(ii) Executive summary and table of contents

1. Project title.

Taking tillage out of organic grain crop production with ecology, tools, and technology

2. Project type (see Part II C. of this RFA).

Integrated. Multi-Regional.

3. List the legislatively-defined goals being addressed (see Part I B. of this RFA), and provide an estimate of the percentage of effort/funds dedicated to each (sum of percentages should equal 100 percent). Note that the legislatively-defined goals are not the same as the FY 2018 program priorities.

Legislatively-defined goals addressed:

1) Facilitating the development and improvement of organic agriculture production, breeding, and processing methods. (70%)

2) Evaluating the potential economic benefits of organic agricultural production and methods to producers, processors, and rural communities. (10%)

6) Conducting advanced on-farm research and development that emphasizes observation of, experimentation with, and innovation for working organic farms, including research relating to production, marketing, food safety, socioeconomic conditions, and farm business management. (10%)

7) Examining optimal conservation, soil health, and environmental outcomes relating to organically produced agricultural products. (10%)

4. Indicate the approximate distribution of percentage of effort between research, education and extension.

Research (60%), education (15%), and extension (25%).

5. Program Staff and their role – include name, title, affiliation, address, and e-mail for PD(s), Co-PD(s) and Key Personnel. Please note all people listed as co-PD or co-PI should be eligible and able to fulfill the role of PD/PI for the project if the need arises. Review of Co-PD roles will be included in project review. Please be clear about Co-PDs vs sub-contractors.

Matthew Ryan (PD) – Associate Professor, Cornell University, 515 Bradfield Hall, Cornell University, Ithaca NY 14853, mrr232@cornell.edu

Erin Silva (co-PD) – Associate Professor, University of Wisconsin-Madison, 593a Russell Labs 1630 Linden Dr, Madison, WI 53706, emsilva@wisc.edu

Sarah Pethybridge (co-PD) – Associate Professor, Cornell University, 211 Barton Laboratory, 15 Castle Creek Drive, Geneva, NY 14456, sjp277@cornell.edu

Miguel Gomez (co-PD) – Associate Professor, Cornell University, 340D Warren Hall, Cornell University, Ithaca NY 14853, mig7@cornell.edu

6. A brief summary (2-3 sentences) describing the critical stakeholder needs addressed by the project and the project's long-term goals (provide cross-references to full descriptions in the narrative).

Organic grain and forage crop farmers in the Northeast and Upper Midwest need effective solutions to improve soil quality while addressing the crop production challenges associated with increased frequency and intensity of both heavy rain events and late summer drought conditions. Reducing tillage with rolled-crimped cover crops has potential, but **decision support tools and adaptive management are needed to optimize production and increase farmer adoption**. The long-term goal of this transdisciplinary project is to develop robust management strategies for reducing tillage in organic grain- and forage-based cropping systems and facilitate the transformation to a more sustainable agriculture that better balances tradeoffs between productivity, environmental impact, and farmer quality of life (*see page 1, Narrative*).

7. A brief summary (2-3 sentences) of the outreach plan proposed by the project (provide a cross-reference to the full description in the narrative).

To increase adoption of organic no-till crop production, our team will develop a comprehensive extension program that engages farmers and agricultural service providers including Cooperative Extension, educators at farmer organizations, crop consultants, and industry partners. Outreach strategies will include creating and posting short videos online, facilitating farmer-to-farmer learning at on-farm field days and conferences, developing an organic no-till production guide, and sharing research reports with farmers. In the last year of the project, we will host an **international summit on organic no-till production** that brings together farmers, researchers, extension educations, and other agricultural service providers (*see Obj. 4, Approach*).

8. A brief summary (2-3 sentences) describing potential economic, social, and other benefits (Who benefits and how will it be measured?).

Organic farmers in the Upper Midwest and the Northeast regions who grow grain crops as well as forages, and who have struggled with decreased profitability over the past several years due to challenges stemming from extreme weather, pest outbreaks, or weaker markets, will benefit from our project. We aim to help these farmers lower production costs by replacing soil tillage and cultivation with using mulch from cover crops, which decreases labor and fuel requirements. Multi-criteria assessment will be used to examine the performance of organic no-till crop production in terms of crop yield, yield stability, profitability, energy use, greenhouse gas emissions, pest suppression, and soil health (*see page 15, Approach*).

9. A brief summary (2-3 sentences) describing stakeholder engagement throughout the project (provide a cross-reference to the full description in the narrative).

This proposal was developed in close collaboration with organic grain crop farmers who serve as advisors (*see letters from Klaas Martens, Thor Oechsner, Luke Gianforte, Jim Miller, Mark Doudlah, and John Wepking*), and integrates feedback and insights from interactions with organic farmers at field days and workshops, as well as farmers' perspectives captured through targeted surveys. We will use a co-learning approach with organic farmers and engage them as research partners in this transdisciplinary project. Farmers will serve on an advisory board that will meet at least two times each year, participate in on-farm research, host field days, and contribute to farmer-to-farmer learning in workshops (*see page 7, Stakeholder Involvement*).

Table of Contents

Research and Extension Collaborators

1 – Mr. Fay Benson, Small Dairy Educator, Cornell Cooperative Extension of Cortland County

2 – Dr. Janice Degni, Area Extension Specialist, South Central NY Dairy & Field Crops Team

3 – Dr. Art DeGaetano, Director, NOAA Northeast Regional Climate Change Center

4 – Ms. Betsy Leonard, Organic Research Farm Coordinator, Cornell University

5 – Dr. Brian Luck, Assistant Professor of Biological Systems Engineering and Extension Specialist, University of WI-Madison

6 – Dr. Paul Mitchell, Professor of Agriculture & Applied Economics, University of WI-Madison

Organic Farmers

1– Mr. Kirk Arnold, Twin Oaks Dairy, Truxton, NY

2 – Mr. Mark Doudlah, Doudlah Farms & FarmRite Organics, Evansville, WI

3 – Mr. Luke Gianforte, Gianforte Farm, Organic Grain Farmer, Cazenovia, NY

4 – Mr. Dan Gladstone, Organic Grain and Forage Crop Farmer, Newfield, NY

5– Mr. Klaas Martens, Martens Farms, Penn Yan, NY

6 – Mr. James Miller, R&G Miller & Sons Farms, Columbus, WI

7 – Mr. John Myer, Myer Farms, Ovid, NY

8 – Mr. Thor Oechsner, Oechsner Farms, Newfield, NY

9 – Mr. Tony Potenza, Potenza Farms, Trumansburg, NY

10 – Mr. Tom Ryan, Ryan's Rose Organic Farm, Batavia, NY

11 – Mr. John Wepking, Meadowlark Organics, Ridgeway, WI

12 – OGRAIN 'Organic No-till Thursday' farmer sign-on letter

Organic Farming Organizations

1 – Ms. Victoria Ackroyd, Program Manager, Northeast Cover Crops Council

2 – Mr. Franklin Egan, Education Director, Pennslyvania Association for Sustainable Agriculture

3 – Ms. Bethany Wallis, Education Director, Northeast Organic Farming Association of NY

Industry Stakeholders

1 – Mr. Joe Bassett, President, Dawn Equipment and Underground Agriculture

2 – Mr. Kenneth Dallmier, President, Clarkson Grain Company

3 – Mr. Mac Ehrhardt, President, Albert Lea Seed

4 – Mr. Robert Gelser, President & General Manager, Once Again Nut Butter Collective, Inc.

5 – Mr. Anders Gurda, Farm Profit Program Director, Pipeline Foods

6 – Mr. Jake Munroe, Soil Management Specialist, Ontario Canada Ministry of Agriculture, Food and Rural Affairs

7 – Mr. Logan Peterman, Agricultural Data Scientist, Organic Valley/CROPP Cooperative

8 – Ms. Emily Reiss, Princicpal Technical Advisor, Kreher Family Farms

(iii) Outcome from previous awards

Agroecological strategies for balancing tradeoffs in organic corn and soybean production (ORG 2014-51106-22080). Cover crops are an important tool that organic farmers can use to suppress pests, manage soil nutrients, and reduce tillage. We conducted research in NY, PA, and MD and tested the effects of corn planting density on the performance of an interseeded cover crop. We evaluated ecosystem services from interseeded cover crops and quantified impacts on soil health as well as weed seed predation. Weed biomass was 46% lower in plots with interseeded cover crops compared to plots without (Youngerman et al. 2018). A separate experiment was conducted in NY only and focused on organic no-till soybean. We documented improved soil health and increased water infiltration in plots with rolled-crimped cereal rye compared to plots without a cover crop. **One of the main findings was that although soybean yield was high in no-till plots during the first year, no-till soybean yield was lower in the second year when rainfall in the spring was limited.** This outcome prompted a major change in extension programming focused on rolled cover crops for organic no-till and served as the basis for the transition to using adaptive management in organic no-till soybean production. In addition to several presentations at farmer workshops, field days, and scientific conferences, four articles were published in scientific journals (Jernigan et al. 2017, Crowley et al. 2018, Youngerman et al. 2018, and Youngerman et al. 2019). Two graduate students were supported at Cornell University and earned their MS degrees and two undergraduate students developed honors theses based on research associated with this project. A new course at Cornell University titled 'Principles and Practices in Certified Organic Agriculture' was developed and has been offered to students every spring since 2017. This course is the capstone of a new Organic Agriculture concentration within the Plant Science and Agricultural Sciences majors at Cornell University.

Building resilience in the northeast through double cropping and forage diversity (OREI 2016-25-8468). The Forage Intercropping for Resilience Experiment (FIRE) was established in fall of 2016 in NY, NH, and VT and terminated in 2019 when a uniformity trial was conducted. In this experiment we compared different levels of mixed intercropping, ranging from monoculture to polycultures consisting of multiple varieties of different forage species in both perennial and annual cropping systems. Results show that intercropping in perennial forage production can increase productivity and reduce variability; however, winter annual grass species outcompeted winter annual legumes and the effects of increased crop diversity were limited in annual forage production. Intercropping benefits in perennial production stem from different crops performing better at different times throughout the year. In order to realize benefits in annual systems, seeding rates of aggressive species need to be reduced considerably to avoid asymmetric competition. Information from this on-going integrated project was shared with organic farmers at over a dozen extension events this past year. Preliminary results were presented at scientific conferences and a review article focused on intercropping was published (Bybee-Finley & Ryan 2018). Two papers will be submitted in the coming month that focus on 1) selecting seeding rates for mixed intercropping systems (Bybee-Finley et al. In Prep), and 2) plant soil feedback and legacy effects from intercropping on weed-crop competition (Menalled et al. In Prep). Two PhD students at Cornell University and one PhD student at the University of NH have dissertation research programs focused on research associated with this project. A new course at the University of NH on agroecology was developed and will be offered to students starting in Fall 2020.

(iv) Introduction

Project Goal and Objectives. Our long-term goal is to develop robust management strategies for reducing tillage in organic grain and forage based cropping systems and facilitate the transformation to a more sustainable agriculture that better balances tradeoffs between productivity, environmental impact, and farmer quality of life. We will achieve our long-term goal through the following five objectives:

1. Test adaptive management strategies and new weed management tools for optimizing organic no-till soybean production.
2. Develop an organic reduced-tillage cropping system for grain and forage production that decreases soil disturbance across an extended sequence of crops in a rotation.
3. Conduct a series of on-farm research and demonstration trials to develop a real-time decision support tools for management of cereal rye in an organic no-till soybean phase.
4. Develop extension tools and activities to facilitate farmer-to-farmer learning, create on-line videos and a production guide and host an international summit on organic no-till production.
5. Train the next generation of farmers, agricultural service providers, and educators by developing course modules and experiential learning activities focused on organic no-till.

1. Critical Needs

The organic market, after experiencing double-digit growth for almost a decade, has now entered a new, more challenging era. Market changes and softening of pay prices, fraudulent grain imports, labor shortages, and increased frequency of extreme weather events (including both drought and floods) are increasingly slimming the margins of organic dairy and grain farms. For farms to better navigate these uncertainties and remain profitable into this new era, additional tools and strategies are necessary to lower production costs while increasing resilience in the face of more erratic and extreme weather.

Weed management is one of the primary challenges in organic grain production (*see letters from Klaas Martens, Thor Oechsner, Kirk Arnold, Jim Miller, Mark Doudlah, John Wepking, and Logan Peterman*). While systems-based strategies utilizing diverse crop rotations, cover crops, and cultivar selection are all components of a sound organic weed management plan, tillage and cultivation are often the primary weed management tools used by organic grain and forage crop farmers. Soil tillage and cultivation in organic crop production has several drawbacks including: 1) leaving the soil vulnerable to erosion from extreme rainfall events; 2) degrading soil structure and overall soil health; and 3) requiring additional labor and fuel (Peigné et al. 2007). Additionally, effective mechanical weed management relies upon time-sensitive field activities, which can be limited by wet spring weather. Data from the Wisconsin Integrated Cropping Systems Trial, a 30+-year comparison of organic and conventional grain management, shows that in years when timely cultivation practices were possible, organic yields were statistically equivalent to conventional yields, but in wet years when timely cultivation did not occur, organic yields were 25% lower than conventional yields (Posner et al. 2008).

No-till planting crops directly into rolled-crimped cover crops (Fig. 1) is an effective solution to problems accompanying reliance on tillage for in-season weed management. While many organic farmers are already using this approach with organic soybean no-till planted into cereal rye (*see WI survey data, page 10*), adoption remains challenging in more northern states with shorter growing seasons such as NY and WI, especially compared to NC, MD, and PA. Limitations to adoption include: 1) variability in soybean performance related to both poor cover crop growth and spring drought conditions where soil moisture is reduced from cereal rye growth, 2) challenges with integrating into existing crop rotation as cereal rye needs to be seeded relatively early in the fall to maximize cover crop growth and because it can be difficult to seed winter crops such as wheat or triticale after soybean is harvested in the fall, and 3) lack of information and farmer resources specific to these regions, which are characterized by a shorter growing season and a greater proportion of organic dairy, and thus have more opportunities to integrate forage crops into rotations.

Figure 1. Roller-crimper for mechanically terminating cover crops (left). Organic soybean that were no-till planted into rolled-crimped cereal rye (right).

Farmers who have adopted organic no-till within the soybean phase of their rotation have greatly reduced the amount of soil disturbance required for the production of this cash crop. However, soil tillage and cultivation are used for other crops in their rotation, which limit the benefits associated with continuous no-till. **Recent advances in agroecology, technology, equipment, and crop breeding have made organic no-till more feasible and created an opportunity to redesign cropping systems to regenerate soil health, decrease reliance on fossil fuels, and increase farmer prosperity and quality of life.**

2. Stakeholder Involvement

Project objectives arose directly from needs identified by organic farmers and industry partners (*see Rationale section, letters of support*). Research priorities and knowledge gaps were discussed at several organic farmer meetings [e.g., OGRAIN 'Organic No-till Thursday' discussion prior to the OGRAIN Winter Conference in 2018, 2019, and 2020 (*see farmer sign-on letter*, https://ograin.cals.wisc.edu/events/ograin-winter-conference/) as well as New York Certified Organic (NYCO) in 2018 and 2019 and Northeast Organic Farming Association of New York (NOFA-NY) in 2018 and 2020 (*see sign-on letter*)] and **we integrated these suggestions into this project proposal.** Stakeholders, including farmers, researchers, extension agents, industry affiliates, and other members of the organic farming community, will continue to be involved in this project by contributing to research, extension, and education activities.

Project advisory board. Organic farmers and other stakeholders will work with Co-PDs to review project progress, examine emerging results, and develop outreach and extension programs. The project advisory board, consisting of six organic farmers (three regional farmer representatives from each state) will meet at least two times each year, with the first meeting will be hosted by PD-Ryan at Cornell University in January 2021. We will work with our advisors to finalize management plans and data collection protocols. We will have a summer check-in meeting via videoconference in July 2021. Co-PD Silva at UW-Madison will host the second in-person meeting in January 2022, at which time we will discuss preliminary results and finalize plans for remaining outreach activities. We will rotate between videoconferences and in-person meetings in NY and WI for the remaining years of the project. Meetings in years 3 and 4 will focus on extension activities and preparing for the international summit in year 4.

On-farm research and farmer participation. Organic field crop farmers will participate in multi-site field research involving the collection of data related to cereal rye growth and biomass that will contribute to the decision support tool (*see Objective 4*). Additional farmers will be recruited to work with our team to field test the decision support tools that we will develop. Feedback from the farmers who test the decision support tools will be integrated and used to improve the tools. In addition to these trials, we will interview at least ten organic farmers and develop case studies to highlight successful farmers who are using organic no-till practices.

Farmer-to-farmer learning. Cooperating farmers will share their expertise, experience, and perspectives at workshops, field days, and conferences. Information generated from on-farm research will also be available in case studies and farmer videos that will be posted online through *eOrganic* and distributed to organic farmer groups such as the Organic Grain Resource and Information Network (OGRAIN), Northeast Organic Farming Association (NOFA), Northeast Organic Dairy Producers Alliance (NODPA), and the Cornell Dairy Initiative.

3. Summary of Knowledge and Past Activities

Organic agriculture in New York and Wisconsin. Organic agriculture is critically important for agricultural communities in NY and WI, which are national leaders in organic grain crop and dairy farming. In 2016, with 142,176 acres in NY and 128,772 acres in WI, these states rank #1 and #2 in terms of acreage of certified organic field crops (USDA NASS 2018). In 2016, with 471 certified farms in NY and 453 farms in WI, these states again rank #1 and #2 in terms of the number of organic dairy farms. Although our multiregional project is focused on these two organic grain and forage crop production hubs, farmers in adjacent states will also benefit from this project, especially organic farmers in MN, IL, IA, and PA.

Extreme weather. Organic farmers in North America are facing major challenges associated with extreme rain events which can cause severe soil erosion if they occur shortly after soil tillage. **For example, Thor Oechsner and Dan Gladstone received 5.5 inches of rain in 1 hour in June 2015, which resulted in devastating soil erosion and prompted them to reconsider their use of moldboard plow tillage.** Their experiences are congruent with a recent global analysis showing that heavy rain events have increased in frequency (**Fig. 2**, Papalexiou et al. 2019) and "100-year" rain events are occurring more often (Jeffery-Wilensky 2019). These trends are also consistent with climate change projections and are expected to persist (**Table 1**).

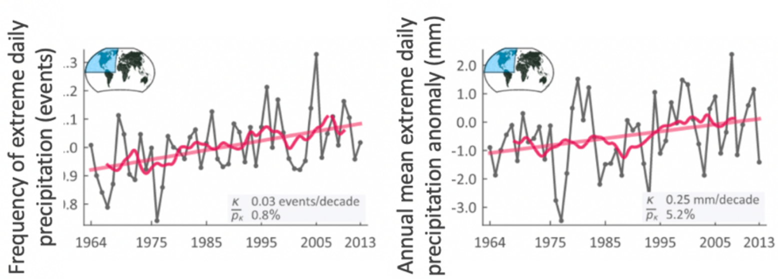

Figure 2. Mean trend values of frequency (events/decade) and magnitude (mm/decade) of extreme daily precipitation in North America from 1964–2013 (smooth line is the 7-year moving average). Modified from Papalexiou et al. 2019.

Table 1. Trends and projections for Wisconsin and New York (Modified from Lane et al. 2019).

x	Historical Data 1950–2006 for WI1 1970–2008 for NY2	Climate Change Projections 2050 (WI)1 2055 (NY)2
Temperature	• Increased 1.1–2.5 °F statewide in WI and 2.32°F in NY, with the greatest warming in the winter • Growing season has increased 12 days on average (WI) • Last frost comes earlier, and first frost comes later	• Likely to be 4–9 °F warmer overall in WI and 3.0–5.5 °F warmer overall in NY • Growing season projected to increase by 4 weeks • Milder winters • Heat waves are very likely to become more frequent, intense, and longer in duration
Precipitation	• Increased an average of 10% statewide in WI with greatest increases in winter and autumn. No significant differences in NY • Intense precipitation has increased in both frequency and magnitude	• Either too much or too little water overall in WI, with extreme events in spring and fall • More rain than snow in winter • Thermal heat index (temp and humidity) expected to increase in summer

Soil tillage in organic production. A foundational principle in organic agriculture—and a requirement in certified organic production—is to implement practices and manage soil in a way that maintains or improves soil health (Howard 2006). Paradoxically, soil tillage and cultivation are often used in organic grain crop production to manage weeds (Smith et al. 2011). **Although effective at killing weeds, soil tillage and cultivation can degrade soil health (Triplett et al. 2008) and make cropping systems vulnerable to extreme weather events (Sasal et al. 2010).** Soil tillage and cultivation are also labor intensive and require a large amount of on-farm fuel use (Mirsky et al. 2012). Cover crops are one solution that can suppress weeds, offset damage from soil tillage, and help regenerate soil health. In addition to competing with weeds while they are growing, cover crops can be managed and terminated to provide a surface mulch that suppresses weeds (Mirsky et al. 2012). Previous research has shown that organic no-till planted soybean can produce relatively high yields (**Fig. 1**) (Mirsky et al. 2013, Smith et al. 2011, Liebert & Ryan 2017). In research comparing different organic soybean production practices, rolled-crimped cereal rye cover crop plots had greater soil respiration and water infiltration than plots without a cover crop (Crowley et al. 2018). Improved soil pore structure is linked to greater resistance to flooding due to improved hydraulic conductivity (McGarry et al. 2000). This is relevant to organic farmers who are interested in improving resilience to climate change (Lane et al. 2019).

Organic no-till. Past research has documented a diverse array of economic and management benefits associated with organic no-till, including decreased input costs (Brown 2018, Silva and Delate 2017) and reduced labor requirements (Ryan 2010, Mirsky et al. 2012). However, **adoption of organic no-till soybean is constrained by inconsistency in weed suppression and soybean yields related to misguided management such as incompatible cover crop-cash crop combinations, inadequate cover crop growth, inappropriate equipment, and spring drought conditions where cereal rye growth limits soil moisture.** Additionally, integrating an organic no-till soybean phase into standard crop rotations can be difficult. Often the crop rotation needs to be redesigned to allow for: 1) early seeding of cereal rye in the fall, which is necessary to obtain adequate biomass for weed suppression, and 2) timely planting of winter annual cash crops, such as winter wheat, after soybean harvest. Further, even when organic no-till soybean phases are successful, tillage is still used in other phases of the rotation, which limits soil health benefits from reaching their full potential. Despite these challenges, **new opportunities with equipment, technology, and knowledge are enabling farmers to move from "rotational" no-till toward continuous no-till.** Agricultural engineers and equipment companies are recognizing the demand from organic farmers for innovative tools and are investing in their design and production. New equipment (e.g., inter-row mowers, weed zappers, weeding robots, and between-row crimpers) combined with existing equipment (e.g., high-residue cultivators) can help reduce the risk and inconsistency which limits adoption.

Incorporating resilience. Compounded with recent market and price challenges, increased occurrences of extreme weather in both the Upper Midwest and Northeast have stressed organic production even further. Organic dairy farmers, already struggling with low pay prices, are further threatened by ‘too wet’ or ‘too dry’ weather, which prevents planting, decreases yields, and strains their feed supplies. Designing crop rotations that can be nimble in response to ever-changing weather conditions will create added resilience required to allow for adaptation to this new reality. Diversifying feeding strategies through the incorporation of different organic grains and feeding forages (including sorghum, sudangrass, and ryelage) can enhance the ability to remain productive in the face of seasonal variation in weather conditions. Additionally, as mechanical weed management efficacy varies by soil moisture, designing crop rotations and alternative strategies that limit reliance on cultivation will build more resilience into the system.

4 and 5. Recently Completed Activities and Preliminary Data

Organic no-till production. PDs Silva and Ryan have each been conducting research in reducing tillage in organic cropping systems for over a decade, including no-till planting organic soybean and corn into rolled-crimped cover crops (Sayre 2003; Ryan 2010; Mirsky et al. 2009; Silva 2014; and Silva and Delate 2017). Together they published a comprehensive review of organic no-till corn and soybean crop production along with collaborators in France (Vincent-Caboud et al. 2019). **Research from both Ryan and Silva’s programs has shown that in most years, organic no-till soybean yields have not significantly differed from traditional tillage based organic soybean.** Co-PD Silva’s work has demonstrated gains in soil microbial activity, weed management, and savings in labor and input costs. PD-Ryan has shown lower fuel use and labor requirements (Ryan 2010) and increased soil health and water infiltration research in plots where soybean was no-till planted into rolled-crimped cereal rye compared to plots where tillage and cultivation were used (Crowley et al. 2018). Increased soil health and water infiltration suggests that organic no-till can be used to address challenges associated with extreme weather events including heavy rain and short-term droughts in mid to late summer, which are projected to increase as a result of climate change (**Table 1**, Hayhoe et al. 2008). **However, adaptive management is needed to avoid problems with soil moisture depletion from the cereal rye cover crop, which can occur under dry spring conditions and result in lower yield of organic no-till planted soybean compared to traditional tillage-based soybean** (**Fig. 3**).

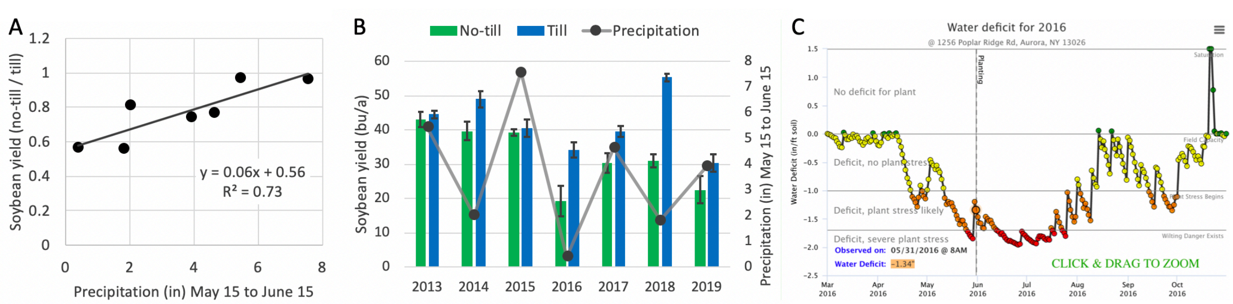

Figure 3. The yield gap between tillage-based organic soybean production and organic soybean no-till planted into rolled-crimped cereal rye is driven by soil moisture in the period just prior to, and immediately after, soybean planting (~June 1). **A)** Relationship between soybean yield (i.e., no-till yield/tilled yield) and precipitation from May 15 to June 15. **B)** Actual soybean yield in no-till and tilled soybean from experiments in central NY from 2013 to 2019 and precipitation from May 15 to June 15. **C)** Estimated soil water content in 2016 from the Climate Smart

Farming Water Deficit Calculator (http://climatesmartfarming.org/tools/csf-water-deficit-calculator/). The water deficit calculator and 10-day extended forecast will serve as the foundation for the decision support tools developed in this project (*see DeGaetano letter*).

On-farm organic no-till soybean. PDs Silva and Ryan have conducted a broad range of on-farm research focused on different aspects of organic no-till production. Specifically, Co-PD Silva conducted on-farm research on the use of different cover crops, cover crop planting dates, and equipment options, including different crimping and planting modifications in WI (Vincent-Caboud et al., 2019). In NY, on-farm research ranged from un-replicated strip trials to different replicated cover crops (cereal rye, triticale, and barley), and soybean seeding rates and dates. At Klaas Martens' farm (Penn Yan, NY), cereal rye and triticale provided improved weed suppression compared to barley in organic no-till planted soybean. Farmers Thor Oechsner and Dan Gladstone (Newfield, NY) were pleased with weed suppression in their trial of organic soybean planted into rolled-crimped cereal rye (*see letters of support*) in 2018. **In 2017, at the Scheffler Farm (Groton, NY) substantial soil erosion was observed in strips where soybean was planted into tilled soil, but no erosion in the strips in which soybean was no-till planted into cereal rye.** PD Ryan also have extensive experience with weed management in organic no-till cropping systems (*see Ryan biosketch*).

Innovating and advancing recommendations in organic no-till planted soybean and corn. Co-PDs Silva and Ryan have conducted extensive field research on increasing yields in organic no-till planted soybean. PD Ryan tested the effect of different planting rates on weed suppression and yield in organic no-till planted soybean. **Weed biomass decreased with increasing soybean planting rate, and partial returns based on seed costs and market value were greatest at 650,000 to 720,000 seeds/ha (i.e. double conventional recommendation) (Liebert et al. 2017). Co-PD Silva has been able to increase yields further by no-till planting soybean prior to cereal rye termination.** However, yield gains using this management strategy are highly dependent on weather conditions (e.g. soil temperature and moisture) (Silva and Vereecke, 2019), indicating that decision-support tools would be valuable to farmers. Additionally, using new equipment designed in partnership with Dawn Equipment-Underground Agriculture, Co-PD Silva's program has made significant headway in the design of organic no-till corn phases, using a combination of optimized planting equipment and in-row cover crop management which overcomes the historic bottlenecks of insufficient cover crop management and poor stands.

Rolled–crimped cereal rye suppresses white mold in no-till soybean and dry bean. Co-PDs White mold caused by the fungus, *Sclerotinia sclerotiorum* is amongst the most devastating and recalcitrant plant diseases worldwide, and results in substantial annual losses in crop production. White mold is difficult to manage due to long-lived primary inoculum (sclerotia), the broad host range of the fungus, and the absence of appreciable host resistance in many crops. Dry beans, soybeans, and sunflower are amongst the most susceptible crops to white mold. Pethybridge and Ryan conducted an experiment in Geneva, NY in 2017 and 2018 to test the effects of rolled-crimped cereal rye on white mold in organic soybean and dry bean. **Cereal rye mulch significantly reduced the incidence of white mold compared with the no cover crop control**. Similar results were observed in dry bean and in both crops in year 2 (Pethybridge et al. 2019). Including rolled-crimped cereal rye in a rotation can potentially exhaust inoculum in the upper soil profile and reduce the risk of loss due to disease in subsequent crops. **We will expand on this research and test the effects of different rolled cover crops on white mold suppression in sunflower, soybean, and dry bean in Activity 2c.**

Organic no-till wheat. In 2019, PD Ryan conducted an experiment at two sites in central NY to test the effects of no-till drilling wheat into rolled-crimped cover crops (**Fig. 4**). He compared five cover crops (sunn hemp, soybean, sorghum sudangrass, radish, and buckwheat) that were seeded on three dates in summer, which created a broad range of mulch conditions. Results showed that early- and mid-sown buckwheat produced high biomass that suppressed weeds, and resulted in greater wheat seedling density (329 plants/m^2) than the no cover crop control plots (235 seedling/m^2). Sorghum sudangrass and sunn hemp also produced high biomass and suppressed weeds, but wheat seedling densities were more variable than those in buckwheat. Although this wheat will be harvested for grain in 2020, our preliminary results suggest that we can use this same approach to establish winter cereal cover crops such as cereal rye. This would enable organic farmers to move away from the rotational no-till management that is currently used in organic no-till soybean and toward an extended sequence of organic no-till crops.

Figure 4. No-till drilling wheat into rolled-crimped sorghum sudangrass on September 28, 2019 (left). Wheat seed excavated from seed furrow after drilling (right).

(v) Rationale and Significance:

Organic farmer research priority. Organic farmers have identified that more research into successful no-till production is a priority. In his letter of support, farmer Klaas Martens of Penn Yan, NY, wrote, "*I am very interested in finding ways to further reduce tillage in organic farming*." He then goes on to describe his work with cereal rye cover crops and challenges with uneven stands and insufficient cover. Farmer Thor Oechsner, of Newfield, NY, wrote, "*I believe reducing tillage and working towards full no-till is the way we need to go. Not only for the rainfall reasons but because of the greenhouse gas emissions from tillage, the destruction of soil structure and biology.*" Additionally, our conversations with farmers at the NOFA-NY and UW-Madison's Organic Grain Resource and Information Network (OGRAIN) winter meetings (*see sign-on letter of support*), summer field days, and at recurring winter organic farmer advisory board meetings illustrate that **organic farmers are concerned about how much they till, but feel they are lacking in strategies and tools to change their practice**. Almost all the farmers on our organic advisory board named weed management as their biggest hurdle in reducing tillage (e.g., *see letter from Kirk Arnold of Twin Oaks Dairy*).

A recent farmer survey conducted by Dr. Silva's program at the University of WI-Madison documented specific priorities and past experience with reduced tillage in organic production. In 2019, 260 surveys were collected from farmers in IA, PA and WI. The results of this survey clearly documented the importance of reducing tillage on organic grain farms, with **83% of survey respondents citing tillage reduction as a priority for their operation**; only 17% of surveyed farmers reported that reducing tillage was not a priority on their farms. Among the respondents, 59% reported using reduced tillage practices at some point in their farming operation, and **one-third had used roller-crimping at some point in their organic farm**

management. The three most limiting factors to reducing tillage/cultivation were reported as "Access to appropriate equipment" (21%), "Need for knowledge/information of best practices" (17%) and "Other" (23%), wherein which the majority of farmers indicated lack of consistent weed suppression by the cover crop as the challenge.

The USDA National Organic Standards Board (NOSB) also listed "**Organic no-till practices for diverse climates, crops, and soil types**" among their 2019 research priorities (https://www.ams.usda.gov/sites/default/files/media/MSResearchPrioritiesFall2019.pdf). However, despite this need by both organic farmers and the NOSB, **OREI has not invested in funding a new organic no-till grain research project since 2014.**

Priorities and their relationship to our objectives

1) *Conduct advanced on-farm crop, livestock, or integrated livestock-crop research and development that emphasize observation of, experimentation with, and innovation for organic farms, including production, marketing, and socioeconomic considerations.*
We will conduct advanced on-farm research and field experiments at university research stations focused on improving the success of no-till organic agriculture guided by our advisory board of organic farmers. Our project is transdisciplinary and we will work with organic farmers, Extension educators, and researchers outside the field of agronomy to meet our project goals and objectives. We will examine the socioeconomic factors that may influence adoption of no-till organic management. We will identify factors that reduce yields in organic no-till production and develop tools to help producers monitor the likelihood of success for a given season of no-till management. **Economic analyses will be conducted on all management practices and cropping system rotations in this project.**

2) *Develop and demonstrate educational tools for Cooperative Extension personnel and other professionals who advise producers on organic practices.*
Our team has a record of excellence in outreach and extension activities. This project will capitalize on the vibrant farmer-industry-researcher network created through Co-PD Silva's Extension program (OGRAIN) and the tight-knit relationships between Cornell researchers and their existing organic farmer advisory board. In addition to advising, organic farmers will evaluate and assist in the development of extension and education products. **We will develop an online suite of adaptive management tools to create a decision support system that provides real-time, site-specific management recommendations for organic no-till soybean production that are delivered directly to subscribed farmers.**

5) *Explore technologies that meet the requirements of the National Organic Program (NOP) and protect soil, water, and other natural resources.*
We will improve weed management in organic no-till production and develop best management practices that will protect soil health and reduce erosion. We will quantify the effects of no-till management on crop performance, soil health, weed and disease suppression, and profitability. We will explore the efficacy and safety of new weed management techniques like interrow mowers and weed zappers. Farmers have expressed interest in these technologies including Luke Gianforte, who is "*interested in the innovative weed management technologies that I understand would be part of this project*". Other farmers on our advisory board are already investing in new weed management equipment, including Thor Oechsner who in 2019 purchased a new camera guided cultivator for precision interrow cultivation. Emily Reiss (Kreher Family Farms, NY) and Mark Doudlah (Doudlah Farms, WI), who both recently purchased electric weed zappers, will be assisting us with learning how best to use this new tool (*see letters of support*).

8) *Develop new undergraduate and/or graduate curriculum for organic agriculture.*
As part of this transdisciplinary project, PDs Ryan and Silva will develop new curriculum for courses on organic agriculture at Cornell University and the University of WI-Madison to train the next generation of students about organic no-till crop production. Experiential learning opportunities for students will include hands-on participation in crop and weed biomass data collection and field trips to local farms where no-till practices are being demonstrated.

vi) Approach:

1 and 2. Activities and methods for each objective

Our approach builds on our success with no-till planting organic soybean into rolled-crimped cover crops and involves research to optimize this system (**Fig. 5**). We will expand beyond soybean and develop tools and strategies for managing other crops as part of a **complete organic no-till system.** We will co-learn with organic farmers as they conduct their own research and development, and new information generated in this project will be integrated into undergraduate curriculum and distributed through direct farmer-to-farmer learning, presentations at field days, workshops, and an international summit.

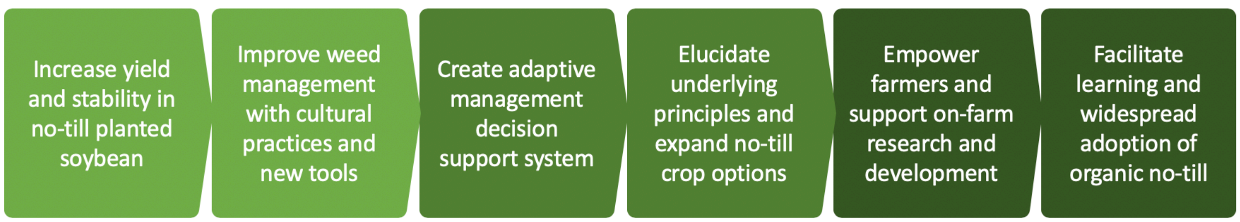

Figure 5. Conceptual model showing progression of objectives toward our project goal.

Objective 1) Create a suite of adaptive management strategies and test new weed management tools for optimizing organic no-till soybean production.

Background. Soybean can be successfully no-till planted into rolled-crimped cereal rye. Previous research has shown that 1) rolled crimped cereal rye can provide effective weed suppression when high cereal rye biomass is achieved, and 2) this system can produce yields that are comparable to traditional tillage-based organic soybean production in most years. Mirsky et al. (2012) identified that 8000 kg/ha was needed for weed suppression. Although that level of cereal rye biomass can be readily achieved in MD and NC, lower cereal rye biomass is common in the Northeast and Upper Midwest. Moreover, concerns about sole reliance on cover crop mulch for weed suppression and the inability to manage weeds that are not suppressed has been cited by farmers as a critical limitation preventing greater adoption of organic no-till soybean. Farmers need new tools and strategies to manage weeds if cereal rye biomass is insufficient.

Delaying soybean planting until early June when the cereal rye cover crop reaches anthesis can be problematic in the northern tier of the US. Rolling cereal rye too early or too late can lead to incomplete termination or mature seed production. In experiments that compared different soybean planting dates in traditional organic systems, early planting has consistently resulted in greater soybean yield. In an experiment in PA, rolling too early or too late led to volunteer rye in the subsequent wheat crop (Keene et al. 2017). In that experiment, soybean was harvested, plots were tilled, and wheat was drill-seeded. However, this typically results in a very late planting date for wheat. Small grain establishment after soybean harvest has been challenging in NY, especially in years with wet fall conditions such as 2018. An alternative approach is to no-till plant soybean as soon as the soil has reached the minimum temperature for rapid germination and growth, before cereal rye can be effectively terminated, and manage to facilitate self-seeding. This research builds on work done by co-PD Silva in WI where soybeans are no-till planted into a standing cereal rye cover crop at the boot stage, and then the cereal rye is terminated by rolling-crimping over the emerged soybean seedlings when the cereal rye reaches 50% anthesis. This allows farmers to plant 2-3 weeks earlier than the typical recommendations for organic no-till systems at 50% cereal rye anthesis. While increased yields have been reported using this system (Silva and Vereecke 2019), cool and wet conditions after planting can reduce soybean stands and yields compared to the standard approach of no-till planting at 50% cereal rye anthesis.

Activity 1a. Self-Seeding Cereal Rye in Organic Soybean Experiment

Limitations addressed:

- Current organic no-till recommendations call for delayed soybean planting, limiting yield potential and willingness to adopt among organic farmers.
- Rolling cereal rye prior to 50% anthesis will result in incomplete termination and volunteer cereal rye seedlings that do not elongate or compete with soybean.
- Soybean harvest is often late in the season, preventing farmers from establishing wheat, triticale, or other winter cereals.

Hypotheses:

1. No-till planting soybean early combined with a late relative maturity soybean variety will result in greater yields than the standard approach of no-till planting an early relative maturity soybean variety when the cereal rye is at 50% anthesis.
2. Cereal rye seedlings growing with soybean will not reduce soybean yield or interfere with soybean harvest compared with soybean without cereal rye seedlings.
3. Ryelage yield and forage quality of self-seeded cereal rye will not differ from cereal rye that is interseeded into soybean planted in tilled soil.

Experimental design. The Self-Seeding in Organic Soybean Experiment will be initiated in September 2020 on certified organic land at Cornell and UW Agricultural Research Stations. The field experiment will be repeated each year in a different field at both sites for a total of 6 site-years. The experiment design will be a split-split-split randomized complete block with two levels of four different factors:

1) Tillage system (rolled cover crop vs. tillage-based)
2) Soybean planting date (early vs. late)
3) Relative maturity of soybean variety (e.g., RM group 3 vs. RM group 1)
4) Cover crop management (self-seeded/interseeded vs. none)

The tillage system factor will compare rolled cereal rye with cereal rye that has been terminated with tillage prior to stem elongation. The soybean planting date treatments will compare two contrasting strategies; planting based on soil temperature (54°F) vs. planting based on when the cereal rye can be effectively terminated (early anthesis - Zadok's stage 61). In order to understand the full yield potential of planting soybean at different times, we will compare two different varieties of soybean that vary in their relative maturity grouping. We expect that cereal rye termination efficacy will vary by planting date in the rolled cover crop plots. Cereal rye that survives rolling at the early planting date will be either mowed with an inter-row mower (self-seeded) or left unmanaged (none). We will interseed cereal rye into the soybean plots in the tillage-based plots at 3 bu/A on the same day as inter-row mowing to evaluate potential interactions between tillage systems and cover crop management. Inter-row mowing will also be used to manage excessive growth of cereal rye seedlings that might interfere with soybean harvest, if needed. Individual plot sizes (experimental units) will be 20 ft × 100 ft. Cereal rye will be planted in the fall at a rate of 3 bu/A after harvesting corn for silage, with planting occurring prior to October 1 as per University recommendations. Soybean will be planted at the appropriate soil temperatures or rye growth stages at a rate of 250,000 seeds/A. As our preliminary data suggest (**Fig. 2**), dry spring conditions appear to exacerbate the yield gap between tillage systems. Therefore, in order to maximize the value of this experiment, we will implement irrigation split-block treatments using self-propelled irrigation reels if the is a water deficit and potential for plant stress. **The irrigation treatment and the experiment in general will be used to evaluate and refine decision support tools developed in Objective 3.**

Data collection. We will measure soil temperature (Watchdog data loggers) and soil moisture (neutron probe) continuously in rolled cover crop and tillage-based plots to better understand weed suppression and competition. Ground cover of cereal rye will be measured using Canopeo (Patrignani and Ochsner 2015) (**Fig. 6**). Protocols and sampling methods will be similar to those used in previous research (Silva 2014; Liebert & Ryan 2017). We will use 0.5 m^2 quadrats to quantify cereal rye biomass, cereal rye volunteer seedling density, weed biomass, soybean density, and soybean biomass. We will also quantify soybean yield components and yield using a plot combine, and biomass and forage quality of cereal rye in the following spring. Forage quality parameters, including crude protein, acid detergent fiber, neutral detergent fiber (NDF) and NDF digestibility, will be determined (DairyOne, Ithaca NY). We will track costs and report on profitability of different treatments with analyses conducted by agricultural economists at UW-Madison (supervised by Dr. Mitchell) and Cornell University (Co-PD Gomez).

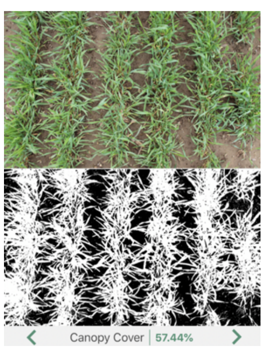

Figure 6. Cereal rye in spring prior to stem elongation: raw image (above); black and white image (below) from Canopeo, which estimated ground cover to be 57.44%. This tool will be used as part of the adaptive management decision support system for organic no-till soybean.

Activity 1b. Supplemental Weed Management in Organic No-till Soybean Experiment

Limitations addressed:

- Organic no-till works better in fields with small populations of perennial weeds and small soil weed seed banks.
- Inconsistent weed suppression in organic no-till soybean limits widespread adoption.
- Lack of research on equipment to manage break-through weeds and most effective practices to integrate these tools into different cropping systems.

Hypothesis:

1. Weed biomass will be lower with inter-row mowing and electric weed zapping than high-residue cultivation in organic no-till soybean.
2. Efficacy of high-residue cultivation, inter-row mowing, and electric weed zapping will vary by weed species and functional groups (e.g., monocots and perennials), resulting in different weed communities among treatments.

Experimental design. The Supplemental Weed Management in Organic No-till Soybean Experiment will be initiated in September 2020 by seeding cereal rye in certified organic land at Cornell and UW Agricultural Research Stations. The field experiment will be repeated each year in a different field at both sites for a total of 6 site-years. The experiment will be designed as a split-plot randomized complete block with four treatments: 1) Standard management (rolled-crimped cereal rye alone); 2) High-residue cultivation, 3) Inter-row mowing, and 4) Electric weed zapper (**Fig. 7**). Each main plot (40 × 120 ft) will be split to evaluate weed management efficacy under ambient weed populations and supplemented weed seed bank conditions. Cover crop and soybean planting will occur in a single pass operation at cereal rye anthesis as described above. Supplemented weed seed bank conditions will be created by spreading locally collected seeds of dominant weed species at each site at a rate of >3000 seed/m (*see Nord et al. 2012*).

Figure 7. Supplemental weed management tools that will be compared: a) high-residue cultivator, b) inter-row mower (R-Tech Industries Ltd.), and c) electric weed zapper (https://www.youtube.com/watch?v=gTSn8gDEheY).

Data collection. Quadrat sampling (0.5 m^2) will be used to quantify cereal rye cover crop biomass, weed density and biomass of individual species, and soybean density and yield components. Weeds will be characterized as cool-season broadleaf annuals, warm-season broadleaf annuals, cool-season grass annuals, warm-season grass annuals, broadleaf perennials, and grass perennials (*see methods described above under Activity 1a*). We will also conduct a partial budget analysis to evaluate the profitability of different weed management practices. Co-PD Gomez has extensive experience with economic analyses and will work with the project postdoc and graduate student on the partial budget analysis.

Objective 2) Develop an organic reduced-tillage cropping system for grain and forage production that decreases soil disturbance across all crops in a rotation.

Background. Soybean and corn are the most common crops that organic farmers no-till plant into rolled-crimped cover crops, due to their large seed size (Vincent-Caboud et al. 2019). While no-till planting organic soybeans is accessible to farmers, they often plant other crops into tilled soil. Some short-term benefits arise from using no-till methods rotationally (e.g., decreased labor and fuel use, increased protection from soil erosion) but many other benefits associated with no-till management manifest over a longer period (e.g., increased soil organic matter and enhanced water infiltration from preferential flow channels) (Aziz et al. 2013). Thus, the need remains to develop strategies for growing other organic grain crops without using soil tillage. Having a more diverse set of cash crops that can be grown using organic no-till methods is the first step toward transitioning to continuous organic no-till crop production.

Currently, organic no-till soybean (and corn) production involves establishing winter cover crops in soil that has been tilled. Instead of soil tillage, we will evaluate the effect of rolling down smother cover crops (e.g., sorghum sudangrass and buckwheat) prior to establishing winter cover crops and winter cereal cash crops. We aim to elucidate underlying principles that drive plant-soil feedbacks and agroecosystem productivity. As Klaas Martens (organic grain crop farmer in Penn Yan, NY) has stated, "*each crop should be grown after its most suitable predecessor*" (Martens 2018). Biological processes that drive agroecosystem productivity are influenced differently by different crops. For example, various cover crops (e.g., cereal rye and hairy vetch) can affect nitrogen availability differently. Cover crops that are in the same plant family as the subsequent cash crop might spread disease or insect pests. Allelopathy is another factor that can affect compatibility of cover crops with cash crops. We will explore nutrient legacies, allelochemicals, and the impacts on pests and beneficial organisms.

Activity 2a. Reduced-tillage Rotation Experiment

Limitations addressed:

- Certain soil health benefits found in continuous no-till cropping systems are not realized in rotational no-till systems.
- Previous research has failed to develop and demonstrate a complete system with crop rotation options for an extended sequence of organic no-till production.

Hypotheses:

1. An extended sequence of organic no-till crop production can be as profitable as traditional tillage-based organic production if weed populations are adequately controlled.

Experimental design. The Reduced-tillage Rotation Experiment will be initiated in September 2020 on certified organic land at Cornell and UW agricultural Research Stations. This experiment will strive towards a viable, continuous organic no-till crop rotation by building upon existing organic no-till management research of summer annuals, grains, and winter annual cereals. This continuous organic no-till crop rotation will consist of linking together established rolled-crimped system crop couplets of a) cereal rye-soybean, b) buckwheat-winter wheat and c) hairy vetch-corn by employing cultural weed management tactics, utilizing no-till seeding equipment, reducing weed seed rain via strategic mowing & forage harvests, exploiting cover crop competition and biology, and implementing innovative weed management tools. The field experiment will continue at each site until the fall of 2023. Each experimental unit will be split to evaluate the effect of weed competition on crop yield and profitability. Split plot treatments will compare 1) standard management and 2) supplemental management and hand weeding to prevent weed competition and weed seed additions.

Data collection. Over the course of the project, we will collect soil samples from each experimental unit and quantify changes in 1) soil health indicators (Comprehensive Assessment of Soil Health) and 2) the soil weed seed bank. Quadrat sampling (0.5 m^2) will be used to quantify cover crop biomass, weed density and biomass of individual species, crop density, and crop yield, as described above in Objective 1. We will track expenses and labor associated with supplemental weed control and hand weeding, and conduct a partial budget analysis to evaluate the profitability of the different phases of the rotation with economists Gomez and Mitchell.

Activity 2b. New Crops for Organic No-till Experiment

Background. We will compare production across several winter and summer cash crops that are no-till planted into rolled-crimped cover crops. This work will give farmers more flexibility when designing no-till crop rotations, facilitating the adoption of organic no-till. This experiment will also serve to elucidate underlying principles relative to cover crop and cash crop complementarity. Farmer Klaas Martens states ***"each crop should follow its most suitable***

predecessor in a rotation so that the vigor of the crop alone suppresses the growth of weeds and helps the crop resist pests". We aim to explore plant-soil feedbacks, nutrient legacy effects, and other mechanisms that might affect crop performance and then use this information to develop management guidelines.

Limitations addressed:

- A theoretical framework for understanding the complementarity between cover crop and cash crop species used in organic no-till is lacking, which has limited advances and application of the rolled-crimped cover crop system.
- Current research and extension materials focus on no-till planting corn and soybean into rolled-crimped winter cover crops, and very little information is available on organic no-till management of winter annual cash crops, hindering adoption of continuous no-till.

Hypotheses:

1. Complementarity between cover crop and cash crop species is governed by nitrogen availability, allelopathy, and disease susceptibility.

Experimental design. This experiment will be conducted at the Cornell and UW Agricultural Research Stations. Using a gradient of crop species representing different plant families that have beneficial traits with respect to management and market options, we will examine biotic (pests, cover crop growth, etc.) and abiotic (soil moisture, soil nutrient, temperature, etc.) factors that affect cash crop establishment, growth, productivity, and profitability. We will use a split-block RCBD with cover crop as the main plot factor and cash crop as the sub plot factor. The experiment will involve two separate sections, one for winter annual cash crops and another for summer annual cash crops (**Table 2**). A no cover crop control will also be included in both sections. Each section of the experiment described below will compare 25 treatments (5 cover crops × 5 no-till crops) and will include four blocks (100 plots in each section). Each plot will measure 30 × 60 ft. All cash crops will be planted on the same dates across the cover crop treatments using seeding rates that are appropriate for each crop based on recommendations and feedback from our organic farmer advisory board. We will target the first week of September for planting winter cash crops and the first week of June for planting summer cash crops.

Winter cover crops	Summer cash crops
Hairy vetch (HV)	Tofu soybean
HV x CR	Dry bean
Cereal rye (CR)	Flint corn
Canola	Grain sorghum
Tillage control	Confectionary sunflower
Summer cover crops	**Winter cash crops**
Sorghum sudangrass (SS)	Hard red winter wheat
SS x SH	Cereal rye
Sunn hemp (SH)	Hairy vetch*
Buckwheat	Winter pea
Tillage control	Canola

Table 2. Treatments in the New Crops for Organic No-till experiment. Crops on the right will be no-till planted into cover crops listed on the left in a full factorial. *Hairy vetch (a cover crop) will be no-till drilled into rolled-crimped cover crops.

Data collection. Expenses and labor will be tracked in each treatment and assessed along with crop yields to calculate profitability. Prior to grain harvest, we will evaluate the density and biomass of each weed species within a 0.5 m^2 quadrat in each experimental unit. Weed community structure will be assessed through multivariate analysis (e.g., nonmetric multidimensional scaling, PERMANOVA, indicator species analysis). Structural Equation Models (SEM) will be used to evaluate the relative contributions of nutrient availability, allelopathy, and phylogenetic relatedness.

Activity 2c. Suppressing* white mold *in Soybean, Sunflower, and Dry Bean

We will test the effect of rolled cover crops on white mold in several of the main crops (soybean, sunflower and dry bean) within Activity 2c at the Research North facility of Cornell AgriTech at the NY State Agricultural Experiment Station, Geneva, NY. This field is transitioning to certified organic production and has been uniformly inoculated with *S. sclerotiorum* for six consecutive years. The experiment will be repeated twice in different positions of the field over the course of this project.

***Carpogenic germination of* Sclerotinia sclerotiorum.** The effect of rolled cover crop on *S.sclerotiorum* apothecia will be tested in two complementary approaches in each of the main crops. First, we will monitor the number of apothecia produced in two pre-marked 1-m transects within the center rows of each plot. The number of apothecia will be counted at 3-day intervals from pre-flowering to 2 days prior to harvest. In addition, eight sclerotia conditioned in the laboratory (Pethybridge et al. 2015) will be placed in sand within each of six pots/plot (three in each of the two center rows). We will count the number of apothecia produced within these pots and use these data to verify disease incidence.

Sclerotinia sclerotiorum *ascosporic inoculum density.* The effect of rolled cover crop on release of *S. sclerotiorum* ascospores into the main crop canopies will be quantified using the blue-plate technique (Ben-Yephet & Bitton 1985). This will involve exposing 90-mm petri plates containing semi-selective media to passively intercept airborne fungal spores. The plates will be placed 30 cm above the soil surface at approximately 45° facing the prevailing winds for 3 h in the morning. New plates will be placed daily from pre-flowering to 3 days before harvest. Exposed plates will be evaluated at 72 h intervals. The mean number of colony forming units for each treatment will be estimated from the number of airborne ascospores on each sampling date.

White mold incidence. To quantify the efficacy of the cover crop treatment on disease incidence, white mold will be assessed in two center rows of each plot at the end of flowering and at harvest. Disease assessments will be altered according to each main crop (e.g. in sunflower, we will capture both stem rot and flower blight) thus assessing both disease phases. For the leguminous crops, the incidence of white mold on pods and plants will be evaluated.

3. Conduct a series of on-farm research and demonstration trials to develop real-time decision support tools for management of cereal rye in an organic no-till soybean phase

On-farm research. Using a co-learning approach, we will conduct a series of research and demonstration trials at collaborating organic farms in the Upper Midwest and Northeast to **evaluate adaptive management strategies**, **develop decision support tools**, and refine management practices and strategies tested in Objectives 1 and 2. On-farm research will focus on timing of no-till planting soybean and other cultural weed management practices in addition to testing new weed management tools, including inter-row mowing and electric weed zapping. Additional trials to explore no-till planting other crops, including wheat, sunflower, and dry bean, will also be conducted based on farmer interest. All on-farm research and demonstration trials will be done on certified organic land or land that is in transition to organic certification. Treatment details will be developed with farmer participants who serve on our advisory board. Experiments may vary by state and will be designed to answer questions that arise during our advisory board meetings. This flexibility will ensure that our research is building on successes and insights that we develop through this project. The experimental design will be replicated strip plots. Additional research and extension activities will focus on the following four sub-objectives related to developing adaptive management decision support tools and packaging these tools as a system:

1) Collect on-farm data from organic grain and dairy farms across the Upper Midwest to further improve the cereal rye biomass prediction model of Mirsky et al. (2009).
2) Create a beta version of an online **decision support tool** allowing farmers to optimize their planting and termination dates for adaptive use of cereal rye in organic no-till soybean.
3) Work with over 150 Northeastern and Upper Midwestern farmers to implement, evaluate and improve the prediction tool over three growing seasons, culminating in a public version.
4) Improve farmer knowledge of cereal rye growth to support adaptive management.

Our team will engage in three main types of activities to address these sub-objectives: 1) empirical data collection, 2) statistical modeling and application development, and 3) outreach. Researchers and collaborating Extension educators will work with collaborating farmers and assist with data collection for strip trials focused on testing management practices and strategies. Similar methods will be used to those described above. A group of 20 farmers will be recruited for helping to develop thresholds for adaptive management and the online decision support tools.

Modeling and application development. In fall of year 1, cereal rye phenology predictions for project participants will be made by the project coordinator working directly with the improved prediction function. In winter of year 1, the data analytics subcontractor will spend 15 weeks working to embed the cereal rye prediction function within a web/mobile application that collects user input to provide cereal rye phenology predictions based on site information. Site information will include latitude and longitude, 10 years of daily weather data from the PRISM database for the fall through spring growing season (this layer will be preloaded and stored on the server to shorten processing time), soil textural and organic matter data from the NCRS web soil survey (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm; also preloaded and stored on the server), rye planting date, seeding rate and cultivar. Users may obtain phenology and biomass predictions in one of two ways: 1) they can input a desired cereal rye spring termination date and see a figure showing the likelihood of rye being ready to terminate on that date for a given planting date in the fall; and 2) they can input a desired fall planting date and see a figure showing the likelihood of rye being ready to terminate on given dates in the spring. The application will enable users to provide feedback of two types: 1) qualitative (was prediction of termination date early or late by how many days); and 2) quantitative (user will provide information on rye Zadoks growth stages for different dates in the spring). After each growing season, the rye prediction equation will be updated and used to refine the statistical prediction model. In year 2 of the study, the data analytics subcontractor will spend an additional 15 weeks refining the application based on user feedback from the core participant group and from winter meetings in WI and NY. **We will avoid the proliferation of related, overlapping tools and websites by sharing our results with the regional Cover Crop Councils.**

4. Develop extension tools and activities to facilitate farmer-to-farmer learning, create on-line videos and a production guide, and host an international summit on organic no-till

Background. A critical component of our research is the communication of findings to the organic farming community. The PDs have a strong track-record of engaging with organic farmers across the Northeast and the upper Midwest, ensuring that project results and newly created extension tools will reach their target audience of organic grain and forage crop farmers at field days, conferences and workshops. In addition to leading a large organic cropping systems research program, Co-PD Silva also is the UW State Extension Specialist in Organic Agriculture, with a 75% Extension appointment. In this capacity, she works closely with county-level Extension staff and other UW Extension specialists (*see letters of collaboration from Luck and Mitchell)* to plan field days, events, and assess farmer needs. **Co-PD Silva's Extension program, branded "OGRAIN" (the Organic Grain Resource and Information Network), reaches a large community of organic grain farmers and industry representatives in the Upper Midwest and across the United States.** OGRAIN reaches farmers through its email-based listserv (>650 members), Facebook page (365 followers), YouTube channel (212 subscribers) and Twitter account (218 followers). Co-PD Silva's outreach materials (housed on the UW Extension Nutrient and Pest Management website and the OGRAIN website) have been viewed extensively; **her organic no-till videos have been viewed 800,000 times**, with thousands more views of her recorded webinars and presentations. OGRAIN also hosts regular summer field days at organic farms as well as a winter annual conference, with each event typically drawing 200+ participants.

Farmer-to-farmer learning. A core group of six organic grain and dairy farmers have agreed to actively assist with our research program and serve as regional representatives. These farmers will then become peer leaders sharing expertise, experiences, and perspectives at workshops and on-farm field days. On-farm field days, using the "seeing-is-believing" strategy, are an important part of our effort to promote strategies for reducing soil tillage across organic grain rotations. **In each year, at least one cooperating farmer will host an on-farm field day, organized by the farmer, a co-PD, and local Extension staff.** Field days will highlight project results and innovative farm practices. **Based on past attendance, we expect over 600 organic farmers and agricultural service providers from across the Upper Midwest and Northeast to attend field days each year.** In order to further extend the benefits of our peer learning program to other organic grain and dairy producers in the region and throughout the US, we will record at least four short videos of the featured farms (virtual farm field day) and deliver them via media outlets such as *eOrganic*, the OGRAIN/UW Extension YouTube channels, the NODPA website, and university websites. A videographer from each institution will participate in on-farm extension events to film conversations with the host farmers, extension educators, and researchers.

Outreach materials. We will prepare research reports for organic farmers in each year of the project and distribute them to farmers at outreach events and via websites. We will create and distribute a quarterly newsletter via email to project stakeholders, collaborators, and interested farmers. **The newsletter will take a broader and more informal approach than the annual research reports.** It will feature introductions to the team, project profiles, photos from the experiments, tool updates, and applicable stories about organic no-till production from other researchers outside the project. In addition to email, the quarterly newsletters will be available online through the existing university websites. In year 4, we will also publish an extensive **Organic No-till Crop Production Guide** based on our research data, other relevant research, and producer experience. To distribute this information to appropriate regional audiences, we will use a variety of newsletters, websites, and social media outlets, including OGRAIN, MOSES (an OGRAIN partner organization), the Land Connection in Illinois, the IDEA Network (managed by Dr. Adam Davis at the University of Illinois), and the Iowa Organic Association

International organic no-till summit. Outreach Specialist Jody Padgham (UW-Madison) will organize the International Organic No-Till Summit and bring together people who are interested in organic no-till from around the world. The summit will be held in January 2024 in partnership with the OGRAIN Winter Conference in Madison, WI, thus allowing for efficiencies in facilities costs and speaker travel, as well as ensuring strong farmer participation to complement the research presentations. The structure for the conference will be similar to the highly successful 'OGRAIN Organic No-till Thursday' event, which combines formal research presentations and farmer panels with small and large group discussions. All sessions will be videotaped by a professional UW-Madison videographer working with the OGRAIN event and posted on the OGRAIN website. Additionally, proceedings from this event will be published, working with open-access peer-reviewed journals such as '*Organic Agriculture*' to ensure that the information presented and gathered through the event are available to a wide international audience.

5. Train the next generation of farmers, agricultural service providers, and educators by developing course modules and experiential learning activities focused on organic no-till

Long-term impact will be strengthened by integrating innovations developed in this project into undergraduate and graduate student curriculum. PD-Ryan has 50% teaching responsibilities at Cornell University and is actively engaged in the developed of curriculum in the area of organic agriculture. PD-Ryan's course 'Principles and Practices in Certified Organic Agriculture' was first developed with support from ORG (2014-51106-22080), and in 2019 it was expanded from a 2-credit to a 3-credit course that serves as a capstone for students enrolled in the new Organic Agriculture concentration within the Agricultural Sciences and Plant Sciences majors. Co-PD Silva is leading the development of a new undergraduate certificate in Organic Agriculture at UW-Madison, which will include the development of new organic-specific coursework and capstone experiences/experiential learning opportunities. **We will engage students with experiential learning activities that increase their understanding of organic no-till crop production, weed ecology, soil science, systems research, and agroecological theory.** Students will learn about using cover crops to reduce tillage in organic crop production by visiting field research sites. Student learning objectives include: 1) introduction to the role of no-till agriculture as a way to adapt to changing weather patterns from climate change, 2) understanding adaptive management through using our decision support tool on theoretical scenarios, 3) developing capacity to formulate solutions to weed management challenges in organic production, and 4) fostering an appreciation of co-learning with farmers during field trips to the farms of our participating advisory board.

Modules developed for the class will be shared with other professors by posting them on-line and promoting them through our project newsletter. PD-Ryan is also leading a national education team for another NIFA Sustainable Agricultural Systems funded project (Precision Sustainable Agriculture) that is focused on using cover crops to facilitate no-till production in conventional agriculture. As part of that project we are developing a new multi-institution undergraduate course on cover crops where students in different universities will engage with each other in experiential learning activities including a cover crop competition assignment where students compete with one another to grow the greatest biomass for the lowest seed cost. Modules developed in this project focused on organic no-till crop production will be integrated into the new multi-institution course on cover crops.

Table 3. Timeline of activities arranged by objective

July 2020 to June 2024	Year 1				Year 2				Year 3				Year 4			
Objectives	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S
1. Create adaptive management strategies & test weed management tools for organic no-till soybean																
Self-seeding in organic soybean exp.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Supplemental weed mgnt. exp.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Analyze data from experiments					■	■			■	■			■	■		
Conduct partial budget analysis							■	■			■	■			■	■
Develop strategies & tools					■	■	■	■	■							
Share strategies & tools at field days								■				■				■
Publish peer-reviewed articles													■	■	■	■
2. Develop organic reduced-tillage cropping system for grain and forage production																
Reduced-till rotation experiment	■	■	■	■	■	■	■	■	■	■	■	■	■			
New crops for organic no-till	■	■	■	■	■	■	■	■	■							
Suppressing sclerotinia experiment			■	■	■	■	■	■	■	■	■	■	■	■	■	■
Analyze data from experiments					■	■			■	■			■	■		
Conduct economic & labor analyses					■	■			■	■			■	■		
Farmer-advisor discussion of results						■				■				■		
Host field day, demonstrate system								■				■				■
Publish peer-reviewed articles													■	■	■	■
3. Conduct on-farm research trials to develop decision support tool for cereal rye in organic soybean																
Collect on-farm temp. & Zadoks data	■		■		■		■		■		■					
Use data for rye growth prediction		■	■			■	■			■	■			■	■	
Refine model with farmer feedback						■	■									
Share model w/ cover crop councils														■	■	■
4. Create extension tools, online videos & production guide, and host summit on organic no-till																
Create online videos	■	■	■	■	■	■			■	■			■	■		
Prepare research reports for farmers					■	■			■	■			■	■		
Farmers host on-farm field days				■				■				■				■
Organic No-till Production Guide													■	■	■	■
Assess knowledge gain thru surveys				■	■			■	■			■	■			■
Plan international summit	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Host international summit														■		
5. Develop modules to train the next generation of farmers, service providers, and educators																
Conduct farmer case studies	■	■	■	■												
Test experiential learning activities	■	■	■	■												
Develop course modules					■	■	■	■								
Share modules with other educators									■	■	■	■	■	■	■	■

3. Expected outcomes and contribution to long-term sustainability of organic agriculture. Expected outcomes from this project include addressing many of the remaining barriers to organic no-till adoption. Additionally, our research will provide greater understanding of the benefits of the no-till system, including impacts on soil health indicators and reduction of erosion. Other outcomes include a more thorough understanding of the causes of variability in system performance and impacts of different equipment modifications and fertility management approaches. With our multi-site approach, we are expecting to more thoroughly elucidate practices to optimize weed suppression, cash crop establishment, and crop yield. **From this work, we will develop improved recommendations, decision support tools, and outreach materials to mitigate risks and facilitate adoption of organic no-till.** The decision support tool will allow farmers to assess the likelihood of success early in the production season when alternative options are still viable. A thorough economic analysis of the system, including break-even probability, will further guide farmers as they navigate adaptive management options.

4. Means by which results will be analyzed, assessed, or interpreted. We will use a variety of descriptive, univariate, and multivariate statistics to analyze data collected in this project. Mixed effects analysis of variance (ANOVA), and/or analysis of covariance (ANCOVA), will be used for routine hypothesis testing in the research trials. Advanced multivariate procedures will be used to examine treatment effects on temporal changes in weed populations, disease pressure, and soil health. Potential multivariate procedures include nonmetric multidimensional scaling (McCune & Grace 2002) to visualize data, and permutational multivariate analysis of variance (Anderson 2001) to determine causal relationships between weed populations, disease, crop yield, and profitability. Factor analysis, partial least squares regression (Carrascal et al. 2009), and structural equation modeling (Grace 2006) will be used to quantify the effects of such factors as precipitation, crop density, disease incidence, and weed biomass on crop yield and profitability. Results will be translated into several farmer-friendly formats such as interactive spreadsheets and recommendations, made available on *eOrganic* and other regional websites. In addition, our results will be published in several peer-reviewed journals such as *Organic Agriculture, Renewable Agriculture and Food Systems,* and *Agronomy Journal*. The adoption rate of new practices will be analyzed through workshop surveys and evaluations after educational events. Data will be analyzed to determine the impact of management guidelines, Extension activities, and decision support tools on farm viability.

5. Use of results and products. As described above, project data will be summarized and interpreted for public distribution in annual reports, individual PI websites, and for eOrganic. **These products will provide research results and conclusions to the organic farming and scientific community, allowing farmers and agricultural researchers to build on project findings, include cover crops in their suite of organic practices, and develop further avenues of organic reduced-till experimentation.** Further, publications will introduce other scientists to the potential of organic no-till practices to reduce erosion and enhance soil quality and health. All research results and educational tools developed from this project will be delivered to farmers, agricultural professionals, and other associated industry in the Upper Midwest and NE through **on-farm field days, winter conferences, regional presentations, national webinars, or online tools.** In addition to journal articles, other researchers will access data generated in this project through the Cornell eCommons data repository (*see Data Management Plan*), extending the value of our work and reducing duplicity among researchers.

6. Outreach plan. Outreach to stakeholders is a critical component of this project (*see Objective 4*). Impacts and learning outcomes will be quantified throughout the project. Overall, our evaluation plan will answer questions about content quality, delivery effectiveness, and project outcomes. We will evaluate farmer interest in the material, knowledge gain, change in intentions and attitudes, and, most importantly, changes in behavior. Using both print and electronic means, participants will be directed to complete end-of-event surveys, which will feature post-reflective and yes/no questions and open-ended feedback. We will also conduct follow-up evaluations to determine if farmers make changes on their farms, focusing on OGRAIN and NOFA-NY conference participants. Summative evaluations will also include an assessment of page views per day and most-accessed content, attained with Google Analytics and other usage statistics through YouTube, eXtension.org, and university websites. Analysis of these statistics will offer an estimate of the audience reached as well as demographics of the content users. Summative data will be analyzed and included in annual and final project reports. These data will also guide any future improvements and additions to the materials developed.

7 and 8. Potential pitfalls and limitations to proposed procedures. We expect few pitfalls and limitations in this project. Crop damage from herbivores such as deer or groundhogs is a potential pitfall. We will manage this risk by establishing a crop damage monitoring and pest capture program. Pest and weather-related risk will be reduced by having multiple site-years. Potential hazards related to farm equipment and research will be minimized with proper training on lab safety and equipment operation. Other potential pitfalls will be avoided by discussing plans with collaborators and anticipating challenges. Poor winter weather during the week of the international conference could complicate travel and be a pitfall. We will schedule activities appropriately and encourage participants to arrive early by coordinating pre-conference activities. Additionally, each of the project partners has been working in the area of organic no-till for over a decade, and has a wealth experience to ensure project success, as well as strong interdisciplinary collaborations with faculty in soil science, entomology, weed science, plant pathology, agricultural economics, and agricultural engineering.

9. Explanation of potential hazards and precautions. Potential hazards are similar to those of any commercial-scale farming operation that involves tractors and heavy implements. Standard farm safety procedures and laboratory safety will be followed to reduce the risk of harm. Additional training will be provided on the use of the electric weed zapper to ensure proper use and to minimize potential for electrocution.

Centers of Excellence Justification. Our team already has strong relationships with other major groups that would be developing organic no-till systems in the Northeast and Upper Midwest, thus our interconnectedness will limit redundant efforts and make us strong candidates for Center of Excellence designation. For instance, PI Silva is actively collaborating with the Rodale Institute (Kutztown, PA), PI Ryan has strong ties with researchers at Penn State and with the Northeast Cover Crop Council, and PI Silva has a far-reaching network of relationships through the OGRAIN. In addition, our history of receiving grants, in addition to our relationships with agriculture industry groups (*see letters of support*) positions us to successfully leverage supplementary resources. Our project partners have been working in the area of organic no-till for over a decade, bringing a wealth of experience to ensure the success of no-till teaching and outreach initiatives. The ultimate goal of our project is to lower the economic and labor burden on farmers by replacing soil tillage with using mulch from cover crops, thus increasing economic returns to rural communities.