INTRODUCTION

The recent development of conservation-tillage strategies for organic grain systems is a response to organic producer interest in combining the soil-conserving and labor-saving capacity of no-till practices with the soil health-building capacity of organic practices, which include diversification of crop rotations and incorporation of cover crops [1, 2]. Despite a growing body of academic research and farmer experimentation in North America [3-5], conservation-tillage strategies that reduce the reliance on inversion tillage remain in a nascent stage due to their considerable ecological complexity – an inherent feature of organic agriculture.

Within the Mid-Atlantic region of the United States, recent research has focused on the development of a cover crop-based, organic rotational no-till annual grain production system using a corn (*Zea mays* L.) – soybean (*Glycine max*) – wheat (*Triticum aestivum*) rotation [3]. In organic grain systems, overwintering cover crops are typically terminated using inversion tillage, which both incorporates the cover crop as a green manure and controls weeds. The development of the roller-crimper has provided an alternative means for terminating cover crops and enables no-till planting of cash crops into rolled cover crop mulches that serve as a primary weed suppression tool [4]. This practice is the foundation for our current organic cover crop-based, rotational no-till system [3]. In a recent regional experiment utilizing this system [6], we developed cultural and mechanical strategies that effectively controlled weeds below economic thresholds [7] and promoted conservation biological control of early-season invertebrate pests [8]. Yet, grower adoption is precluded by significant agronomic challenges that result in variable crop yields [9-11], that can include: 1) inconsistent termination of cover crops with the roller-crimper, 2) inconsistent establishment of cash crops in high residue, rolled cover crop mulches, 3) a narrow agronomic window for supplemental N supply to cash crops, and 4) climatic constraints to establishing overwintering cover crops following cash crop harvest.

Systems-based research and integrative extension programs are needed to refine our current rotational no-till system and develop alternative reduced-tillage strategies in organic grain production systems. *Our proposed project will address constraints to adoption by integrating our existing approach, no-till planting into rolled cover crop mulch, with additional alternative reduced tillage strategies: 1) relay planting of cover crops into standing row crops using inter-seeder technology, 2) no-till drill-seeding of cover crops into a cereal grain in late winter, and 3) manure injection using subsurface banding technology, enabling no-till cash crop management.* In comparison to our current approach, these strategies may lengthen cover crop and cash crop growing season windows, and/or provide greater nutrient management flexibility (incorporation of cover crops, manure application timing and placement) for maximizing crop yields, while reducing or maintaining similar tillage frequency and intensity within the cropping system.

<u>Long-term Goals</u>. Our long-term research goal is to develop sustainable organic cover crop-based, reduced-tillage organic feed grain production systems that integrate pest and soil management practices to overcome grower-defined production constraints. Our long-term extension goal is to facilitate the adoption of reduced-tillage practices by fostering peer-to-peer learning through existing organic grower networks in support of cover crop-based reduced-tillage practices in organic grain production. To accomplish these goals, we will integrate on-station research with farmer-participatory research on organic farms, and develop a decision-support tool to help farmers manage the complexity of organic systems (**Fig. 1**).

Critical Needs Addressed.

This project addresses several defined research needs for organic agriculture. We will utilize knowledge and experience from our previous and on-going research to refine reduced-tillage and cover crop management strategies, through the use of existing (roller-crimper) and new (inter-seeder, manure injector) implements. Development of reduced-tillage organic systems, as well as design and testing of new equipment to implement these systems, has been identified as a critical applied research need [12]. We will also measure the effect of alternative reduced-tillage and cover crop management strategies on weed and insect-pest suppression, and determine how reduced-tillage strategies, cover crop species selection and fertility management influence nutrient cycling within an organic grain system. Our nutrient cycling and pest management research will be used to develop a decision-tool that will help farmers make decisions that optimizes fertility and pest management in systems that integrate reduced-tillage practices, manure and cover crops. This tool builds on an existing cropping systems model [13, 14] that will be tailored for organic agriculture. In addition, the tool will leverage farmer and researcher expertise related to organic no-till management of pests. Each of these project objectives has been identified as a critical research need in organic agriculture [12]. Our project will be conducted under certified organic conditions, involve collaborative on-farm research with organic producers and will utilize a multi-disciplinary systems approach for managing pests and soil fertility. These characteristics have been identified as critical to addressing the needs of organic producers [12].

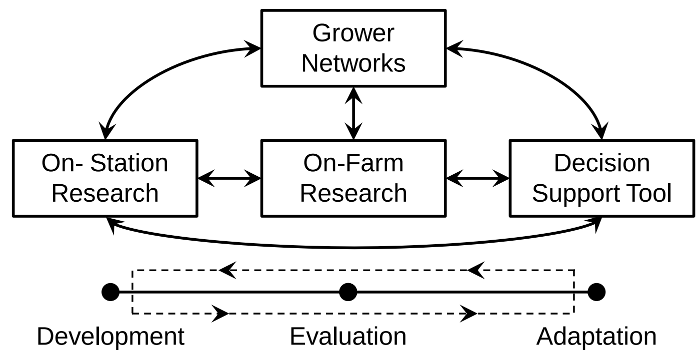

Figure 1. *Iterative research and extension process leading to adaptation of reduced-tillage practices by organic growers.*

Demand for organic dairy and other livestock products remains high in the mid-Atlantic region, yet supply is often limited by high feed and fuel prices [15]. Consequently, demand for supplemental organic feed grain is likely to remain high in the future, particularly in major organic dairy regions such as Pennsylvania and New York [16]. Despite market premiums, transitions from conventional to organic grain production are limited by high labor and fuel costs associated with intensification of tillage and perceived risks associated with pest management. Information on pest management, in relation to cropping system sequences and tillage strategies, has been cited as a priority in surveys of Pennsylvania organic grain growers [17, 18], and a short growing season is consistently identified as a constraint (64% of 719 field crop producers) to incorporation of cover crops [19]. In comparison to full-tillage systems, integration of cover crops and reduced-tillage practices can reduce labor, time and fuel costs incurred by organic growers [20]. Our project will identify trade-offs among agronomic, environmental and economic factors for alternative reduced-tillage strategies. Development of reduced-tillage strategies that conserve and build soil quality, and reduce fuel and labor costs, while maintaining adequate pest suppression and crop productivity, may facilitate transitions to organic feed grain production, thereby stabilizing the organic dairy and livestock feed supply chain.

Project Objectives. Our project objectives are to evaluate the agronomic, economic and environmental benefits and costs of alternative approaches to reducing tillage and incorporating overwintering cover crops in an organic feed grain system. The alternative approaches will be tested in four systems that differ in cover crop species, cover crop termination and establishment methods, fertility management, and cash crop season length. To accomplish our project objective, we will integrate (**Fig. 1**) on-station (O1) and on-farm (O2) research with extension programming (O3), which will facilitate the development of a decision support tool (O4).

Research Objective (O1a): Compare the effects of four approaches to reducing tillage and incorporating overwintering cover crops into annual feed and forage systems on a suite of grower-identified priorities, including: 1) weed suppression, 2) insect pest regulation, 3) nutrient supply and retention, 4) soil quality, 5) crop productivity, and 6) short-term profitability.

Research Objective (O1b): Determine how the interaction between cover crop management (species, establishment and termination methods) and associated soil fertility management (timing and method of manure application) among the four systems affect nutrient cycling processes, including: 1) nutrient retention by and supply from cover crops, 2) nutrient uptake by cash crops, and 3) potential nutrient losses to the environment. We will use field measurements and modeling to evaluate these interactions.

Research Objective 2 (O2): Determine on-farm performance and management constraints of using overwintering cover crops through farmer participatory research that includes one or more reduced-tillage approaches (rolled cover crop termination, inter-seeded, or frost drill-seeded cover crop establishment) utilized in on-station (*O1a* & *O1b*) research.

Extension Objective 3 (O3)*:* Foster co-learning in regional organic grain producers' networks to support education of growers and other agricultural professionals about the benefits and challenges of organic cover crop-based reduced tillage systems and facilitate grower experimentation with reduced tillage and cover crop management practices through the use of: 1) field-based education events (*O2*), 2) workshops for farmers and other agricultural professionals, and 3) extension products (e.g., newsletter articles, fact sheets, brochures, and webinars).

Extension Objective 4 (O4): Develop a decision-support tool to support decision-making about tillage reduction and cover crop management based on farmer-prioritized goals (fertility management with manure and cover crops, weed management, insect management) within reduced-tillage organic grain systems that accounts for site-specific factors, including: 1) nutrient requirements of the cash crop, 2) magnitude and timing of nutrient supply by cover crops, 3) weed abundance thresholds, 4) insect pest forecasts and 5) crop rotation constraints.

Past-Activities, On-going Work & Preliminary Studies. Our proposal builds on knowledge gained from two completed [21-22, 60] and three recently completed or on-going experiments that have focused on the effects of cover crops, tillage practices and manure management at Penn State's Russell E. Larson Agricultural Research Center (PSU-RELARC).

ROSE. Our most recently completed experiment (PD Barbercheck, PI Curran), the USDA-OREI-funded project 'Reduced-tillage Organic Systems Experiment (ROSE), was conducted at three mid-Atlantic study sites: PSU-RELARC (PA), University of Delaware's Carvel Research and Education Center (DE) and USDA-Beltsville Agricultural Research Center (MD) [23]. This experiment compared weed and early-season insect and invertebrate pest management strategies in a cover crop-based, organic rotational no-till annual grain production system using a corn – soybean – wheat rotation [3], using agronomic practices developed in component research over an 8-year period focusing on the integration of a hairy vetch-triticale mixture before corn and cereal rye before soybean [36-41]. Delayed cash crop planting was evaluated as a strategy to avoid early season weeds and insect pests and to increase physical weed suppression via higher cover crop biomass. In addition, the use of high residue cultivation was evaluated for supplemental weed control and the performance of a single cash crop variety was compared to varieties with maturities appropriate for the planting date treatments. With few exceptions, delayed cash crop planting resulted in significantly greater levels of cover crop biomass and reduced weed abundance; high residue cultivation further reduced weed abundance, up to 60% [7]. Furthermore, delayed planting resulted in a lower abundance of early season insect and invertebrate pests, which was correlated with higher observed levels of predators, predation rates and parasitoids [8]. Despite these agronomic benefits, corn and soybean yields were highly variable across years and study sites [9]. Preliminary analyses suggest that yield variability results from inconsistent cash crop establishment in high residue cover crop mulches [61], but technological improvements in planter and residue management equipment will likely improve establishment consistency [11]. Publications are in development. *We will utilize our findings to refine our proposed research (O1) and decision support tool (O4).*

<u>*Inter-seeding Cover Crops*</u>. On-station and on-farm research (NRCS-CIG-funded) is currently evaluating the use of inter-seeder technology, developed by PSU research staff (PD Curran), to address cover crop establishment challenges within short growing seasons in conventional grain systems [62]. The inter-seeder consistently seeds winter cover crops into V5 to V8 growth stages of corn in till- and no-till production systems. In 2010, two experiments established at PSU-RELARC compared conventionally produced corn to corn inter-seeded with red clover, annual ryegrass or red clover-annual ryegrass. Corn yields were greater within inter-seeded plots in comparison to the control and a positive linear relationship was observed between cover crop biomass in the spring and subsequent grain yield [63]. In 2011-12, ten on-farm demonstrations across central PA in no-till corn production had fair to excellent stand establishment of inter-seeded annual ryegrass and clover despite drought stress throughout the region. In 2013, we established 30 trials in the mid-Atlantic and 70% had good to excellent cover crop establishment; poor establishment resulted from drought or insect pest and slug damage at the remaining sites. *These results suggest that this approach may be adapted to address the critical need of extending cover crop planting windows in organic crop production systems.*

<u>*Cover Crop Cocktails*</u>. Our proposed research also draws upon knowledge gained from our current OREI-funded project (PD Kaye, PI Barbercheck), '*Cover Crop Cocktails: Finding the Right Mix'*, which is evaluating the agronomic, environmental and economic benefits and costs of using cover crop mixtures in organic annual crop production systems [24]. This study utilizes on-station research at PSU-RELARC and on-farm research at three PA organic farms to determine how the level of cover crop diversity affects a suite of grower-defined priorities and ecosystem services. Preliminary results suggest that grass-legume cover crop mixtures can balance N provisioning and retention. However, N fixation by legumes in cover crop mixtures can be insufficient for corn production due to short growing seasons and plant competition, particularly from cereal rye. *These results provide important insights into the influence of cereal rye and hairy vetch on nutrient management, which will be used in this proposed research*.

<u>*Manure Management*</u>. Our proposed research will draw on knowledge gained from a 4-year NE-SARE-funded project (PI Curran) that explored manure injection in conventional no-till corn [64]. Shallow-disk manure N reduces the need for side-dress N and produced similar crop yields, but is more costly than broadcast applications. However, 30 to 70% of total N can be volatilized as ammonia within 36 hrs following broadcast manure applications [65]. Manure

injection has the potential to conserve manure N and increase yields when properly managed. *In this project, manure injection would enable no-till crop management*. *This technique has yet to be compared with broadcast + incorporation methods in our organic reduced-tillage system*.

Extension-Outreach Programming. The *ROSE* and *Cocktails* projects benefit from organic farmer participation on project advisory boards and in research and extension activities, and have led to the development of educational tools for participatory extension learning [66, 67], and have provided considerable experience in conducting multi-disciplinary, long-term, large-scale organic cropping systems research [68]. Our team has a strong history of outreach activities, including field days, farmer network meetings, workshops, webinars and other educational programs for sustainable and organic farmers.

Decision Support Tools. Our proposed research will also draw upon knowledge gained from previous agricultural modeling projects (PD Kemanian) that have focused on soil carbon cycling under various scenarios [13, 14]. These projects have utilized a simulation tool, Cycles, to predict soil organic matter component pools and fluxes under changing environmental conditions and management practices such as tillage and organic amendment additions [69].

RATIONALE AND SIGNIFICANCE

The main *rationale* for our work is that organic farmers have expressed a strong interest in adopting conservation tillage practices. Significant research contributions have been made to develop cover crop-based reduced tillage strategies, particularly in feed and forage systems within the mid-Atlantic, but many agronomic challenges remain before growers will consider adoption. These challenges principally involve cover crop management tactics that are time-sensitive, environmentally variable, and include trade-offs among grower priorities. *Looking forward, we suggest that adoption of cover crop-based reduced tillage practices will require an adaptive management approach, yet there is a paucity of experiments and extension materials that have evaluated multiple methods for reducing tillage within a given cropping system.* The collective experience of our research and extension team will facilitate the development of a suite of cover crop-based reduced tillage approaches that may be managed adaptively by a grower to fit site-specific priorities or constraints.

There are several *novel aspects* to our approach. Within the mid-Atlantic, reduced tillage strategies have primarily focused on the use of the roller-crimper, which enables no-till planting of cash crops but entails significant agronomic management trade-offs. We introduce three alternative methods, which we have developed and evaluated in previous and on-going experiments: 1) relay planting cover crops into standing row crops with an inter-seeder; 2) no-till drill-seeding cover crops into a cereal grain in late-winter; and 3) no-till cash crop planting following manure N injection using subsurface banding technology. These methods mitigate many of the agronomic trade-offs associated with no-till planting of cash crops into rolled cover crops.

In addition, many extension materials are available that provide decision support to organic growers, but these tools are primarily focused on single components of cover crop management in organic systems. We will develop a beta-version of a decision support tool (Cycles-OT) that incorporates cover crop, weed, pest and nutrient management factors under alternative reduced tillage scenarios.

A CRIS search generated several on-going or completed projects that are investigating agronomic aspects of a particular reduced-tillage strategy in organic production systems, but we did not observe any projects that explicitly compare the effect of alternative approaches to reducing-tillage on the various priority functions that influence grower management strategies, and we know of no decision support tools that integrate information on cover crop establishment and termination methods on nutrient, weed and insect-pest management at a cropping systems level. Stakeholders will benefit locally through grower interactions in three regional organic producers' networks and through extension materials and events. Our outreach and co-learning approaches will increase the capacity for farmers to successfully incorporate reduced tillage strategies into organic grain systems. Our project will address four *legislatively defined goals* and three *program priority areas* for FY2014, as outlined in the Executive Summary.

APPROACH

<u>Institutional Roles & Key Personnel</u>. Personnel at Penn State University, three extension offices, and three organic crop producers in PA will collaborate to address the proposed research and extension objectives (**Fig. 1**). Penn State scientists will work with a stakeholder advisory board as they refine a long-term systems experiment (O1), collaborate with county-based extension educators to facilitate on-farm research (O2) and three regional organic crop producer networks (O3), and develop a decision support tool (O4). The key personnel on the project are:

Collaborators and stakeholder advisory board. Farmer collaborators *Wade Esbenshade, Elvin Ranck* and *David Hoover* will help plan, manage, and evaluate on-farm experiments (O2). Their certified farms represent common mid-Atlantic organic grain and forage cropping systems and are located in southeast, southcentral and northcentral PA. A stakeholder advisory board consisting of the farmer-collaborators, a seed company agronomist (*David Wilson*), Rodale Institute farm manager/director (*Jeff Moyer*), and the education and outreach director of Pennsylvania Certified Organic (*Lee Rinehart*), will provide guidance on research and outreach activities.

Outreach and extension team. County-based extension educators *Mena Hautau, Chris Houser* and *Elina Snyder* will facilitate on-farm research (O2) and coordinate activities with organic crop producer networks (O3).

Campus-based team. *Mary Barbercheck* will serve as project director and lead evaluations of pest regulation and soil quality indicators at the PSU (O1a) and on-farm (O2) sites. *Bill Curran* will lead agronomic field operations and evaluations of weed suppression, cover crops, and crop yields at the PSU (O1a) and on-farm (O2) sites. *Jason Kaye* will lead measurements of nutrient dynamics at the PSU (O1) and on-farm sites (O2). *Armen Kemanian* will lead modeling efforts for characterizing nutrient dynamics with the proposed cropping systems (O1b) and will lead the development of the decision support tool (O4). *Sarah Cornelisse* will conduct analyses of short term profitability at the PSU (O1a) and on-farm (O2) sites, building on her extension program in value-added agricultural entrepreneurship. *John Wallace* will coordinate analysis of measurements at the PSU site (O1a), oversee on-farm research activities (O2), and assist in the development of the decision support tool (O4). *Ron Hoover* will provide technical assistance for reduced-tillage operations at the on-farm sites (O2).

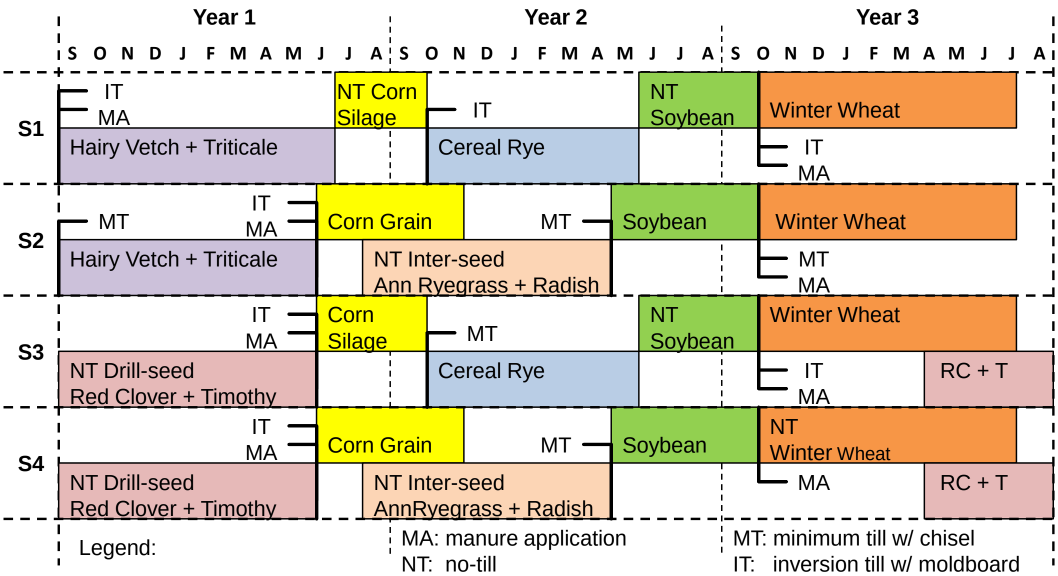

Figure 2. Field operations schedule (3-yr) for four cropping system treatments.

<u>Methods</u>. Our approach includes four interconnected activities (**Fig 1; Table 1** – *end of document*): experiment station research at PSU-RELARC (O1), on-farm research at three organic farms (O2), extension outreach through producer networks (O3), and development of a decision support tool (O4).

Experiment Station Research (O1): We will establish a randomized complete block design experiment with four replications in which four cropping system treatments that utilize various cover crops and reduced tillage strategies will be embedded in a corn-soybean-wheat rotation (**Fig. 2**). This crop rotation is common to many organic feed and forage farms in the Mid-Atlantic and includes longer (following small grains) and shorter (following corn silage) cover crop growth windows. We will utilize a full-entry experimental design to account for crop legacy and annual weather effects. The experiment will be established in 4.05 hectares of certified organic land utilized for our previous ROSE project [42]. Each complete block will be comprised of three crop entry main-plots (110 x 18 m) and four cropping systems treatment sub-plots (49 x 9 m). Main plots will be separated by mown, grass alleys (12 m).

<u>Cropping System Treatments</u>: Our cropping system treatments represent four approaches for reducing tillage in a crop rotation that utilize cover crops. *A traditional organic full-tillage 3-yr annual grain rotation utilizing cover crops will typically use 5 primary tillage events (moldboard or chisel plow) and 8 or more supplemental tillage events (disking, cultivating) for weed control and incorporation of fertility inputs*. Our proposed cropping system treatments will utilize no-till planting of cover- or cash-crops (1 to 3 events per rotation) to reduce the frequency of primary tillage events and will evaluate minimum tillage practices (chisel plow) to reduce the intensity of primary tillage within a 3-yr rotation in comparison to a full tillage system (**Table 2**). No-till planting and primary tillage treatments are a function of the different cover crop management strategies chosen for the proposed cropping systems, which are summarized below:

System 1 (S1): Corn grown for silage and soybean are no-till planted into a rolled hairy vetch-triticale mixture and cereal rye, respectively. The system will have 3 primary inversion tillage events and 4 supplemental tillage events for weed control using a high-residue cultivator over the 3-yr rotation. Cover crops will be rolled twice, approximately 1 wk apart to ensure adequate termination [10]. Shallow high residue inter-row cultivation, which minimally disturbs the soil and leaves cover crop residue on the surface, will supplement weed control provided by the cover crop mulch [70]. ROSE results show an average 50% reduction in weed biomass with high-residue inter-row cultivation [7]. Inversion tillage, using a moldboard plow, will occur after cash crop harvest to establish winter wheat or cover crops (hairy vetch-triticale, cereal rye) and suppress perennial weeds. Manure will be applied before wheat and fall-seeded cover crops are sown. Cover crop termination timing will be guided by ROSE results. This system will represent the rotational no-till standard [3], which has been evaluated at PSU-RELARC and other regional study sites in a cropping systems experiment (ROSE) conducted between 2010 and 2014 [23].

Table 2. Frequency and intensity of primary tillage events and no-till planting in 3-yr rotation cropping system treatments.

	No-Till Planting		Primary Tillage Events	
System	Cover Crop	Cash Crop	Minimum	Inversion
S1	0	2	0	3
S2	1	0	3	1
S3	1	1	1	2
S4	2	1	1	1

System 2 (S2): This system introduces an annual ryegrass-forage radish (*Lolium multiflorum-Raphanus sativus*) cover crop inter-seeded into corn grown for grain; an alternative approach to growing cereal rye before soybean. Hairy vetch-triticale will be terminated with a moldboard plow, which allows for earlier corn establishment (about 2 weeks) compared to roll-killed hairy vetch. The system will have 3 primary minimum tillage, 1 primary inversion tillage, and 8 supplemental tillage events.

After the final cultivation in corn (V5-V6), the annual ryegrass-forage radish mixture will be inter-seeded between the rows [62], allowing for corn grain production with the winter cover crop already established at grain harvest. Annual ryegrass will be terminated by chisel plowing before soybean planting. Forage radish winter-kills after hard frosts. Weeds will be managed via supplemental tillage (e.g., blind till, inter-row cultivation) in corn and soybean. Manure will be incorporated before corn and wheat crops.

System 3 (S3): This system introduces a red clover-timothy (*Trifolium pretense-Phleum pretense*) cover crop mixture before corn grown for silage, which will be no-till drill seeded into wheat in late winter (frost-seed) and terminated by tillage the following spring before planting corn [64]. In previous research, under-seeding red clover in spring into winter wheat provided multiple benefits over hairy vetch [71]. Red clover can produce an equivalent or greater amount of N compared to hairy vetch if it's growing season is lengthened by no-till drill seeding, and red clover seed cost is substantially less than hairy vetch [64]. Soybeans will be no-till planted into a rolled cereal rye cover crop [42]. In ROSE, no-till soybean yields were competitive with conventional averages, offering credibility to this management tactic [9]. This system will have 1 primary minimum tillage, 2 primary inversion tillage, and 4 supplemental tillage events for weed control over the 3-yr rotation. As in System 2, incorporation of the cover crop (red clover-timothy) allows for earlier corn planting and harvest, and subsequently earlier cereal rye establishment after corn. Weeds will be managed using supplemental high-residue inter-row cultivation, and termination timing of cereal rye will be guided by ROSE results [61]. Manure will be incorporated before corn and wheat. This system serves as a hybrid between S1 and S4.

System 4 (S4): This system combines the two new alternative approaches (S2, S3) for reducing tillage: 1) inter-seeding annual ryegrass-forage radish into standing corn to enable corn grain production and to lengthen the cover crop growing season before soybeans, and 2) no-till drill seeding red clover- timothy into wheat in early spring (frost-seed) to lengthen the growing season before corn. In addition, we will no-till drill seed winter wheat into soybean residue and apply manure prior to planting using sub-surface banding technology [72]. As a result, the system will have only 1 primary minimum tillage event and 1 primary inversion tillage event over the 3-yr rotation. Weeds will be managed using supplemental high-residue inter-row cultivation, and manure will be incorporated before corn is planted.

Experiment Initiation. We will utilize the ROSE study site (4.05 ha), which is scheduled for organic certification in the summer of 2014. After the final crop phase in the fall of 2013, we established the proposed treatment plots and planted fall cover crops and winter wheat. In 2014, treatment plots will be managed uniformly to homogenize potential legacy effects of the previous experiment. We will be able to initiate the proposed experiment in the fall of 2014.

On-Farm Research (O2): On-farm research will allow us to determine the performance and management constraints of the incorporation of cover crop-based reduced tillage approaches into organic feed grain production systems through farmer-participatory research (O2). Each farmer will select one cropping system from the on-station research, and devise a second cropping system based on their interests that utilizes either roller-crimper, inter-seeding or frost-seed drilling approaches for reducing tillage. These treatments (T1-T2) will be compared to a standard treatment (T3), which will entail the practices the farmer currently uses for a 3-year grain rotation. The three cropping system treatments will be replicated three times in a randomized complete block design. Plots will be width of two planter passes. Plot length will depend on field constraints, but we anticipate that total field size will be between 2 and 4 ha. On-farm experiments will be initiated in fall of the 2nd year. Farmers will manage the systems according to on-station protocols (T1, T2) or by standard practices (T3). Specialized equipment (roller-crimper & inter-seeder) will be made available to farmers and research staff (PI Hoover) will assist farmers in the planning and field operations using specialized equipment.

A subset of measurements related to weed suppression, insect pest regulation, nutrient supply and retention, soil quality, crop productivity and short-term profitability will taken by on-station research staff, in collaboration with the county-extension staff and cooperating farmer. Data collection will utilize the sampling methodology described in the above section. A standard *soil fertility analysis* will be performed on a composite soil sample (20 cm depth) of each field prior to cover crop establishment. Ground cover of *weeds* and *cover crops* will be visually estimated (0.5 m^2 quadrats) in late fall and early spring, and cover crop and weed biomass will be sampled (0.5 m^2 quadrats) at termination and mid-summer, respectively. *Invertebrate pests and beneficial insects* will be sampled in late spring, prior to cover crop termination and shortly after cash crop emergence. *Nutrient concentration and uptake* of the cover crop and weed shoot biomass will be measured in late spring. Composite soil samples (20 cm depth) will be collected from each plot in July after cover crops have been incorporated with tillage and just prior to rapid nutrient uptake by the cash crop. Soil from this sampling date will be analyzed for *nutrient availability, aggregate stability, active C,* and *particulate organic matter C and N*. *Cash crop yield* will be measured by hand harvest (10 m^2). *Short-term profitability* will be calculated with a partial budget analysis of the cover crop treatments.

Extension Outreach Plan (O3): Key stakeholders will learn about project results and provide directive input into the research and extension program through regular communication, including a project newsletter, website, annual stakeholder advisory board meetings, organic farmer network meetings, field days, conference workshops and online resources. Through evaluation of past extension events, many farmers have expressed that, in addition to seeking specific technical content, they value participatory learning environments where they can learn from each other because they trust that other farmers have learned through experience [96, 97]. Therefore, outreach will be a cooperative activity of the research and extension personnel, farmer-researcher cooperators, and our stakeholders.

County extension educators *Hautau* and *Houser* will coordinate and facilitate the Southeast Pennsylvania Organic Crop Producers' Network in southeastern PA and the Central Susquehanna Valley Organic Crop Growers' Network in north-central PA, respectively. County extension educator *Snyder* will help facilitate the creation of a third organic grower network in south-central PA. In 2015 and 2016, a *winter network meeting* will be devoted to alternative approaches for incorporating cover crops with reduced tillage strategies. At these meetings, farmers will share their perspectives on the potential benefits and constraints of reduced tillage approaches and the project team will share results from the on-farm and research station experiments. In 2016 and 2017, a *spring network meeting* will be hosted by farmer collaborators on their farms to view performance of the reduced tillage treatments. At this meeting, network participants and the project team will share their experience with reduced tillage approaches and research results. Farmer experiences shared at network meetings will be distilled into *newsletter articles* and incorporated into *fact sheets* for broader and longer-term impact.

Two *field days* based at PSU-RELARC, co-hosted by Pennsylvania Certified Organic (PCO), will be held in the spring of 2016 and 2017 to view performance of the cropping system treatments containing reduced tillage approaches. Diverse stakeholders will also attend project team organized *workshops* on the topics included in this proposal at PASA's annual Farming for the Future conference. PASA's annual conference brings together over 2,000 growers, buyers, distributors and consumers from the across the U.S. We will develop 1 *webinar* per year and 2 *articles* per year in years 3 and 4 of the project to disseminate information resulting from our research and co-learning activities to a national audience of diverse stakeholders. Article topics will focus on the effects of reduced tillage approaches on grower defined priority functions: nutrient supply and retention, soil quality, regulation of insect pests, weed suppression, yield, and profitability. We will conduct *evaluation surveys* on-site and on-line to assess impacts on user attitude, knowledge, and behavior change.

Decision Support Tool (DST) Development (O4): To help farmers evaluate management options and tradeoffs among tillage practices, cover crop management, nutrient management, and weed and insect pest management, as well as their interconnectivity, we will assemble a beta-version of a *web-based* decision support tool (DST) tailored to organic systems: *Cycles-OT (Cycles-Organic Tool)*. This tool will permit growers, land managers, and service providers to evaluate their options through a simple, intuitive, user friendly interface.

The conceptual framework for Cycles-OT is illustrated in **Fig. 3**. Due to the inherent ecological complexity of organic cover crop-based, reduced-tillage systems, Cycles-OT will utilize *grower priority inputs*, *grower management inputs*, and *model inputs* to provide management recommendations (e.g., manure application and timing) and illustrate likely management scenarios (e.g., potential weed suppression based on spring cover crop biomass assessment) for various *decision points*. Cycles-OT will combine two sources of model inputs: 1) decision-trees based on previous and on-going research, and 2) an assimilated database of model simulations based on the cropping systems model, Cycles [69]. *Cycles-OT cannot substitute for the knowledge and judgment of the grower, but can greatly enhance their ability to judge options and bound risks*.

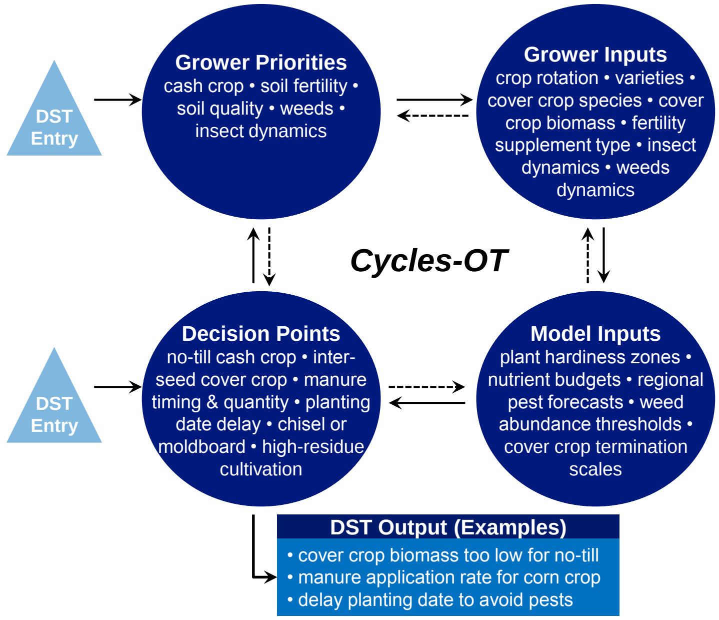

Figure 3. Conceptual framework for decision support tool (*Cycles-OT*)

A grower/user will enter Cycles-OT (triangles) and explore options based on priorities defined by the type of system, or at specific decision points (**Fig. 3**). These pathways will be defined with grower participation to reflect their actual decision process. Grower inputs will define the environmental and management scenarios underlying the decision process, which will result in: 1) decision trees for cover crop and pest management, and/or 2) a look up table database from model simulations that display the modeled consequences of soil fertility management scenarios. For example, based on a grower-evaluation of legume cover crop establishment in late spring, the tool will display both the average N supply expected from the decomposing cover crop, the response to manure addition for 25 climatically different years, and the weed suppression potential if used as rolled mulch. Our 4-yr developmental process follows:

Year 1: Grower Input & Assembly: The Cycles-OT conceptual framework will be presented at grower learning circle network workshops to gather *grower inputs* about priorities, decision points, potential assessment methods and preferred tool design. We will utilize this feedback to define the information required from two sources of *model inputs*: 1) decision-trees for cover crop and pest management scenarios, and 2) simulation models for fertility management scenarios.

Decision-Trees will be developed for cover crop and pest (weed & insect) management scenarios that may occur in our proposed cover crop-based reduced tillage systems. Previous studies have developed weed management and cover crop establishment and termination strategies for no-till planting into roll-killed cover crops in central PA [36-41]. We will *synthesize* past research, ROSE results, and our proposed project results to produce decision trees for alternative site-specific reduced tillage scenarios. Grower inputs may include: 1) weed seedbank legacies (perennial, summer annual, winter annual), 2) insect pest forecasts, and 3) cover crop biomass assessments, to assist management decisions related to cover crop termination timing and method, cash crop planting date and supplemental weed control techniques.

Simulation modeling (*Cycles*) will be used to develop look-up tables that guide nutrient management decisions for alternative site-specific reduced tillage scenarios that consider: 1) cash crop N demand, 2) cover crop species, biomass and termination/incorporation method, 3) N losses to the environment, 4) manure type, timing and application method, 5) and nutrient cycling factors such as crop rotation, soil type, plant available water and weather. This will require setting up simulations under many scenarios (e.g., 30-yr series per soil type using historical weather data), analyzing the results, and summarizing them in a useful format. This simulation database will enable growers to explore the results of El Niño years, for example, rather than 30-yr averages.

Year 2: Assembly & Evaluation: We will utilize our proposed on-station and on-farm research data to *evaluate* components of Cycles-OT. At each decision point, we will compare Cycles-OT output with observed outcomes in the field. We will use an iterative development-evaluation approach, and incorporate additional inputs or model outputs to increase the performance of Cycles-OT. This exercise will provide a test of concept. We will also coordinate an intensive advisory board workshop to evaluate Cycles-OT components and gather *feedback*.

Year 3: Evaluation & Co-Learning: In the spring, we will *facilitate* grower network learning circles that focus on spring cover crop management decision points. Decision trees and simulation model outputs will be distributed and grower cooperators, extension educators and research staff will co-present on how these tools may be utilized. Grower *feedback* will be utilized to refine the Cycles-OT beta-version. On-station and on-farm research data will be utilized again to *evaluate* decision tool components.

Year 4. Beta-Version Communication: A *web-based* beta version of Cycles-OT will be made available to our regional grower networks at the conclusion of the project. We anticipate that the *beta version* will include all conceptual components, but will be directed at a small target audience. In Year 4, we will utilize written extension materials and programming (fact sheets, newsletter articles, workshop presentations) to *communicate* conceptual components of Cycles-OT and advertise the web-based version to stakeholders. We will also monitor digital downloads and encourage user feedback.

Long-Term Goals. The long-term goal is to expand Cycles-OT geographically as the product is refined through interaction with growers and other users, and as knowledge is gained in our field research. Though we intend for Cycles-OT to become a web-based and/or mobile application in the long-term, we anticipate that cover crop and pest management decision tree components and elements of the nutrient cycling simulation outputs will be utilized in other written extension publications, such as fact sheets, case studies or the PSU Agronomy Guide to meet the needs of stakeholders who do not utilize web-based products.

Expected Results & Outcomes.

Experiment Station Research (O1). Our cropping system (S1-S4) treatments represent some alternative approaches for reducing tillage in an organic cover-crop based grain system over a 3-yr rotation (**Table 3**). Systems S2-S4 are designed to address the major grower-identified constraints of our current cropping system (S1) approach: 1) inconsistent termination of cover crops with the roller-crimper, 2) inconsistent establishment of cash crops in high residue, rolled cover crop mulches, 3) a narrow agronomic window for supplemental N supply to cash crops, and 4) geographic constraints to establishing overwintering cover crops following cash crop harvest.

Table 3. *Field operations for cropping system treatments (S1-S4) at PSU RELARC (O1).*

Field Operations	System 1 (S1)	System 2 (S2)	System 3 (S3)	System 4 (S4)
Corn Phase				
Cover crop (CC)	vetch + triticale	vetch + triticale	clover + timothy	clover + timothy
CC establishment	fall planting	fall planting	no-till drill seed	no-till drill seed
CC termination	roller-crimper	tillage	tillage	tillage
CC residue	surface mulch	incorporated	incorporated	incorporated
Manure timing	CC planting	corn planting	corn planting	corn planting
Tillage before corn	no-till	inversion	inversion	inversion
Corn production	silage	grain	silage	grain
Soybean Phase				
Cover crop (CC)	cereal rye	ryegrass + radish	cereal rye	ryegrass + radish
CC establishment	fall planted	inter-seeded	fall planted	inter-seeded
CC termination	roller-crimper	tillage	roller-crimper	tillage
CC residue	surface mulch	incorporated	surface mulch	incorporated
Tillage before soybean	no-till	minimum-till	no-till	minimum-till
Wheat Phase				
Tillage before wheat	inversion	minimum-till	inversion	no-till
Manure application	broadcast	broadcast	broadcast	subsurface band

We expect that these alternative approaches may create other agronomic challenges, benefits, or management tradeoffs within different phases of the rotation (**Table 4**). Our experimental design and interdisciplinary approach will allow us to compare the effect of alternative strategies on grower priority functions (weed suppression, insect pest regulation, N supply and retention, soil quality, crop productivity and short term profitability) throughout the rotation and characterize management tradeoffs.

Table 4. *Expected outcomes of cropping system treatments (S1-S4) at PSU-RELARC (O1).*

Field Operations	Cropping System Treatment Comparisons
Corn Phase	
Cover crop (CC)	Greater weed suppression w/ vetch (S1-S2); comparable N provisioning
CC establishment	Higher soil quality, insect predators & profit w/ no-till plant (S1, S3, S4)
CC termination	Greater volunteer cover crops w/ roll-killed hairy vetch (S1)
CC residue	Greater N availability & fewer insect predators w/ incorporation (S2-S4)
Manure timing	Greater N availability, corn productivity & profitability at planting (S2-S4)
Tillage before corn	Higher corn populations & greater perennial weed control w/ tillage (S2-S4)
Corn production	Higher short term profitability w/ corn grain (S2-S4)
Soybean Phase	
Cover crop (CC)	Greater weed control, insect predators & N retention with cereal rye (S1, S3)
CC establishment	Higher soil quality and short term profitability w/ inter-seeding (S2, S4)
CC termination	Volunteer CC will be greater in roll-killed cereal rye (S1, S3)
CC residue	Greater N availability & fewer insect predators w/ incorporation (S2, S4)
Tillage before soybean	Higher bean populations & greater perennial weed control w/ tillage (S2, S4)
Wheat Phase	
Tillage before wheat	Greater soil quality, insect predators & profits w/ min- (S2) and no-till (S4)
Manure application	Greater N uptake & less N loss with subsurface banding (S4)

On-Farm Research (O2). We expect that growers will prefer alternative approaches (S2 to S4) to reducing tillage that address the major constraints to adoption of the roller-crimper no-till method (S1). We also expect that management tradeoffs among weeds, insect pests, nutrient supply & retention, soil quality, crop productivity and short term profitability will be highly variable across on-farm sites.

Extension-Outreach (O3). We expect members of two current and one newly established regional organic crop producers' networks, including our farmer cooperators, will adapt information shared at on-farm network meetings to incorporate reduced-tillage practices in their farm operation. We also expect that members will place a high value on the quality of information received at network meetings, which will contribute to the growth and persistence of networks.

Decision-Support Tool (O4). Similarly to O3, we expect grower cooperators to utilize the beta-version of Cycles-OT to inform their decision making process related to reduced tillage practices and incorporation of cover crops. We also expect that members will place a premium on the decision support tool due to their involvement in its development.

	2014-2015			**2015-2016**			**2016-2017**			**2017-18**	
Research & Extension Activities	**10-2**	**3-6**	**7-9**	**10-2**	**3-6**	**7-9**	**10-2**	**3-6**	**7-9**	**10-4**	**6-9**
1. PSU Research Station Experiment											
Preparation & experiment initiation	X										
Data collection & analysis	X	X	X	X	X	X	X	X	X	X	X
2. On Farm Research											
Preparation & experiment initiation	X	X	X								
Data collection & analysis				X	X	X	X	X	X	X	X
4. Extension Education & Outreach											
Advisory board meeting	X			X			X			X	
Network meetings on cover crops	X			X	X				X		
Field days, webinars, articles					X		X		X	X	
5. Decision Support Tool Development											
Grower input, assembly & evaluation		X		X	X	X	X	X	X		
Communication										X	X

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