stakeholders and organize training efforts on the certification process, farm plan development, environmental benefits, and best management strategies while transitioning to organic production: This will be initiated in Year 2 of the project. **PUBLICATIONS (not previously reported):** 2016/09 TO 2017/08 1. Type: Other Status: Published Year Published: 2016 Citation: Texas A&M leading organic grain crop study. Popular article published in AgriLife Today. <https://today.agrilife.org/2016/10/21/texas-leading-organic-grain-crop-study/> 2. Type: Conference Papers and Presentations Status: Accepted Year Published: 2017 Citation: Zapata, D., N. Rajan, K.D. Casey and R. W. Schnell. 2016. Diurnal Greenhouse Gas Emissions Under Different Carbon and Nitrogen Input from Cover Crops. Abstracts, ASA-CSSA-SSSA Annual Meeting, 22-25 Oct., Tampa, FL. 3. Type: Conference Papers and Presentations Status: Accepted Year Published: 2017 Citation: Rajan, N., R. Schnell, M. Bagavathiannan, S. Nair, D. Constance, K.D. Casey, D. Zapata, J. Moreno and S. Samuelson. 2017. Transitioning Organic Grain and Soybean Cropping Systems in Texas: Challenges and Benefits. Abstracts, ASA-CSSA-SSSA Annual Meeting, 22-25 Oct., Tampa, FL. 4. Type: Conference Papers and Presentations Status: Accepted Year Published: 2017 Citation: Moreno, J., R. Schnell, M. Bagavathiannan, C. Neely and N. Rajan. 2017. Organic Farming Implementing Cover Cropping and Varying Tillage Practices. Abstracts, ASA-CSSA-SSSA Annual Meeting, 22-25 Oct., Tampa, FL.

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Research and Extension to Remove Barriers That Limit Transition from Conventional to Organic Maple Syrup Production

Accession No.	1010375
Project No.	VT-0077CG
Agency	NIFA VT.\
Project Type	OTHER GRANTS
Project Status	NEW
Contract / Grant No.	2016-51106-25717
Proposal No.	2016-06202
Start Date	01 SEP 2016
Term Date	31 AUG 2019
Grant Amount	\$469,740
Grant Year	2016
Investigator(s)	van den Berg,

NON-TECHNICAL SUMMARY

Although maple producers are paid a large premium for organic maple syrup and the product is currently in very high demand, less than 5% of U.S. maple operations are currently certified organic. Maple producers, certifying agents, and other stakeholders have identified two primary barriers which exist that deter producers from transitioning from conventional to organic maple production: a lack of empirical data to support tapping guidelines for certified organic maple production, and a lack of an effective certified organic defoaming agent for use in maple syrup processing. These factors pose significant risks of reducing crop value, and thus they both discourage producers from becoming certified organic, and can cause substantial financial losses for currently certified operations. The overall goal of this project is thus to conduct the research and extension outreach activities necessary to remove these barriers and increase the number of certified organic maple operations in the U.S. First, organic certifying agents specify guidelines for tree tapping practices that must be followed by certified organic maple operations, and that are aimed at ensuring that sap collection is sustainable in the long-term. However, the current guidelines are based on little scientific data on whether these practices actually result in the desired sustainable outcomes, and following them can result in significantly reduced yields and revenues for producers. The risk of reduced economic returns without a substantiated need supported by scientific data presents a significant barrier that deters producers from transitioning to certified organic maple production, and thus the first objective of this project is to collect the data necessary to support guidelines for sustainable tapping practices for certified organic maple production. Also, organic maple producers are required to utilize a certified organic defoaming agent for foam control during processing of sap into syrup, and most opt to use organic vegetable oils. However, because these products are not specifically formulated for this purpose, they exhibit poor foam control and contribute to the development of off-flavors that substantially reduce the value of the syrup produced. This presents a substantial risk of profitability reduction that deters maple producers from becoming certified organic, and thus the second objective of this project is to identify an effective certified organic defoamer for maple syrup production. To accomplish the project objectives and overall project goal, we will first conduct experiments to determine the volume of nonconductive wood generated by taphole wounds in maple trees, the impact of tapping on tree growth and health, and the sap yields from smaller diameter trees. These data will then be used in model analyses to develop and support guidelines for tapping practices required to ensure that organic maple syrup production sustains the growth and production of maple trees. We will also conduct a series of laboratory and commercial-scale experiments to identify an effective certified organic defoaming agent, and develop best practices for its implementation. Once the project's experiments are complete, we will conduct a variety of extension outreach activities to communicate project information and results to maple producers,

organic certifying agents, and other stakeholders throughout the maple-producing region of the U.S. to help remove existing barriers and encourage conventional maple producers to transition to certified organic maple production, including technical articles, a project website, presentations at maple industry conferences and meetings, and online seminars. These activities will help achieve the overall project goal of increasing the total number of certified organic maple operations in the U.S. In addition to numerous benefits to forest and tree health, ecosystem processes, food safety, and syrup quality, the achievement of this goal will also directly benefit producers by increasing the value of their syrup crops and net annual revenues. Thus, the outcomes of this project will ultimately help increase the competitiveness and economic sustainability of certified organic maple producers, as well as those transitioning from conventional to organic production.

OBJECTIVES

The overall project goal is to conduct the research and extension outreach activities necessary to remove existing barriers that limit transition from conventional to organic maple syrup production, and increase the total number of certified organic maple operations in the U.S. This overall goal will be met by accomplishing four primary objectives: Objective 1: Collect the data necessary to develop and support guidelines for tapping practices required to ensure that organic maple syrup production sustains the growth and production of maple trees and meets the NOP standard for Wild Crop Harvesting. Four supporting objectives will be accomplished to achieve this main objective: Determine the volume of nonconductive wood generated by taphole wounds in maple trees, Determine the impact of tapping and sap collection on tree growth rates and health, Determine the average sap yields attainable from smaller-diameter trees and whether the value of these yields balances production expenses, and Determine recommendations for the minimum diameter and tapping practices required to ensure that the growth and production of maple trees is sustained. Objective 2: Identify an effective certified organic defoamer for maple syrup production and best practices for its implementation. Two supporting objectives will be accomplished to achieve this main objective: Identify one or more defoaming agents that meet maple processing requirements and optimize rapid foam control with the quantity required, and Identify and develop best practices for the effective application of the identified defoamer(s) in maple syrup processing. Objective 3: Extension - Disseminate and communicate project information and the results of project research to maple producers and stakeholders throughout the maple-producing region of the U.S. Objective 4: Evaluation - Monitor progress and evaluate the achievement of project objectives, outcomes, and impacts.

APPROACH

To accomplish the project goal and objectives, first, experiments will be conducted to collect the data necessary to accomplish Objective 1, develop and support guidelines for tapping practices required to ensure that organic maple syrup production sustains the growth and production of maple trees. First, an experiment will be conducted in which trees of 4 size classes in stands representing each of 3 levels of site quality at 15 cooperating certified organic maple operations are tapped, and subsequently felled and segmented. Digital photography and image analysis software will be used to measure the volume of nonconductive wood (NCW) generated by each taphole wound. These data will be compiled and used to calculate the average volume of NCW generated by taphole wounds overall, and in trees of each size class and level of site quality. Analysis of variance (ANOVA) will be used to determine if significant differences exist in the volume of NCW generated between trees in each size class, and/or the level of site quality. A second experiment will be conducted to determine the impact of tapping and sap collection on tree growth rates and health. In each of 15 stands located in organic maple operations, 10 healthy sugar maple trees in each of 5 size classes that have not been previously tapped for sap collection will be selected. Beginning in Year 1, 5 randomly selected trees in each size class at each stand will be tapped annually for sap collection; the remainder of the trees in each size class will serve as controls. Beginning in the summer of Year 1, the diameter and tree health indicators of each tree will be measured annually. Data will be compiled and ANOVA used to determine if significant differences exist in the growth rates or tree health indices of tapped and untapped control trees overall, and within in each size class. A third experiment will be conducted to determine the average sap yields attainable from smaller-diameter trees. Ten healthy sugar maple trees in each of 4 size classes (4, 6, 8, and 10" dbh) in a single stand will be selected. During each production season, all trees will be connected to a standard maple vacuum system, tapped with a single standard maple spout, and the sap volume and sugar content from each tree will be measured throughout the production season. These data will be used to calculate the total volume of sap and syrup equivalent produced by each tree annually, and the overall mean and variation in sap and syrup yields for trees in each size class. Financial analyses will be conducted to determine the estimated net profit of sap collection from trees in each size class tested and thus evaluate whether sap yields from smaller-diameter trees are to result in net profits if included as crop trees. Finally, a model of the tapping zone of a maple tree will be used to determine recommendations for the minimum diameter and tapping

practices required to ensure that the growth and production of maple trees is sustained. Data from the first two experiments will be used to parameterize the model and conduct analyses to determine the tapping practices and conditions required for the proportion of NCW to remain at sustainable levels over time. The results of these model analyses will be analyzed in conjunction with other results and observations from the experiments (differences observed in growth rates of tapped and control trees, the profitability of sap collection from smaller-diameter trees, etc.) to determine recommendations for the minimum diameter and other tapping practices required to ensure tapping trees for sap collection results in sustainable outcomes. To accomplish Objective 2, identify an effective certified organic defoamer for maple syrup production and best practices for its implementation, first, a series of laboratory-level experiments will be used to evaluate the effectiveness of a variety of candidate certified organic defoaming agents using the ASTM standard test method for defoamers. The 2 agents which best meet maple processing requirements and optimize rapid foam control will then be used in subsequent experiments conducted with commercial maple processing equipment to confirm their efficacy in production-scale applications and actual processing conditions, and to determine best practices for the effective application of each defoamer in maple syrup processing. After these preliminary practices are developed, the defoamers and best practices will be pilot-tested in cooperating maple operations to confirm their efficacy and gather feedback to help refine and finalize best practices. In addition to recording their observations and experiences with the candidate defoamers and best practices, 3 syrup samples will be collected from each of the cooperating operations. The chemical composition of each sample will be analyzed to assess the quantity of defoamer or derivatives present in the finished syrup. Taste evaluations will also be conducted to determine if any defects in flavor or texture are detected in the syrup samples. The information and data obtained from producers in the pilot testing will be used together with the results of the previous experiments to refine recommendations for an effective certified organic defoamer for maple syrup production and best practices for its implementation. Once the experiments are completed, the information and best practices will be communicated to maple producers and stakeholders throughout the U.S. through a variety of efforts to help remove existing barriers and encourage and stimulate conventional maple producers to transition to certified organic maple production. A project website will be created that will serve as a primary hub for communicating project information to stakeholders. Presentations of the project information, data, recommendations, and best practices will be delivered by project team members to maple producers and stakeholders at meetings and conferences throughout the maple-producing region of the U.S. Three online seminars will also be presented in order to reach producers that are unable to attend live presentations. Project results and information will also be incorporated into a technical report which will be posted on the project website, and published in maple industry and organic agriculture publications. The overall goal of the project is to conduct the research and extension outreach activities necessary to remove existing barriers that limit transition from conventional to organic maple syrup production and increase the total number of certified organic maple operations in the U.S. Thus, the primary outcome of the project will be an increase in the number total number of certified organic maple operations in the U.S. The achievement of this outcome will be evaluated by measuring the number of conventional maple producers who become certified organic after receiving the project information. We will first collect email addresses from producers who receive the project information through project extension outreach activities (attend a presentation, download the technical article, etc.). We will then conduct follow-up surveys of these producers to determine how many of the conventional producers who received the project information have become certified organic after receiving the project information. Achievement of the primary outcome will also result in increases in the crop values and annual revenues of producers who transition from conventional to organic maple production. Thus, a secondary outcome of this project will be an increase in crop values and annual revenues of producers who transition to certified organic maple production. We will conduct additional subsequent surveys of producers to determine the total value of their annual syrup crops before and after organic certification, and the percentage change in the annual net revenue of their maple production operations.

****Progress**** 09/01/16 to 08/31/21

****Outputs**** Target Audience: The target audience served by this project consists of conventional and organic maple producers, organic certifying agents for maple syrup production, other maple industry members (equipment manufacturers, etc.), and maple Extension personnel throughout the maple-producing region of the U.S. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Nothing Reported How have the results been disseminated to communities of interest? Obj. 3: Extension - Results and information from this project, including guidelines for sustainable sap collection practices, and best practices for foam management in organic maple production, have been disseminated to the project's target audience through a variety of mechanisms. More than 30 presentations have been made at maple producer and industry conferences throughout the maple-producing region, and have reached more than 1,000 stakeholders directly. Additionally, recorded versions of these seminars posted on the Proctor Maple Research Center (PMRC) and UVM Extension YouTube channels have collectively been viewed more than 4,300 times to date. Technical articles outlining the results of the project's research have been published in maple industry publications, and two articles for peer-reviewed publications are in preparation. The guidelines for sustainable sap collection practices developed in this project have been incorporated into the tapping guidelines in the

forthcoming 3rd edition of the North American Maple Syrup Producers Manual, the primary English-language reference manual for maple producers. Results from this work have also been communicated directly to organic certifying agents. This outreach is ongoing and will continue. Obj. 4: Evaluation - A survey instrument was created and deployed to assess project outcomes and impacts to date. To date, 85% of responding certified organic maple operations indicated they have implemented at least one new best practice after receiving project information, and 30% percent indicated they have changed organic defoamer or defoaming practices. Of respondents who were not already certified organic, 22% indicated they are considering becoming organic after receiving project information. We expect these numbers to increase as outreach continues. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported **Impacts** What was accomplished under these goals? IMPACT: This project developed data-based guidelines for tapping practices required to ensure that organic maple syrup production sustains the growth and production of maple trees, and identified an effective certified organic defoamer and best practices for defoamer use in organic maple syrup production, removing two of the main barriers that limit transition from conventional to organic maple syrup production, helping to increase the total number of certified organic maple operations in the U.S and the economic and ecological sustainability of certified organic maple operations. The following activities were completed to achieve the project objectives and overall goal: Obj. 1.1: A study was conducted to quantify the volume of nonconductive wood (NCW) formed in response to taphole wounds in maple trees. 150 trees at 11 certified organic maple operations across VT were tapped with a standard taphole during the 2018 production season. Trees were subsequently felled and dissected into 2"-wide cross-sections. Each was photographed, and image analysis software used to quantify the volume of NCW generated by each taphole wound. Growth rings were measured to quantify the radial growth rate of each tree. The average volume of NCW generated in response to taphole wounds was 50.9 times (± 3.6) the volume of the taphole. There was no significant linear relationship between radial growth rate and the volume of NCW generated ($p > 0.7672$). Of note, 32 of the NCW columns were unusable because they interacted with the tree's central column of discolored wood (CCDW). The diameter of these trees was significantly smaller (mean = 6.7" ± 0.28) than trees for which tapholes did not interact with the CCDW (mean = 8.9" ± 0.26 , $p < 0.0001$). Obj. 1.2: An experiment was conducted to determine the impact of sap collection on tree growth and health at 15 organic maple operations across VT and NY. Plots were established in stands that had never been tapped for maple production. In each, 10 healthy trees in each of 5 size classes were selected. Half in each size class were assigned to the Treatment group, and half to the Control group. Beginning in 2018, Treatment trees were tapped annually for sap collection with vacuum, and Control trees remained untapped. The health indices and diameter of each were measured before tapping commenced and have been remeasured annually. To date, there is no significant difference in the growth rates of Treatment and Control trees. The experiment will continue as a long-term study to assess whether sap collection results in significant effects on tree growth or health over time. Obj. 1.3: An experiment to quantify the mean sap yields from trees of varying sizes near the current minimum diameter specified in tapping guidelines for organic maple production was completed. The total syrup yield from 48 healthy trees in 6 diameter classes (4-9") was quantified during the 2018 and 2019 production seasons under standard vacuum collection conditions. There was a direct linear relationship between tree diameter and yield, and average total production ranged from 0.11 (± 0.008) gallons of syrup equivalent per tree in 4" trees, to 0.42 (0.010) in 9" trees. Obj. 1.4: Data from Objs. 1.1-1.3 were used to determine recommendations for the minimum diameter and sustainable tapping practices. First, the mean volume of NCW generated in response to taphole wounds (Obj. 1.1) and the growth rates of tapped trees (Obj. 1.2) were used to parameterize a model developed by our team which estimates the proportions of conductive (CW) and nonconductive (NCW) sapwood in the tapped area of a tree over time. The model was then used to assess the growth rates and tapping practices required for trees of varying diameters to maintain a high level of CW (95%) over time. This threshold is considered sustainable both in terms of tree health and practical maple production and economics. The accumulation of large proportions of NCW is likely to disrupt water transport and can increase the likelihood of the development and spread of internal decay. It also increases the likelihood that existing NCW will be encountered when drilling a new taphole annually - this not only increases the risk of disease and decay, but also results in the development of substantially more NCW (double or more) than a wound made in CW. Further, tapholes drilled into NCW yield significantly less sap - an average of 75% less - than those drilled into CW. Thus, as NCW accumulates, consequences for the tree and the economics of maple production increase. Generally, with the growth rates observed in tapped trees in this study to date, trees in size classes from 8-14" are estimated to have sustainable quantities of CW over time when appropriate tapping practices are used. For trees with slower growth rates, in some cases tapping practices can be modified to achieve sustainable outcomes. However, in some cases growth rates will not be sufficient for sustainability with any modification of tapping practices, and in these cases practices to increase the growth rates of crop trees must be employed before sustainable tapping and sap collection is possible. Although the sap yields from trees smaller than 8" in diameter were not insubstantial (Obj. 1.3), the dynamics of the relationship between NCW, tree health, and sap yields render tapping trees in these smaller size classes not economically or physiologically sustainable in the long-term. First,

the quantity of CW in the tapped area of these trees is inherently smaller. Thus, NCW accumulates more rapidly in smaller trees, increasing to unsustainable levels in only a few years. Further, the crowns of many smaller trees are not in the main canopy and have lower radial growth rates than trees in the main canopy, further exacerbating the rapid accumulation of NCW and its consequences. Finally, there is a higher risk of taphole wounds in smaller trees interacting with the CCDW, resulting in substantially greater volumes of NCW. This further exacerbates the challenges of achieving sustainable outcomes in trees of these small size classes, from both tree health and economic perspectives. In conclusion, the results of this work indicate that a single minimum tree diameter is not an optimal approach to achieve sustainable outcomes in organic (or conventional) maple production. The appropriate minimum diameter and tapping practices are dynamic and determined by the growth rate and health of the tree. The recommendations developed in this work provide guidelines for producers to make decisions about the minimum tree diameter and tapping practices necessary to achieve sustainable outcomes based on assessments of the growth rates and health of their trees. Guidelines for implementing practices to encourage vigorous growth and health of crop trees in general, and in order to bring about conditions required for sustainable sap collection, are also provided. Although a strict minimum size is not prescribed, generally, trees less than 8" diameter are not recommended to be tapped due to the numerous inherent challenges to achieving economic or physiologic sustainability with trees in these size classes. These recommendations will be updated as needed as data from the study of the long-term impacts of tapping on tree growth and health become available.

Obj. 2: A series of pilot-scale evaluations and laboratory and commercial-scale experiments were conducted to identify a candidate agent that exhibited better efficacy than the current standard organic defoamer used in maple production (certified organic culinary vegetable oils) (van den Berg and Perkins 2020). Through this work a more effective certified organic defoamer for maple syrup production was identified, and best practices for its implementation created and communicated to producers and stakeholders.

Obj. 3: Extension - See "dissemination" Obj. 4: Evaluation - See "dissemination" **Publications** - Type: Conference Papers and Presentations Status: Other Year Published: 2021 Citation: Keys to maximizing long-term yields, River Valleys Maple Syrup Producers Association (online), November 2, 2021. - Type: Conference Papers and Presentations Status: Other Year Published: 2021 Citation: Proctor Maple Research Center research update (including sustainable tapping research), Vermont Maple Sugarmakers Association Board Meeting (online), October 6, 2021. - Type: Conference Papers and Presentations Status: Other Year Published: 2021 Citation: Early tapping and taphole longevity strategies, Dominion and Grimm Online Open House, April 29, 2021. - Type: Conference Papers and Presentations Status: Other Year Published: 2021 Citation: Tapping practices to optimize yields and sustainability, Dominion and Grimm Online Open House, April 28, 2021. - Type: Conference Papers and Presentations Status: Other Year Published: 2021 Citation: Tapping practices to optimize yields and sustainability and increasing production with red maple, The Ohio State University Maple Day (online), January 15, 2021. - Type: Conference Papers and Presentations Status: Other Year Published: 2021 Citation: Early tapping and taphole longevity strategies, The Ohio State University Maple Day (online), January 15, 2021. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: Fall tapping and taphole longevity strategies, University of Vermont Maple Extension webinar series, September 30, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: Tapping practices to optimize yields and sustainability, University of Vermont Maple Extension webinar series, August 19, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: Keys to high yield maple production and sustainable tapping practices, Ohio State University Maple Day, Middlefield, OH, January 25, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: Keys to high yield maple production and sustainable tapping practices, Ohio State University Maple Day, Fredericksburg, OH, January 24, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: Keys to high yield maple production and sustainable tapping practices, Ohio State University Maple Day, Fulton, OH, January 23, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: An effective defoamer for organic maple syrup production, The University of Vermont Extension Vermont Maple Conference, Brattleboro, VT, January 18, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: Tapping practices to optimize sustainability and yields, The University of Vermont Extension Vermont Maple Conference, Brattleboro, VT, January 18, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: An effective defoamer for organic maple syrup production, Addison County Maple Seminar, Middlebury, VT, January 11, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: UVM PMRC Research Update (including sustainable tapping practices research), Addison County Maple Seminar, Middlebury, VT, January 11, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2020 Citation: Tapping practices to optimize sustainability and yields, 2020 New York State Maple Producers Winter Conference, Syracuse, NY, January 4, 2020. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: An effective defoamer for organic maple syrup production, St-Hyacinthe Regional Maple Producers Union, Ormford, Quebec, December 11, 2019. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: An effective defoamer for organic maple syrup production, St-Hyacinthe Regional Maple Producers Union,

Sutton, Québec, December 11, 2019. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: UVM PMRC Research Update (including organic defoamer and sustainable tapping practices research), St-Hyacinthe Regional Maple Producers Union, Sutton, Québec, December 11, 2019. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: An effective defoamer for organic maple syrup production, North American Maple Syrup Council and International Maple Syrup Institute Conference, Duluth, Minnesota, October 23, 2019. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: Impact of tapping on trees and sustainable tapping guidelines, Lapierre Equipment Open House, Swanton, VT, April 27, 2019. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: Proctor Maple Research Center Research Update (including organic defoamer and sustainable tapping practices research), Dominion and Grimm Open House, St. Albans, VT, April 26, 2019. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: Impact of tapping on trees and sustainable tapping guidelines, Lapierre Equipment Open House, Swanton, VT, April 26, 2019. - Type: Book Chapters Status: Awaiting Publication Year Published: 2023 Citation: Perkins, T.D., van den Berg, A.K., Boutin, J., Childs, S., Wilmot, T.W. Chapter 6: Sap Collection. In North American Maple Syrup Producers Manual., 3rd ed. Perkins, T.D., van den Berg, A.K., Heiligmann, R.B. and Koelling, M.R., Eds. - Type: Conference Papers and Presentations Status: Accepted Year Published: 2021 Citation: Sustainable tapping guidelines for modern maple sap collection practices, Northern Hardwood Conference (virtual), June 15, 2021. - Type: Other Status: Published Year Published: 2021 Citation: van den Berg, A.K., Perkins, T.D., Bosley, W.T., Haynes, B.M., and Isselhardt, M.L. 2021. Wound response to taphole rejuvenation practices. The Maple Digest 60(2): 9-17. - Type: Other Status: Published Year Published: 2020 Citation: van den Berg, A.K. and Perkins, T.D. 2020. Identifying an Effective Defoamer for Certified Organic Maple Production. The Maple Digest 59(1): 8-23. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: UVM PMRC Research Update, (including organic defoamer and sustainable tapping practices research) Ontario Maple Syrup Producers Association Summer Conference, Kincardine, Ontario, July 18, 2019. - Type: Conference Papers and Presentations Status: Other Year Published: 2019 Citation: Proctor Maple Research Center Research Update(including organic defoamer and sustainable tapping practices research), Dominion and Grimm Open House, St. Albans, VT, April 27, 2019.

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