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***Project Title* -** Developing a decision framework that optimizes cover crop integration for weed suppression in Northeast cropping systems

Abstract-project summary. This is a joint research/extension project that involves Penn State University, the University of Maryland, Virginia Tech, the USDA-ARS unit at Beltsville, MD, and the Rodale Institute in Kutztown, PA. In this proposal, we are requesting approximately $126,000 directed toward research and $49,000 for extension. This project will develop a decision framework that optimizes cover crop integration for weed suppression in Northeast cropping systems. This proposal focuses on growers committed to reducing or eliminating tillage in their farming operation. We will evaluate the influence of varying cultural strategies for no-till cover crop management on weed management efficacy in several IPM-based systems.

The project has three main objectives, all are addressed through a coordinated regional approach. First, we will test the effects of cover crop planting date and termination date on weed management and subsequent crop yield across varying initial weed population density and emergence periodicity. Secondly, we will quantify the effects of soil fertility and cover crop seeding rates on cereal rye growth and development on weed establishment and success. Lastly, we will disseminate the results and educational message through grower meetings, on-farm research and a web-based decision support tool. Experiments and educational programs will target producers based on regional differences, management constraints and stakeholder interests. Demonstrations will provide for active participatory learning by farmers thereby increasing adoption and potential adjustment in regional constraints. In addition, these activities and results will be reported through traditional extension channels at grower meetings and at regional and state workshops and symposia. Program success will be evaluated through meeting attendance and participant surveys.

<u>Title:</u> Developing a decision framework that optimizes cover crop integration for weed suppression in Northeast cropping systems

Project Narrative

This is a joint research/extension project that involves Penn State University, the University of Maryland, Virginia Tech, the USDA-ARS unit at Beltsville, MD, and The Rodale Institute in Kutztown, PA. In this proposal, we are requesting approximately $126,000 directed toward research and $49,000 for extension. This project will develop a decision framework that optimizes cover crop integration for weed suppression in Northeast cropping systems. Over the past three years, the USDA Northeast-Region IPM priorities have repeatedly cited the need for alternative weed management systems, research and educational training focused on preventing weed seed production, establishment of weed thresholds, and web-based delivery of such information. All are components of this proposal. This proposal focuses on growers committed to reducing or eliminating tillage in their farming operation. We will evaluate the influence of varying cultural strategies for no-till cover crop management on weed management efficacy in several IPM-based systems. Through this coordinated research and outreach effort we will realize at least a 10% increase in adoption of cover cropping practices in our region over the next five years.

The project has three main objectives. First, we will test the effects of cover crop planting date and termination date on weed management and subsequent crop yield across varying initial weed population densities of economically important agricultural weeds with known difference in emergence periodicities (timing of weed emergence). Experiments will be conducted at Penn State University, Virginia Cooperative Extension, and at USDA-ARS Beltsville that target producers based on regional differences, management constraints and stakeholder interests. We believe that to provide adequate levels of weed management with surface mulches from cover crop residues, the time between cover crop planting and termination date must increase as the density of the weed seedbank increases. Secondly, we believe the efficacy of weed management will depend on timing of cover crop management and emergence periodicity of weed populations. We will test both these hypotheses.

In the second objective, we will quantify the effects of soil fertility and cover crop seeding rates on cereal rye growth and development, competitiveness, and subsequent impact on weed establishment and success on experimental research farms and on stakeholder farms in Maryland, Pennsylvania, and Virginia. Research locations conducting these experiments include The Rodale Institute (Pennsylvania), The Lower Eastern Shore Research and Education Center (LESREC) and Virginia Cooperative Extension. We believe that cereal rye cover crop competitiveness will increase with increasing soil fertility and cover crop seeding rate, and that increasing cover crop competitiveness during spring weed establishment will reduce summer annual weed emergence and fitness. In particular, management guidelines that better promote cover crop competition for weed suppression will help reduce herbicide use and provide important answers for organic growers.

Lastly, we will disseminate the results and educational message through grower meetings, on-farm research, farmer field days and demonstration, and through web-based decision support.

Demonstrations will provide for active participatory learning by farmers, thereby increasing adoption and potential adjustment in regional constraints. In addition, these activities and results will be reported through traditional extension channels at grower meetings, regional and state workshops, and symposia. All members of the team will participate in these activities. Penn State will lead the efforts on modifying and improving the web-based decision support tool. The Rodale Institute will actively promote the project and results on their New Farm website (www.newfarm.org). Program success and impact will be evaluated through participant surveys that gauge understanding of material and the intent to make changes in production practices based on the education programs.

A. The Problem, Background, and Justification

The Problem. Over the past ten years, farmers across the Northeast region have turned to cover crops as a means of enhancing soil quality while at the same time helping manage weeds in their crops. Cover crops are particularly well suited in our region because of the large number of dairy and small diversified farms where cover crops benefit soil quality and prevent soil erosion, sequester or add plant nutrients and help suppress weeds. Within the Mid-Atlantic region, there is considerable interest in integrating cover crops into no-tillage production systems where the cover crop provides green cover over winter, serves as a nutrient sink in the late winter and early spring, and provides a surface residue to minimize soil erosion losses and suppressive environment for weed recruitment and growth. Our regional team has been conducting programs in sustainable cover crop systems as well as worked as facilitators of farmer to farmer information exchange on cover cropping practices (see Appendix I). This ongoing effort has revealed several remaining constraints limiting greater adoption of cover cropping practices. These constraints include: 1) a biomass-based rule set for gauging when a cover crop should be terminated to accommodate the subsequent cash crop and 2) methods of achieving high levels of weed suppression from the cover crops. On the second point, more data is needed on the synchrony of cover crop growth and suppression and weed germination periodicity. In addition, from the numerous field days and grower workshops we have held, it is apparent that gauging the weed infestation level prior to implementing a cover crop practice is important to its success. We believe that through this coordinated research and outreach effort we have the potential of realizing at least a 10% increase in adoption of cover cropping practices in our region over the next five years.

Background. Weed management is consistently listed at or near the top of diversified grain and vegetable crop grower's pest management concerns and is an area highlighted in the 2005 NEIPM General IPM Priorities RFP. In fact, over the past three years, NEIPM priorities have repeatedly cited the need for alternative weed management systems, work focused on preventing weed seed production, quantification of thresholds, and web-based delivery of such information. All are components of this proposal. Furthermore in a survey conducted on research priorities with the Pennsylvania Association for Sustainable Agriculture (PASA) membership in spring 2002, cropping systems, tillage techniques and pest management were clearly recognized as priority areas for research and education (Francis 2002). About 40% of the cropping system priority topics identified in the PASA survey focused on cover crops and reduced tillage and about half of the identified pest management needs focused on weeds in organic and reduced pesticide use systems. Finally, a number of innovative farmers that participated in the

Department of Crop and Soil Sciences Producer Seminar Series at Penn State University as well as in our recent field days focused on ecologically-based weed management have expressed the strong need for both more research and education with cover crop integration and weed management using fewer herbicide inputs. In 2006, over 450 farmers and agricultural professionals participated in one or more field days in Pennsylvania that focused on integrating cover crops, reduced tillage, and ecologically-based weed management. Participants at these events confirmed through field day evaluations that weed management in reduced pesticide and organic conservation tillage cropping systems is a priority for research and education in the Northeast.

***Need for conservation tillage*.** The decrease in soil quality following the onset of intensive row crop cultivation (Doran and Parkin, 1994) has lead to a national effort to evaluate soil decline with the goal of conserving soil resources and preserving the productivity of arable landscapes. No-till technology for field crop production has a long, well documented record (30 + years) of effectively managing and improving the soil quality and resilience (Duiker and Myers 2005). The successful adoption of no-tillage agriculture is due in part to the adoption of herbicide resistant crops and the use of highly effective herbicides to reduce the economic damage of weed populations (Curran et al. 1996; Raimbault et al. 1990; Duiker and Myers 2005). However, concerns about non-point source contaminants degrading the quality of surface water supplies exist. The United States Geological Survey under the National Water-Quality Assessment Program, using surveys of 120 agricultural watersheds throughout the United States over the past decade, found that approximately, 95% of streams and 60% of shallow wells sampled were contaminated with pesticides (USGS-NAWA 1999; Barbash et al. 2001).

An additional challenge in continuous no-till crop production is the potential for selection of herbicide resistant weed populations. For instance, increased frequency or Roundup Ready ™ cropping phases within no-till crop rotations has predictably resulted in glyphosate resistant weed biotypes (Owen and Zelaya 2005). Surface water contaminants and declining re-registration of some herbicide product choices, coupled with the development of herbicide resistant weed populations, has prompted interest in research that focuses on reducing herbicide use while maintaining soil quality (Liebman and Gallandt 1997; Wyse 1994). To help reduce reliance on herbicides in no-till systems, many producers and researchers have turned to cover crop technology to physically suppress weeds with surface mulches.

The role of cover crop surface mulches in weed suppression. The relationship and underlying mechanisms (light and temperature) between cover crop biomass and physical weed suppression have been well documented (Mohler and Teasdale 1993; Yenish et al. 1996; Creamer et al. 1996; Zasada et al. 1997). In a review of cover crop contributions to weed management, Teasdale (1996) identifies three features of surface residues from winter annual cover crops that aid in weed suppression. First, weed control increases with increasing residue biomass. He suggests that residue quality (type) is considered to be less importance for weed suppression than amount of biomass accumulation (Mohler and Teasdale 1993). Cover crop residues 2 to 4 times the typical levels (3363 kg ha^{-1}) were considered to be necessary for adequate full season weed control (Mohler and Teasdale 1993). When retained on the soil surface, the residues physically and chemically suppress weeds leading to reduced densities (Mohler and Teasdale 1993). Physically, they suppress weed germination by reducing light penetration to the soil surface by lowering soil temperature. Mulches are also able to chemically suppress weeds, however less than if incorporated, through leaching of allelopathic compounds from precipitation. Second, weed control is species specific. Seed sizes and phytochrome-mediated germination are important mechanisms regulating success of mulch suppression. Smaller-seeded summer annual weeds with light requirements tend to be more effectively controlled.

In general, weed control using cover crops alone has been incomplete, suggesting that additional weed control inputs are necessary. With conventional growers, this generally means an herbicide application. Organic producers rely on mechanical control, which can be hand removal on a smaller scale or in-crop cultivation. Historically, research efforts have focused on the quantity of cover crop biomass accumulation in combination with herbicide rates required for adequate weed suppression (Mohler and Teasdale 1993; Curran et al. 1994). Recent advancements in cover crop residue management technologies (roller/crimper technology) have also increased cover crop biomass uniformity and persistence (Creamer and Dabney 2002), while reducing herbicide requirements through mechanical control of cover crops (Figure 1) (Mirsky et al. 2006; Curran et al. 2006). Roller/crimpers crush or crimp cover crops (Figure 2) to

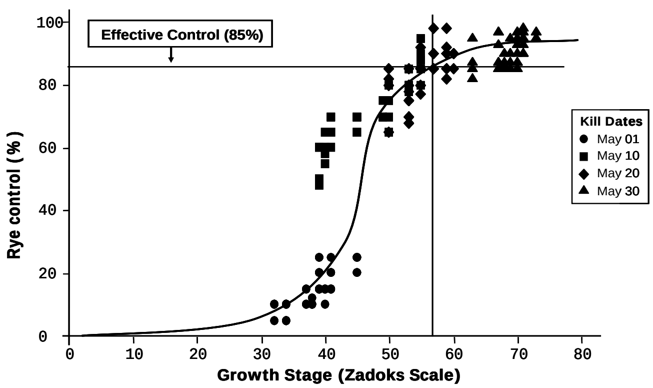

Figure 1. Efficacy of cereal rye termination using crimper/roller technology as a function of growth stage. The range in growth stages are a function of varying planting and termination dates.

Figure 2. Picture of a Penn State roller/crimper rolling a rye cover crop.

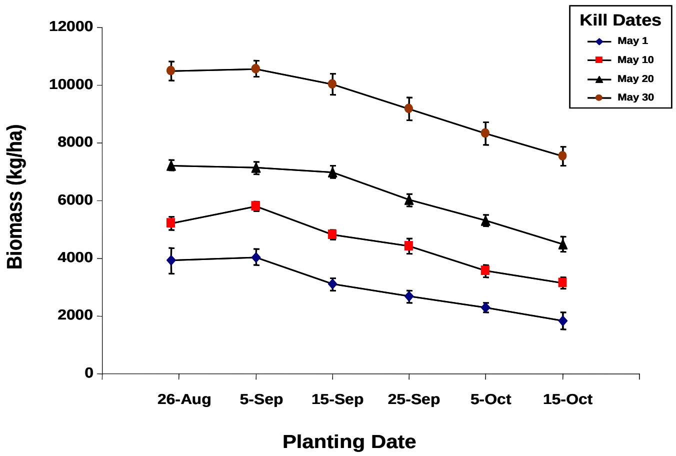

Figure 3. Accumulation of rye biomass across a range of cover crop planting and termination dates

stop growth, while depositing residues close to the soil surface. Roller/crimped cover crop residues are more intact with less exposed surface area than mowed cover crops, which can result in slower decomposition rates, potentially providing longer weed suppression (Creamer and Dabney 2002). In addition, while typical cover crop residue levels are considered to be insufficient for adequate weed suppression, wider ranges of biomass have been observed (Ashford and Reeves 2003; Mirsky et al. 2006b) that could greatly impact weed emergence and growth. In Central Pennsylvania, a cereal rye cover crop produced between 2000 to 11,000 kg ha^{-1} above-ground dry matter (Figure 3), depending on the timing of planting and termination (Mirsky et al. 2006b). Small changes in planting in the fall and killing in the spring can have a marked effect on cover crop growth and biomass accumulation. For example, delayed cover crop termination in the spring can result in markedly higher biomass accumulation and increased C:N ratios, resulting in slower decomposition rates and extending the physical suppressive effects of the cover (Ashford and Reeves 2003). Cover crop management guidelines using roller/crimpers are rapidly coming on-line from a number of different sources (www.va.nrcs.usda. gov/technical/crop_agronomy.html, http://newfarm.org/depts/notill/index.shtml).

Cereal rye and hairy vetch. Winter cereal rye and hairy vetch are widely used winter annual cover crops throughout the United States (Wilkins and Bellinder 1996; Hoffman et al. 1993). Cereal rye is used for its winter hardiness, high biomass production, and persistent residue (high C:N), while hairy vetch is commonly used for its soil quality contributions including N production (Teasdale 1996). Inherent in this project is the use of herbicides and/or mechanical methods for control of cover crops. These tactics are essential for no-till management systems. Roller/crimper technology has been evaluated at several universities as well as in the private sector for control of both cereal rye and hairy vetch. At anthesis, >80% control was observed for cereal rye (Ashford and Reeves 2003; Mirsky et al. 2006b), and > 95% control at mid to late bloom for hairy vetch (Hoffman et al. 1993). These experiments were designed to test control at specific life stages rather than examining mechanical control across a continuum of growth stages. We believe that basing termination on growth stage may overestimate the cover crop maturity required for adequate control. In addition, the interactions between planting and termination date, cover crop growth stage and biomass production, and weed suppression have not been thoroughly investigated.

Until recently, a major problem slowing adoption of no-till systems has been the lack of available equipment. Most of these problems are seeking engineering solutions. At the same time, equipment and associated technology have been developed over the last 10 years to help alleviate problems associated with working in high residue crops (Morse 1998). In addition, slight modifications in crop management can mean the difference between success and failure. In a recent Penn State study, corn planted into late-killed cereal rye produced yields similar to corn planted into early killed rye and the results suggested that killing the cover crop 7 to 10 before planting along with providing adequate N were critical components for the no-till corn cover crop system (Duiker and Curran 2005). This project will investigate some of the biological questions, particularly focusing on weeds in high residue systems that can limit the success of no-till production.

Weed germination periodicity and implications for initial infestation level on weed management.

Time of emergence is influenced by cropping history, environmental conditions, and tillage (Myers et al. 2005a; Hartzler et al. 1999 and Ogg and Dawson 1984). Research in Iowa and Pennsylvania found that although the initial emergence date varied slightly among years, the order of species emergence was surprisingly consistent, with common ragweed and common lambsquarters emerging early, and giant and yellow foxtail and the pigweeds emerging considerably later (Hartzler et al. 1999 and Myers et al. 2005b). A similar experiment in Washington State showed the order of emergence of eight weed species was consistent over years, and tillage affected the magnitude of weed species emergence but not the emergence pattern (Ogg and Dawson 1984). Quantifying weed seedling emergence, using daily air and soil temperatures, and precipitation, have been investigated for modeling weed populations, forecasting tools, and for economically based weed management decision aids (Forcella et al. 1997).

In a completed NE-IPM project entitled *Verification of web-based pest real-time high-resolution weed and insect predictive models for northeast IPM programs,* our team coupled field studies with mathematical models to generate state-wide emergence prediction maps for eight weeds and three important insect species. A number of papers have been published as an outgrowth of that work (Myers et al. 2005a; Myers et al. 2005b) and subsequently adapted for outreach education (Mortensen et al. 2006 and Appendix A). Our goal is to expand on our previously conducted work in several important ways. In order to optimize the suppressive effects of cover crops for Northeast agriculture, the suppressive effects of the covers must be in synchrony with the germination periodicity of the problem weeds in the production system. For example, if a cover crop is suppressed early leaving relatively little biomass for weed suppression and the dominant weed flora emerges several weeks or months later, the cover crop will have little suppressive effect on the emerging weeds. On the other hand, if the cover crop is suppressed late after a considerable amount of biomass has been produced, weed suppression may be optimized, but the cover crops draw down of water in the soil profile may limit the growth of the cash crop (Williams et al. 2000). Lastly, if a weed species emerges early before adequate cover crop growth in the spring is available for suppression, then the weed can have a competitive edge and survive and compete with the cash crop.

Efficacy of weed management in cropping systems with reduced reliance on herbicidal weed control is relatively lower and more variable than conventional herbicide management programs (Forcella et al. 1993; Moore et al. 1994). Low initial weed seed densities within the soil have been suggested to be critical to the success of implementing or transitioning to non-chemical weed management practices (Forcella et al. 1993). Empirical studies testing this relationship systems. The project will be accomplished through three objectives. The first two research objectives will be conducted at different locations in Pennsylvania, Maryland, and Virginia. In objective 3, we will then use a well-established outreach program to effectively communicate our findings to interested stakeholders. Specific research and outreach commitments are provided in table 1.

Objective 1. Test the effects of cover crop planting date and termination date on weed management and subsequent crop yield across varying initial weed population densities and emergence periodicities.

Hypothesis 1-1. To provide adequate levels of weed management with surface mulches from cover crop residues, the time between cover crop planting and termination date must increase as the density of the weed seedbank increases.

Hypothesis 1-2. Efficacy of weed management will depend on timing of cover crop management and emergence periodicity of weed populations.

Objective 2. Quantify the effects of soil fertility and seeding rates on cereal rye growth, competitiveness, and subsequent weed suppression of summer annual weeds using roller/crimper technology in the Mid-Atlantic region.

Hypothesis 2-1. Cereal rye competitiveness will increase with increasing soil fertility, and cover crop seeding rate.

Hypothesis 2-2. Increasing cereal rye competitiveness during spring weed establishment will reduce summer annual weed emergence and fitness.

Objective 3. Disseminate the results and educational message through grower meetings, on-farm research and a web-based decision support tool.

Anticipated Impacts. This project will develop phenological and biomass-based rules for gauging when a cover crop should be terminated to achieve optimum weed suppression and accommodate the subsequent cash crop. Intrinsic to this work, we will identify the synchrony of cover crop growth and weed suppression as it relates to weed emergence periodicity as well as level of weed infestation (thresholds). We believe there are a number of positive impacts associated with the research as described in this ***Project Narrative***.

1.) Through this coordinated research and outreach effort we have the potential of realizing at least a 10% increase in adoption of cover cropping practices in our region over the next five years. Greater cover crop adoption will reduce soil erosion and loss of nutrients and pesticides resulting in improved water quality; promote sequestration of excess soil nutrients and produce nitrogen with legume cover crops; and help build and improve soil quality potentially increasing crop yields.

between initial weed seedbank size and chemical weed management efficacy, while limited, have been reported for (Dieleman et al. 1999; Taylor and Hartzler 2000; Neeser et al. 2002). More recently, Mirsky et al. 2005 (Figure 4) found that high initial velvetleaf densities resulted in disproportionately lower weed management efficacy, even when the control methods were mechanical. The observed density dependent nature of weed control, and the fact that mortality is generally less than 100% for reduced herbicide and organic producers, shows the importance of initial weed infestation levels on weed control. We recognize that this relationship will depend on weed species, genetic variation in tolerance to mortality within the species, the actual mortality event, and the soil and crop environment. However, if the relationship holds as existing data suggests that it will (Dieleman et al. 1999; Taylor and Hartzler, 2000, Neeser et al. 2002), the implications for management could be profound. Profound because past research suggests that at lower weed densities less intensive weed management is needed to achieve acceptable weed suppression (Dieleman et al., 1999; Hartzler and Roth, 1993). While weed management efficacy (mortality) has not been demonstrated to be density dependent in cropping systems using cover crop surface mulches for weed control, clearly the relationship between initial weed seedbank size and efficacy of weed management at different thresholds has important implications for growers using ecologically based weed management practices.

This proposal includes both a weed emergence timing component as well as a weed density threshold variable. We believe that identifying successful management of weeds considering both emergence timing and weed density using cover crop surface mulches can greatly increase their utility in no-till crop production systems.

Justification. Over the past three summers members of this proposal team have conducted research and outreach programs that have complemented one another, all centered on incorporating cover crops into reduced tillage production systems in the northeast. For example, at one all day outreach program at Cedar Meadow Farm (managed by Mr. Steve Groff) Penn State, Pennsylvania Association for Sustainable Agriculture, the Rodale Institute and Virginia Cooperative Extension and Research Scientists conducted a program centered on the use of cover crops in grain and vegetable production. Some 250 farmers attended the field day including 75 who chartered a bus from Staunton, Virginia to attend. The combination of growing interest in incorporating cover crops for manure management and as a method to reduce or eliminate herbicide use has resulted in heightened interest in adopting cover crops in production systems. The combination of farmer interest, market demand (for organic grains and vegetables), and environmental stewardship has moved the farming community to a "tipping point" with respect to cover crop adoption. Yet, practical agronomic questions remain, questions identified through our own research and through comments by our growers. We believe a concerted effort to conduct the research outlined herein and an effective outreach program will significantly increase the adoption of sustainable pest management practices through increased adoption of cover crops in no-tillage production systems.

B. Objectives and Anticipated Impacts

This project will develop a decision framework that optimizes cover crop integration for weed suppression in Northeast cropping systems. We will evaluate the influence of varying cultural strategies for no-till cover crop management on weed management efficacy in several IPM-based

2.) Increased weed suppression by cover crops will allow for lower herbicide rates, fewer herbicide applications, fewer problems with herbicide resistant weeds, and greater adoption of sustainable and organic agriculture.

3.) The educational outreach activities in this project will deliver IPM information directly to at least 1000 growers and agricultural professionals through on-farm trials and associated field days, grower meetings, and other cooperative extension and private sector-sponsored programs. Educational programs will be conducted in three northeastern states at university and Agricultural Research Service research farms, with cooperating growers, and at the Rodale Institute in Pennsylvania. The web-based weed emergence prediction tool is currently available on-line through Penn State at http://psu.zedxinc.com/cgi-bin/site.cgi?location=2&user=psu. This web-based tool includes both insect and weed prediction components. This project will further refine the weed portion of this product thereby increasing site visits, page views, and the use of web-based technology. Our goal is to increase the use of the weed emergence prediction models and thereby increase IPM adoption. In addition, the Newfarm.org website from The Rodale Institute will also provide an outlet for project findings, and will link readers to the Penn State web-based weed emergence tool. Newfarm.org highlights sustainable agriculture news and research in a webzine that reaches over 85,000 farmers monthly (Hepperly, personal communication), thus providing a mechanism for rapid exchange of information pertaining to cover crops in no-till production systems and resulting in increased cover crop adoption.

Table 1. Project directors and collaborator research and outreach commitments

Objective	**Treatment factors**	**PSU**	**USDA-ARS**	**VA Ext.**	**U of M Ext.**	**The Rodale Institute**
1	Planting Date	X				
	Termination Date	X	X	X		
	Weed Density	X	X	X		
	Weed Species	X	X	X		
	IPM-Conventional	X		X		
	IPM-Organic	X	X	X		
2	Seeding Rate			X	X	X
	Fertility Rate			X	X	X
3	On-Farm Research			X	X	X
	Field Days	X	X	X	X	X
	Web-Based Decision Support	X				X

C. *Approach and Procedures*

measured in each plot by clipping all plant material $\geq$ 1-cm in height from two 0.5-m^2 quadrats per plot. A burndown herbicide will be applied about 24 hours prior to rolling/crimping the cereal rye cover crop. The IPM-organic treatments will rely on rolling/crimping alone for cover crop control. Glyphosate will serve as the burndown treatment for cereal rye and 2,4-D LVE for hairy vetch. The IPM-conventional treatment will use the burndown herbicide application as the sole termination tactic for hairy vetch (previous research has showed that herbicide plus rolling is redundant for control of hairy vetch). Cash crops will be planted 7 to 10 days following rolling/crimping, or the burndown herbicide application. Field corn and soybean will be planted in rows spaced 19 and 76 cm apart, respectively. Individual plots will measure 3 by 9 m. P and K will be applied prior to soybean and corn planting based on soil tests. Nitrogen requirements for corn will be rely on residual N provided by the hairy vetch cover crop. Timing of cash crop emergence will be monitored during the emergence period and following emergence cash crop growth stage (v-stage) will be recorded four times at two week intervals to determine crop growth and development. Crop population density will be quantified by counting two rows the entire length of the plot. Plots in the IPM-conventional systems will be further split in half and receive a selective post-emergence herbicide application following the early summer weed seedling density measurement. Crop yield will be recorded from the herbicide treated areas or 0 weed density subplots.

Environmental Monitoring Procedures. For all locations, environmental monitoring will include 2.5 cm soil temperature measurements and rainfall on a daily basis using field based data loggers. Soil degree days will be calculated from recorded soil temperature data. Monitoring of rainfall will begin in the spring, collecting from March through August. Monitoring of soil degree days will begin on January 1 for each location and continue until weed emergence ceases.

Partial Budget Analysis. The economic performance of the contrasting cover crop management systems will be assessed using partial budgeting methods described previously (Liebman et al. 1993). In short, the change in expected profitability will be measured in the "test crop," (corn or soybean). The benefits or disadvantages of increasing cover crop residues, better weed suppression, delayed planting date, and organic management will impact crop yield and profitability.

Expected Results. Field studies are expected to provide strong evidence for or against the economic value of establishing and terminating from early to late, cover crops, based on severity of the weed infestation. Secondly, we believe the efficacy of weed management will depend on timing of cover crop management and emergence periodicity of weed populations. Conducting the study under conditions as close as possible to those practiced by farmers will enhance the likelihood that results quantifying cover crop biomass and weed suppression can be inferred to on-farm settings.

Analysis and Interpretation. Analysis of variance will be conducted using general linear (PROC GLM SAS/STAT) or mixed model (PROC MIXED SAS/STAT) where appropriate. To examine causal relationships, regression and multivariate analyses will be conducted.

Targeted stakeholders. The following experiments will target producers based on regional differences in cropping practices and stakeholder interests. Those stakeholders include: no-till cash grain, no-till livestock feed grain, rotational tillage organic grain, and rotational tillage vegetable producers (Table 2).

Increasing cost of mineral fertilizer has made legume based fertility favorable for cash grain producers. Delayed cover crop termination and high levels of cover crop biomass are necessary to achieve adequate nitrogen concentrations required for legume-based fertility. Additionally, delayed cover crop termination is also necessary for organic producers relying solely on mechanical management. However, delaying cover termination can result in increased pest and management constraints (e.g. slugs/cutworms, and poor crop stands). Both producers are interested in optimizing cover crop biomass accumulation, nutrient availability, and weed suppression.

In contrast, livestock grain producers are often not limited by soil fertility and thus terminate cover crops earlier so that cash crops can be planted early. Primary cover crop benefits for these producers include reduced soil erosion and nutrient losses over winter, reduced herbicide applications in cash crops, and increased opportunities for manure applications.

Finally, vegetable producers are unique in their ability to fit cover crops into their rotation, often having greater flexibility in when crops are planted. Vegetable producers use cover crops for mulch based no-till systems. Vegetables like cucurbits are particularly well adapted for this system because cover crop mulches provide a barrier between fruit and the soil.

Table 2. Targeted stakeholders and cropping systems.

Stakeholders	Cover cropping system
No-till cash grain producers	Legume-Corn Winter cereal-Soybean
No-till livestock/corn forage producers	Legume-Corn silage
Rotational tillage organic cash grain producers	Legume-Corn Winter cereal-Soybean
Rotational tillage sustainable and organic vegetable producers	Winter cereal/legume-Cucurbits

Objective 1. Test the effects of cover crop planting date and termination date on weed management and subsequent crop yield across varying initial weed population densities and emergence periodicities.

Cover cropping systems evaluated. Field experiments will be established at the Russell E. Larson Agricultural research Center in Rock Springs, Pennsylvania and Beltsville Agricultural Research Center in Beltsville, Maryland, to evaluate the effects of timing of cover crop management across a range of weed emergence periodicities on weed suppression and subsequent cash crop yields. The experiments will be established in the fall of 2007 and again in

2008 in a modified split-split plot, randomized complete block design with four replications. The following three cropping systems will be evaluated using conventional and organic methods: 1) a soybean cash crop no-till drilled into an over-winter cereal rye cover crop, 2) corn for grain no-till planted into an over-winter hairy vetch cover crop and 3) corn silage no-till planted into an over-winter hairy vetch cover crop. Soybean and corn trials will be conducted as separate experiments. Main plots treatments will be organized in a modified factorial arrangement focused on four main treatment factors (Table 3). Cover crop fall planting date will be the first factor, consisting of 1 or 2 fall planting dates, depending on cover crop selection (two dates for cereal rye). The cropping systems using hairy vetch will only have one planting date since later planting results in higher over-winter mortality. The second factor is timing of cover crop termination, consisting of three termination dates in the spring. The hairy vetch-corn cropping system for organic producers will be modified to allow a delay in termination in order to achieve adequate control of the cover crop.

Table 3. Number of treatments per factor for rye (soybean) and hairy vetch (corn) cropping systems.

Treatment factors	**Cereal rye**		**Hairy vetch**	
	IPM-conventional	**IPM-organic**	**IPM-conventional**	**IPM-organic**
Planting dates	2	2	1	1
Termination dates	3	3	3	1
Weed density	3	3	3	3
Weed species	3	3	3	3

Establishment of synthetic weed seedbanks. The influence of weed emergence periodicity and initial weed seedbank size on weed suppression will be assessed by establishing three species at varying initial seedbank densities that have known differences in emergence periodicity. The three species chosen for the study are often the dominant species in the Mid-Atlantic region (Myers et al. 2005). Those species include: Common ragweed (*Ambrosia artemisiifolia*), an early emerging broadleaf species, giant foxtail (*Setaria faberi*) a late spring emerging grass species, and smooth pigweed (*Amaranthus hybridus),* an early to mid summer emerging broadleaf species. Weed seeds will be dispersed at three seedbank densities in 0.25 m^2 wide bands across the entire main plots at 0, 400, and 1500 seeds m^{-2} in the fall at cover crop establishment. The effect of varying emergence periodicities and initial weed seedbank densities will be determined by assessing weed seedling recruitment and survivorship at three intervals (spring, early, and late summer). Seedling emergence will be quantified by randomly placing two 0.25 m^2 quadrats within each density plot and counting the target weed species.

Management of the cover crops and test crop. Cover crops will be drill seeded on 19 cm rows at 120 kg/ha for cereal rye and 30 kg/ha for hairy vetch. Percentage of soil cover, a metric for cover crop competitiveness, will be estimated in late autumn and early spring using a visual rating system (Teasdale et al. 2004; Brandaester and Netland 1999). Cover crop biomass, phenology (growth stage - Zadoks scale, Zadoks et al. 1974), and height will be sampled within the sub-sub-plots prior to each termination event. Above ground cover crop biomass will be

Objective 2. Quantify the effects of soil fertility and seeding rates on cereal rye growth, competitiveness, and subsequent weed suppression of summer annual weeds using roller/crimper technology in the Mid-Atlantic region.

Hypothesis 2-1. Cereal rye competitiveness will increase with increasing soil fertility, and cover crop seeding rate.

Hypothesis 2-2. Increasing cereal rye competitiveness during spring weed establishment will reduce summer annual weed emergence and fitness.

Cultural practices. Evaluating the effects of soil fertility and seeding rate on cereal rye growth, competitiveness, and subsequent weed suppression will be a multi-regional effort tested on experimental research farms and on stakeholder farms in Maryland, Pennsylvania, and Virginia. Research stations conducting these experiments include The Rodale Institute (Pennsylvania), The Lower Eastern Shore Research and Education Center (LESREC) and Virginia Cooperative Extension. Current collaborations with producers in these regions will facilitate on-farm experimentation and outreach. The experiments will be established in the fall of 2007 and again in 2008 in randomized complete block designs with four replications. Cereal rye will be drill seeded on a 19 cm row spacing at 135, 202, and 270 kg ha^{-1}, with supplemental N fertility rates of 0, 56, and 112 kg ha^{-1}. Mineral and/or organic sources of N fertilizer will be used, depending on location and farm. Organic farms will apply manure based on P application rates with supplemental N application from other certified organic sources. Fertilizer N applications will be split with half in the fall and half in the spring. P and K will be applied prior to the cash crop based on soil tests and additional N supplements will be provided if necessary using an appropriate fertility supplement. Cash crops will include soybean, pumpkin, or other vegetable systems based on region and farmer cooperators.

Percent ground cover will be estimated in late autumn and spring using a visual rating system (Teasdale et al. 2004; Brandaester and Netland 1999). Cereal rye biomass will be collected at two intervals, first in the spring to evaluate cover crop competitiveness at the beginning of weed emergence, and second at termination of cover crop with roller/crimper technology. Cover crop termination will occur at each location when cereal rye begins anthesis (Figure 1. Growth stage = 60). The effect of seeding rate and soil fertility rate on subsequent weed seedling recruitment will be assessed at three intervals spring, early, and late summer. Cereal rye biomass, percent ground cover, and weed recruitment densities will be measured as reported for objective 1. Crop yield will be measured if deemed appropriate.

Objective 3. Disseminate the results and educational message through grower meetings, on-farm research and a web-based decision support tool.

Grower meeting and on-farm research. In Pennsylvania, Maryland, and Virginia, mechanical control of cover crops will be demonstrated across a range of termination dates. The partners have a great deal of experience with cover crops and their management. These demonstrations will center on components of objectives 1 and 2 within this proposal focusing on one to three management variables. As an example, weed seedbanks ranging in species and emergence periodicity will be incorporated within the current on-farm experiments. In Maryland one such demonstration would contrast the impact of incorporated cover crops vs. those left on the surface in a no-till practice where a roller/crimper is used to lay the cereal rye down (Figure 2) on an organic farm struggling with summer annual weeds. Demonstrations will showcase relevant, site-specific demonstrations of cover crop practices our stakeholders have specifically asked for thereby increasing the likelihood of adoption. In addition, these activities and results will be reported through traditional extension channels at grower meetings and at regional and state workshops and symposia.

Web-based decision support. The current web-based real-time weed emergence forecasting tool developed at Penn State (Figure 4) does not currently include emergence forecasting for no-tillage systems where high crop residue is known to influence emergence prediction (Myers et al. 2005). Data collected in this project will be used to modify and improve emergence forecasting thereby increasing the applicability and reliability of this forecasting tool. In addition to contributing data to the current web-based prediction tool, educational training sessions that promote its utility will be conducted with extension educators, consultants, and producers across the state with the goal of increasing the adoption of web-based prediction models.

The Rodale Institute's Newfarm.org website will provide additional outreach capacity by publishing a series of updates from each of the collaborators, and an overall report when the project is complete. The Newfarm.org site has tracked over 30,000 hits to its No-Till Roller page within the first year and a half of it being posted, and has continued to serve as one of the main sources of information on cover crop based no-till cropping systems. Farmers visiting the site will read about cover crop planting and termination date effects on weed suppression will also see an information sidebar with a link to the Penn State weed emergence web tool. This real time outreach will increase adoption of IPM in the Northeast by enabling farmers with the information they need for better management.

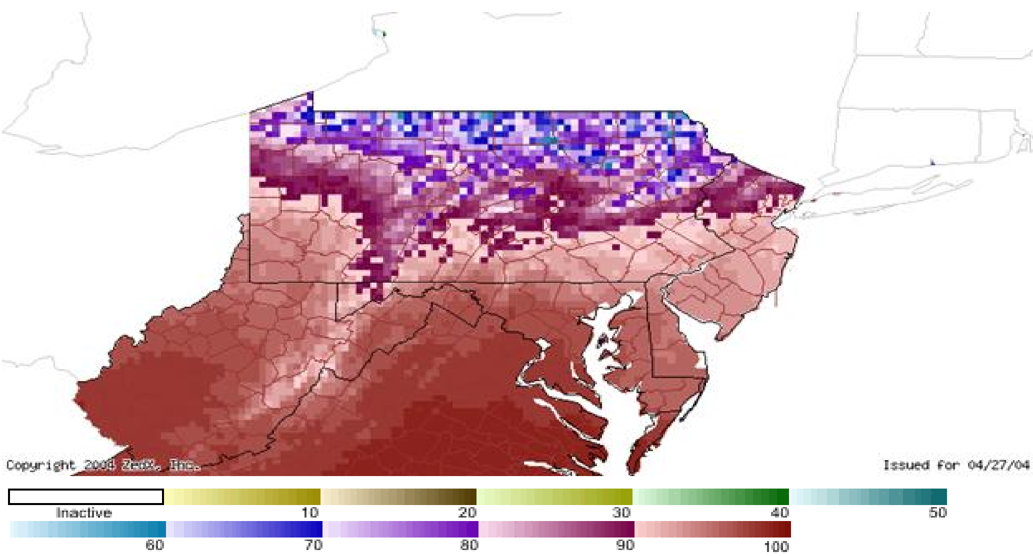

Figure 4. An emergence map for common ragweed April 28, 2004. This web-based tool is available at http://psu.zedxinc.com/cgi-bin/site.cgi?location=2&user=psu.

D. *Implementation and Evaluation Plans*

Evaluation of cover cropping/weed management systems experiments in Pennsylvania, Virginia, and Maryland. Our team has a very strong history of outreach education being actively involved in conducting field days, grower meetings, and other educational programs throughout the Northeast. Pest management tactics elucidated in this proposal will be implemented rapidly though the activities in Objective 3 of this project. The experiment station and on-farm research will capture general concepts from the cover cropping system research and demonstrate these concepts to producers, educators, and other interested individuals. In addition, results from this project will be distributed through traditional extension education channels via workshops, conferences, and other educational activities. Both public agency (i.e. NRCS) and private sector organizations (e.g. Pennsylvania Association of Sustainable Agriculture and Future Harvest of Maryland) will help disseminate results. Finally, the research results will be distributed through traditional scientific avenues such as regional and national conferences and through journals and proceedings. A timeline for these activities are shown in table 4.
We will actively evaluate these educational activities documenting key metrics of implementation success. For example, in our last USDA NEIPM funded project, we surveyed attendee's at a field day training in 2005. The results of this survey showed that 74% had large gains and 26% had moderate gains in understanding of how to use weed emergence prediction maps. In addition, 53% of those attending were highly likely and 42% were moderately likely to use the web-based weed emergence maps to help better manage insects and weeds on their farms or for their farm customers. This project will increase the relevance of the web-based tool resulting in enhanced adoption.

On-farm demonstrations. Field days will be conducted at times when the educational message is most clearly seen in the field. In Pennsylvania, Maryland, and Virginia, field days will serve as a forum to show first-hand the opportunities and benefits of cover crops in no-tillage production systems. A successful field demonstration includes a trial or event that presents a message or provides additional data, well-attended educational activities, and those in attendance leave the activity with increased knowledge of how the production system enhancement could be adapted to fit individual production systems. One metric of effective outreach is high levels of interest in our field demonstrations. Over the past two summers our research and outreach group has conducted no fewer than 18 field oriented field days, *Weed Ecology* Workshops, and training sessions for extension educators reaching approximately 2,000 participants. We will continue to evaluate the success of the educational activities outlined in the proposal through attendance at the field days and surveys conducted at each event. The survey will ask participants about the quality of the program and what they learned as a result of attending. In addition, the survey will attempt to identify whether the grower will implement any specific practices (i.e. reduced pesticide use and increase cropping system diversity) as a result of attending the educational program. The PI's on this project have had extensive experience in evaluating program success.

Table 4. Timeline of activities.

Year	Season	Activities		
		1st Run	2nd Run	Outreach
2007	Fall	Establish cover crops and weed seedbanks		

2008	**Spring**	Cover crop termination/ cash crop establishment		
	Summer	Data collection		Field days
	Fall	Data collection	Establish cover crops and weed seedbanks	New Farm progress report Extension meeting
2009	**Winter**			Regional conferences
	Spring		Cover crop termination/ cash crop establishment	New Farm progress report
	Summer		Data collection	Field days
	Fall		Data collection	New Farm progress report
2010	**Winter**		Data analysis and write-up	New Farm progress report Regional conferences Web-based decision support
	Summer			Follow-up survey Web-based decision support

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Key Personnel

A. The Pennsylvania State University

William S. Curran is a Project Director and Co-principal investigator. Dr. Curran is a Professor of Weed Science and Agronomy at Penn State and has statewide responsibilities for extension and research in weed management. Dr. Curran has an extensive background in applied field research in agronomic crops including the use of cover crops in conservation tillage. Dr. Curran will be responsible for oversight, management, and reporting of all activities related to this project. In addition he will co-advise a Postdoctoral Research Scholar hired for this project

David A. Mortensen is a Co-principal investigator. Dr. Mortensen is a Professor of Weed Ecology at Penn State with a research and teaching appointment focused on ecologically-based weed management. Dr. Mortensen has an extensive background in conducting weed biology and ecology research and will co-advise a Postdoctoral Research Scholar hired for this project and will help direct both the research and education activities of the project.

Steven B. Mirsky is a Co-principal investigator. Mr. Mirsky is currently finishing his PhD degree in Agronomy at Penn State. His dissertation research is focused on the impact of cropping system diversity on weed seedbank dynamics. Mr. Mirsky will be employed as a Postdoctoral Research Scholar working on this proposed project. Mr. Mirsky will serve as project manager for the Penn State research as well as help manage, process and interpret data and results for all locations.

B. USDA-ARS

John Teasdale is a collaborator with USDA ARS. Dr. Teasdale a Plant Physiologist and the Research Leader with the USDA-ARS Sustainable Agricultural Systems Laboratory in Beltsville, MD. Dr. Teasdale conducts research to develop sustainable cover crop and integrated weed management systems and to understand mechanisms underlying weed population dynamics within sustainable agro-ecosystems. Dr. Teasdale will help direct the field-based research across all locations and will be responsible for activities at the ARS research unit.

C. Virginia Cooperative Extension

Brian Jones is a collaborator with Virginia Cooperative Extension. Mr. Jones is an Extension Agent in the Department of Crop and Soil Sciences. Mr. Jones serves a five county area in the Shenandoah Valley of Virginia, including the top two agricultural counties in the state. Mr. Jones will be responsible for conducting the research and educational activities outlined in Virginia.

D. University of Maryland Cooperative Extension

Laura Hunsberger is a collaborator at the University of Maryland and serves as an Extension Educator in agriculture and natural resources in Worcester County, MD. Laura assists farmers in a tri-county area in fruit and vegetable production, organic farming, sustainable agriculture, environmental concerns, and small farms. Ms. Hunsberger will be responsible for conducting experiments and demonstrations on the Eastern Shore of Maryland as well as coordinating extension activities associated with this project in her region.

E. The Rodale Institute

Paul Hepperly is a collaborator with the Rodale Institute. Dr. Hepperly is the Research and Educational Director at the Institute and in this capacity, he helps combine research, education and informational outreach to promote the development of organic and sustainable farming and food systems worldwide. Dr. Hepperly will be responsible for coordinating experiments and educational outreach activities at the Institute that are associated with this project.

A. Appendices to Project Narrative

1. Mortensen, D., W. Curran, M. Ryan, A. Hulting, and S. Mirsky. 2006. Weed germination periodicity: When do weeds wake up? Dept. Crop & Soil Sciences, College of Agricultural Sciences, University Park, PA 16802.

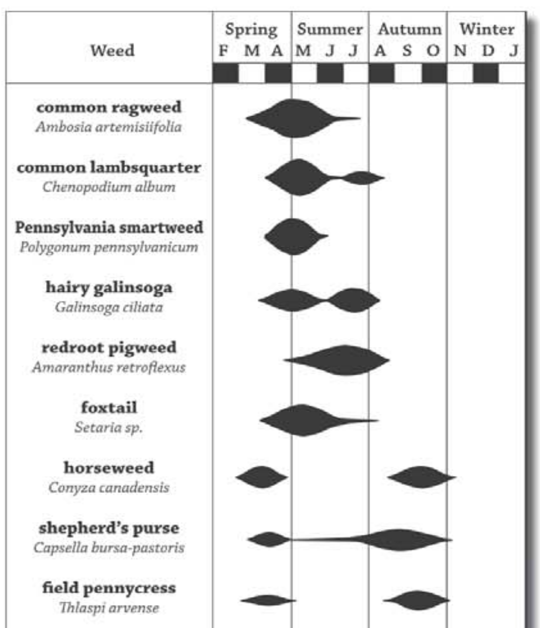
WEED GERMINATION PERIODICITY:

When Do Weeds Wake Up?

Tilling time *does* make a difference!

When we plant a grain or vegetable crop, we expect the seeds to germinate if the soils are warm enough and sufficiently moist. Seed germination for wild plants, including weeds, also requires sufficiently warm and moist soils, but in addition weed seeds possess controls that prevent seeds from germinating, called dormancy. Dormancy comes in a number of forms in weedy plants. Some seeds, like those of velvetleaf and morningglory, are hard-seeded. Here seeds remain "asleep" until the seedcoat is sufficiently etched by organic acids in the soil. Other seeds are sensitive to light, exhibiting the phytochrome response. Here, light quality, specifically a shift in the balance of near and far-red light, will wake seeds up (break dormancy). That shift in light or flash of light is provided by tillage. Weed seeds, like crop seeds, are genetically programmed to germinate once a minimum temperature is exceeded. Unlike crop plants, weed seed germination can be "turned off" once the germination temperature range is exceeded. Recent research on seed dormancy has revealed that weed seed dormancy operates like a combination lock with a number of tumblers that must be aligned for the lock to be opened, for weed seeds to germinate. In effect, each of the tumblers represents an opening and when these tumblers or openings are aligned, seeds germinate. These tumblers define the germination period for each weed species. These periods have been a subject of considerable study and we know that some species germinate in the fall of the year, some in early summer, while others germinate in mid and late-summer. If any of the tumblers aren't aligned, the seeds don't germinate at all, persisting in the soil weed seedbank. Weed seed can persist in a dormant state for several years to decades.

Time of field operations can take advantage of germination periodicity. Tilling the soil early will stimulate early summer annual weeds, such as common ragweed and common lambsquarters, to germinate. Tilling three or four weeks later results in little or no common lambsquarter and common ragweed emergence. The scientific basis for delayed planting as a weed management practice is called ***weed seed germination periodicity***. Planting later in the season takes advantage of the fact that many weed seed have "gone back to sleep" for the remainder of the field season.



Proportion of weed seeds germinating throughout the season in central Pennsylvania.

Myers, M.W., W.S. Curran, M.J. Vangessel, B.A. Majek, D.A. Mortensen, D.D. Calvin, H.D. Karsten and G.W. Roth. 2005. Effect of soil disturbance on annual weed emergence in the northeastern United States. Weed Tech. 19:274-282.

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PENNSTATE

Scientific Content: Dave Mortensen, Bill Curran, Matt Ryan, Andy Hulting, and Steven Mirsky, Weed Ecology and Management, Department of Crop and Soil Sciences, The Pennsylvania State University, University Park, PA.

Data Visualization and Design: Libby Mortensen and Dave Mortensen. For additional copies email dmortensen@psu.edu

The RODALE INSTITUTE®

Proposal Title:
Developing a decision framework that optimizes cover crop integration for weed suppression in Northeast cropping systems

A collaborative effort between researchers at The Pennsylvania State University, USDA-ARS Beltsville Maryland, The University of Maryland Cooperative Extension, Virginia Cooperative Extension and The Rodale Institute.

Basic Objective:
This project aims to evaluate the influence of cultural strategies of cover crop management, in both conventional and organic farm operations, on no-till crop production systems.

Statement of Work:
Objective 1: Test the effects of cover crop planting date and termination date on weed management and subsequent crop yield across varying initial weed population density and emergence periodicity.
Objective 2: Evaluate the potential for increasing cover crop competitiveness on weed management during seedling emergence of summer annual weed populations.
Objective 3: Disseminate the results and educational message through grower meetings, on farm research, and a web-based decision support tool.

Virginia Cooperative Extension responsibilities:
Brian Jones, ANR extension agent in the central Shenandoah Valley, will be leading the effort for Virginia Cooperative Extension in Virginia. Brian has been focusing a number of extension programming efforts towards the increased adoption of continuous no-till production methods that rely heavily on the use of cover crops in a "never-fallow" system. Brian was contacted by The Pennsylvania State University and asked to be a part of a regional research and extension effort funded by the Northeast Integrated Pest Management group, a component of the USDA-CSREES program.

Along with several partners in the local SWCD, NRCS and cooperating farmers, Brian has already established a two year trial funded by the Shenandoah RC&D council looking at the effects of various cover crops and cover crop termination dates using a low-input management tool, the "roller-crimper". The objectives of the proposed project mesh very well with the existing project, and would require very little effort in terms of plot establishment, site procurement, or grower commitment, as this work has already been accomplished.

The primary responsibilities of Virginia Cooperative Extension in the proposed project would be as follows:
Objective 1: Brian will be responsible for establishing the weed population densities, within the existing cover crop trial, and measuring the level of weed management that varying cover crop termination dates provide.

Objective 2: Brian will be responsible for planting varying seeding rates of a small grain cover crop at different planting dates. Brian will be responsible for applying fertilizer treatments to the cover crop treatments and measuring the effects of fertility on cover crop growth and competitiveness.
Objective 3: Brian will be responsible for disseminating the results of this trial through extension programming events that pertain to this topic. In particular, winter crop production meetings and field days. A field day is already scheduled to take place at the cooperating farm where the existing cover crop project is in place. It would be a logical fit to combine the field days and be able to discuss the benefits of cover crop utilization for weed and pest management.

The results from this project will add to a rapidly growing database of information regarding cover crop utilization and management for Shenandoah Valley crop, dairy and livestock producers. Specifically, data gleaned from this regional effort will be very useful for filling a void of information currently available on the impacts of cover crop planting date, termination date and seeding rates for weed management.