Threshold-based Cover Cropping Strategies for Weed Management

<u>Personnel</u>

University of Maine

Eric R. Gallandt, the Project Director, Assistant Professor of Weed Ecology and Management, will be responsible for oversight and management of all aspects of the establishment, maintenance, data analysis, and reporting activities related to the project.

Chris Reberg-Horton is a Co-principle investigator, Sustainable Agriculture Extension Specialist, who will be responsible for co-advising and mentoring the M.S. student involved in the project. He is responsible for management, sampling, analysis and reporting of activities related to on-farm activities, and writing, editing, and publishing of the Maine Case Studies.

The Pennsylvania State University

William S. Curran is a 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.

David A. Mortensen is a Co-principal investigator. Dr. Mortensen is an Associate Professor of Weed Ecology at Penn State with a research and teaching appointment focused on ecologically-based weed management.

Mary E. Barbercheck is a Co-principal investigator. Dr. Barbercheck is a Professor of Sustainable Agriculture in the Department of Entomology with a strong research background in soil biodiversity and function particularly as it relates to soil invertebrates and control of pest organisms.

Ronald J. Hoover is an Agronomist and the On-Farm Research Coordinator at Penn State University. He facilitates the planning, implementation, and analyses of data from applied research projects conducted on producers' farms. He networks with Cooperative Extension county agents and state specialists, farmers, and industry to generate and disseminate practical information for farmers.

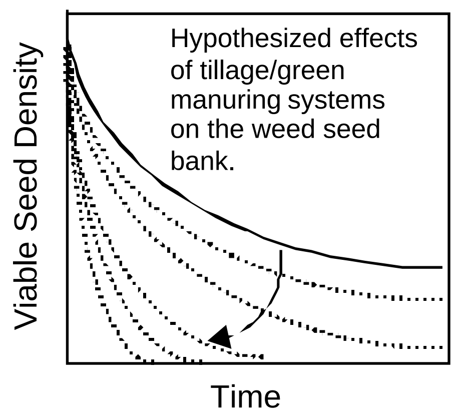
Project Summary

To manage weeds with reduced reliance on, or without herbicides, cropping systems require intervals during which rapid and significant reductions in the germinable portion of the weed seed bank occur or, if already small, seed banks should be managed to maintain a low equilibrium population density. Integrating tillage system and cover cropping practices, this project aims to develop management strategies that will lower the equilibrium density of the weed seed bank (see Figure, below). This systems approach promises an effective means for managing weed seed banks while maintaining or improving soil health. Field experiments and case studies of innovative growers in Maine and Pennsylvania will address the following three objectives:

1) Evaluate the impact of increasing cover cropping system intensity on weed seed bank dynamics.

2) Determine the effect of varying germinable seed bank densities on the efficacy of weed control and yield loss in a subsequent test crop.

3) Assemble innovative cover cropping systems concepts or techniques into case studies and conduct on-farm research that demonstrates key pest and soil management benefits.



Several lines of evidence indicate that cover cropping and green manuring strategies play and important role in managing weed seed banks, while maintaining or improving soil health, and in the case of leguminous green manures, providing an on-farm source of nitrogen for subsequent crops. Following incorporation, green manure crops release their chemical constituents into the soil, often killing seedlings of small-seeded species, an effect evident by subsequent reductions in weed establishment. Rye, *Brassica spp*., and numerous leguminous green manure crops, e.g., red clover, crimson clover, subterranean clover, and hairy vetch, have been shown to reduce weed establishment following their incorporation into the soil. Likewise, as a surface mulch, cover crop residues may also aid in the management weeds while reducing soil and water loss.

Project Description

A. The Problem, Background, and Justification

Throughout the Northeast, weeds are a recurrent and ubiquitous problem on organic and diversified vegetable farms. These two groups share the need for ecologically-based weed management strategies, the former because herbicides are not permitted, and the latter because relatively few herbicides are labeled for the so-called "minor use crops." In addition, grain crop and forage producers also benefit from using ecologically-based weed management by potentially integrating more environmentally friendly strategies.

Weed management is consistently listed at or near the top of grain crop grower's pest management concerns and is an area highlighted in the 2003 NEIPM RFP. The Northeast IPM Needs Assessment (http://neipm.nysaes.cornell.edu:591/NE_Needs/FMPro), information resulting from a focused group of grower meetings, repeatedly cited the need for: more work on alternative management practices, work focused on weed seed production, and establishment of thresholds. All are components of this proposal. In its 1997 National Organic Farmers' Survey, which included a high proportion of MOFGA (Maine Organic Farmers and Gardeners Association) and NOFA (Northeast Organic Farming Association) members, the Organic Farming Research Foundation found weed management to be the number one ranked research priority by the 1,192 nationwide respondents (O.F.R.F., 1998). Asked to list in their own words their worst pest problems, weeds received the greatest attention with foxtail (*Setaria* spp.), pigweed (*Amaranthus* spp.) and quackgrass (*Elytrigia repens*) listed most frequently. Asked to list their weed management methods, 75% of the respondents used mechanical tillage, weeding by hand or with hand implements, and crop rotations. Likewise in a 1999 survey conducted by the University of Maine Board of Agriculture "weed management tools and methods" was the top production-related research priority of the Maine Vegetable and Small Fruit Growers Association (Anonymous, 2000). Further more, 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 (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 in 2001 and 2002 have expressed the strong need for both more research and education with cover crop integration and weed management using fewer herbicide inputs (see support letter). Clearly, weed management in reduced pesticide and organic cropping systems is a priority for an increasing number of growers in the Northeast.

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. Whereas a Regional Project (NE-1000) was established to evaluate the performance of cover crop cultivars and time of planting and termination trials, a systems approach to evaluating cover-crop and management systems to accomplish soil management and weed pest suppression is lacking. A growing body of science underscores the importance of weed infestation level (weed seed bank size) to the efficacy of these soil management practices. This project takes practices that are being experimented with by growers and relates their performance to field and farm specific weed infestation problems.

Need For Managing The Weed Seed Bank

Economic, environmental, and biological problems associated with herbicide- and cultivation-based weed control efforts have promoted efforts to develop ecologically-based weed management systems (Liebman and Gallandt, 1997; Wyse, 1994). Although alternative systems may successfully limit crop yield loss to comparable levels obtained with conventional management, weed control efficacy may be lower and more variable than in conventional systems, resulting in larger annual inputs into the weed "seed bank," i.e., the quantity of viable seeds present in the soil and on its surface (Forcella *et al*., 1993; Gallandt *et al*., 1998; Roberts, 1981). To assure success of alternative systems, Jordan (1996) suggested that biological and cultural weed management methods "must be buttressed by efforts to reduce weed seed banks and maintain them at low levels." Likewise, Mortensen *et al.* (1993) suggested that somewhat higher weed densities and weed seed inputs associated with alternative management strategies may not have negative long term economic consequences if seed bank densities can be maintained at low levels.

To limit yield loss due to weed competition, management efforts focus on reducing weed density early in the growth of the cash crop; later emerging weeds often do not impact crop yield. This "critical weed-free period" has been a central principle of weed management (Wyse, 1992). The focus on limiting crop yield loss instead of weed seed production, however, results in a recurring weed problem—seed production by early surviving weed cohorts is extremely high, and later emerging weeds often produce some amount of viable seed. As long as equilibrium weed seed bank densities remain high, growers are faced with recurring "brush fires" to extinguish. The opportunity for "Many Little Hammers"—e.g., allelopathic effects of residues, enhanced crop competition, seed predation (Liebman and Gallandt, 1997) to maintain low weed density and biomass is overwhelmed and thereby never realized.

There is also an immediate need to better manage the weed seed bank. Managers of organic and highly diversified vegetable cropping systems rely largely on cultivation for weed control. Reference to the "art" and "science" of cultivation emphasizes the importance of the manager in the adjustment of equipment, travel-speed, timing of operation, and knowledge of soil conditions. Independent of the density of weed seedlings present, when these components come together optimally, the proportion of weeds killed is very high, often equal to herbicide-based programs. If circumstances cause any of these factors to be sub-optimal the proportion of weeds killed will be reduced (Mortensen et al., 2000). The density independent nature of cultivation efficacy, and the fact that mortality is generally less than 100%, shows the importance of having low numbers of germinable seeds in the weed seed bank. 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 (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). The density of weeds surviving cultivation and competing with the crop early in its life will be directly proportional to the density of germinable weed seeds in the seed bank (Dieleman et al., 1999). These early weed cohorts that survive cultivation have the greatest impact on crop yield and highest levels of seed production thereby replenishing the seed bank. A first step in the development of weed management systems that are durable enough to withstand the inherent variability of weather and management is the reduction of the weed seed bank.

Seed Bank Dynamics

An adaptive product of natural selection, the ability to establish a persistent seed bank contributes greatly to the success of annual weeds (Cavers and Benoit, 1989; Cook, 1980). Simulation models support the logical conclusion that seed banks are important targets for management efforts. The models show the strong effects of seed mortality on future weed population dynamics (Gonzalez-Andujar and Fernandez-Quintanilla, 1991; Jordan, 1993; Jordan *et al*., 1995). Jordan *et al.* (1995) developed such a model to examine the effects of crop rotation on velvetleaf (*Abutilon theophrasti*) and green foxtail (*Setaria viridis*) population dynamics. Seed survival influenced population dynamics to a greater extent than did plant survival, per-plant seed production, and germination. Lacking input, seed bank size declines sharply through losses to germination and seed mortality, the rate of decline is known to differ among species (Cook, 1980), among locations (Burnside *et al*., 1977; Donald and Zimdahl, 1987; Robocker *et al*., 1969) and among seed sources within a single species (Donald, 1993). Mechanistic explanations of species- and location-specific decay rates are not available, however, the large variation in seed survivorship suggests that there is opportunity to manipulate seed banks.

There appear to be at least four primary causes of seed mortality in the soil: (i) predation by vertebrates and invertebrates (Brust and House, 1988; Zhang *et al*., 1997), (ii) effects of the physical environment on seed survival, such as the effect of fluctuating temperatures (Lonsdale, 1993) and moisture (Simpson *et al*., 1989) near the soil surface; (iii) age-related death of the embryo, as illustrated by the gradual loss of viability of dry seeds (Copeland and McDonald, 1995); and (iv) invasion and decay by microorganisms (Kremer, 1993). The interaction of these factors, such as damage by predation and subsequent microbial invasion, may also result in mortality. While there are research efforts underway to understand how one may manipulate the soil surface environment to encourage mortality of dormant seeds (Kennedy and Kremer, 1996; Kremer, 1993), initial efforts at managing the weed seed bank are likely to have greater success targeting the nondormant, germinable populations of seeds. Promising strategies in this regard, and the focus of the currently proposed research, involve tillage-induced germination, incorporation of phytotoxic green manure residues, surface mulches of cover crop residues, and conservation of resident invertebrate seed predators.

Tillage Effects on the Germinable Weed Seed Bank

Tillage stimulates emergence of some but not all weed species (Ogg and Dawson, 1984), an effect often attributed to light and the known phytochrome response of certain weeds (Milberg *et al*., 1996). In tilled soil, Roberts and Feast (1972) found a 32% annual decline in the abundance of all weed species present compared to 12% in undisturbed soil. Rates of loss attributed to soil disturbance are, however, specific, ranging from 6% per year for field penny cress (*Thlaspi arvense* L.) (Roberts and Feast, 1972) to 52% per year for shepherd's purse (*Capsella bursa-pastoris* L.) (Roberts, 1962). Other weed species, e.g., wild oat (*Avena fatua*

L.), experience a rapid initial decline; after only 7 months losses were 79 and 85% at two field sites (Miller and Nalewaja, 1990).

Cover Cropping Effects on Weeds—Green Manures

Soil-incorporated leguminous and non-leguminous cover crops, i.e., "green manures" reduce the establishment of numerous weed species, with several lines of evidence suggesting that phytotoxins released from decaying residues are causing mortality of non-emerged seedlings. Incorporated rye residues release benzoxazolinones that are be particularly phytotoxic to small-seeded species (Putnam, 1994). *Brassica* species contain glucosinolate compounds phytotoxic to certain weed species. Incorporated residues of *Brassica napus*, for example, reduced weed densities 73-85% in a subsequent potato (*Solanum tuberosum* L.) crop (Boydston and Hang, 1995). Of particular interest to low-external input cropping systems are the nitrogen contribution (Griffin *et al*., 2000) and weed suppressive effects of leguminous green manures (Liebman and Davis, 2000; Liebman and Ohno, 1997).

Many leguminous species, often grown primarily for their nitrogen contribution to subsequent crops, have been shown to reduce emergence of certain weed species, but are not effective on others. Incorporated crimson clover (*Trifolium incaratum* L.) and hairy vetch reduced establishment of morning-glory (*Ipomoea lacunosa* L.), and further decreased the biomass of weeds that did establish (White *et al*., 1989). Lehman and Blum (1997) found that crimson clover and subterranean clover (*T. subterraneum* L.) reduced emergence of both morning-glory and redroot pigweed (*Amaranthus retroflexus* L.), although these studies were conducted in petri dishes. Sampling a field experiment conducted at the Rogers Farm in Stillwater, Maine, Ohno *et al*., (2000) used a wild mustard (*Sinapis arvensis* L.) bioassay to determine the phytotoxicity of soil-water extracts following incorporation of 2530 kg ha^{-1} red clover (*Trifolium pratense* L.). At the first sampling date following incorporation (8 days) extracts from the red clover-amended plots reduced mustard radicle elongation 20% compared to unamended treatments. In a similar field study at the same site Conklin (2000) used a soil bioassay developed by Dabney *et al.* (1996) to assess the phytotoxicity of contrasting soil management practices. In soils bioassayed during the first weeks following incorporation of compost and red clover green manure wild mustard had a higher incidence of *Pythium* and, in one of two years, reduced growth. Bioassays using the larger-seeded sweet corn crop showed not differences between the compost/green manure and the conventionally fertilized soil management systems.

Cover Cropping Effects on Weeds—Surface Mulches

Retained on the soil surface, the residues of non-cash crop species such as rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* L. Roth.) physically and chemically suppress weeds leading to reduced densities (Mohler and Teasdale, 1993). Physically, they suppress weeds by reducing light penetration to the soil surface and lowering soil temperatures. Mulches are also able to chemically suppress weeds but at a different rate than incorporated mulches. Rainwater leaches some allelopathic compounds out of the mulch and onto the soil surface to inhibit weed growth. The rate at which this occurs depends on the amount of precipitation and how the cover crop is killed. A slow acting burndown herbicides like glyphosate leads to a slower release of these compounds than an herbicide which causes quick cellular rupture such as paraquat (Yenish et al. 1995). Unincorporated surface residues of hairy vetch inhibited the emergence or some weeds in a Pennsylvania study, but increased growth of others (Curran et al., 1994). No tillage and surface mulches also cause less disruption to seed predator habitat and are likely to encourage higher predation (Brust and House, 1988). However, the cover crop residues in no-tilled systems, while reducing soil erosion and improving soil quality, alone do not provide acceptable levels of weed control (Teasdale, 1996). By eliminating the option of cultivation, no-tillage commits the grower to a post-emergent herbicide program for weeds that escape being controlled by the cover crop.

“Selectivity” of Green Manures and Mulches.

Early in his work on the allelopathic properties of cereal rye, Putnam proposed that large-seeded and transplanted crops, but not small-seeded weeds or crops, could tolerate and evidently outgrow the phytotoxic effects of the residues (Putnam and DeFrank, 1983). Large, heavier seeds are better able to tolerate and repair damage caused by nutrient stresses, disease, herbivory, and allelochemicals (Westoby et al., 1996). Recent experiments to explicitly test this hypothesis in the context of allelopathic stress from aqueous extracts of red clover confirm that small (light) seeded species suffer greater inhibition than larger-seeded species (Liebman and Davis, 2000).

Invertebrate Seed Predators

Losses due to the activity of seed predators may be considerable, with reports of 90% or greater seed removal or damage commonly reported for certain weed species (Zhang *et al*., 1997a). Similar results in southern Ontario recently prompted Cromar et al., (1999) to conclude that

> ***“…invertebrates with opportunistic feeding strategies that feed on weed seeds may be the most significant broad spectrum and natural form of biological weed control affecting weed population dynamics.”***

Organic cropping practices (Dritschilo and Wanner, 1980), cover cropping in particular (Carmona and Landis, 1999) may conserve and increase the activity of weed seed predators. To determine whether cover-cropping practices affect resident invertebrate seed predators in Maine, a set of preliminary experiments were conducted in August, 2002. Using the relatively large plots of a long-term vegetable cropping systems trial (65 ft. x 135 ft.) we characterized the activity-density of seed predators by pitfall trapping over a 72 h period (96 traps, 2 in each of 4 replicate plots of the 12 cropping systems) as described by Carmona and Landis (1999).

The predominant invertebrate seed predator was a carabid beetle, *Harpalus rufipes*, for which an impressive number of individuals were captured (Figure 1). Over this 10-day period in early August 2002, pitfall trap counts revealed considerable greater density-activity of *H. rufipes* in vegetated plots compared to those recently tilled and planted to a fall cover crop of oat (e.g., compare None, tilled to Winter Squash and Red clover, Figure 1).

To determine the rate of seed predation caused by resident invertebrates, we conducted a typical “feeding” trial in which 25 seeds of each of six weed species were placed in the field. Seed recovery after 10 days in the field (bracketing the interval of pitfall trapping described previously) was determined by samples protected with vertebrate and invertebrate exclosures (a combination of hardware cloth and window screen) whereas separate feeding stations received vertebrate protection (hardware cloth alone), or no protection from potential seed predators (no

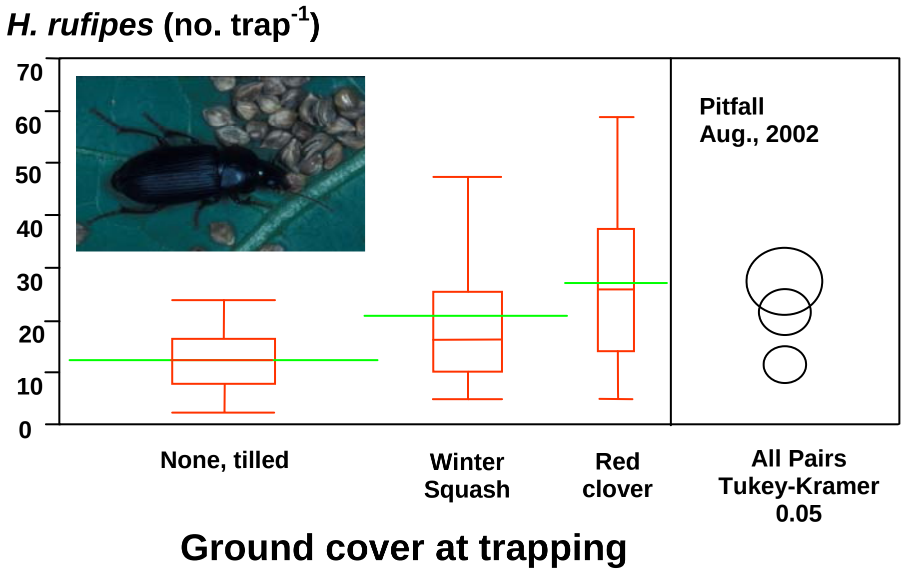


Figure 1. Numbers of the ground beetle, *Harpalus rufipes* (Coleoptera: Carabidae), captured in pitfall traps over the period 13 August 2002 through 15 August 2002. This beetle is a known post-dispersal seed predator. Pitfall traps (96 total) were placed in three contrasting crop environments: No vegetation in recently tilled plots; moderate vegetative cover in winter squash plots; dense vegetative cover in red clover cover crop plots. Source: E.R. Gallandt and F. Drummond, unpublished.

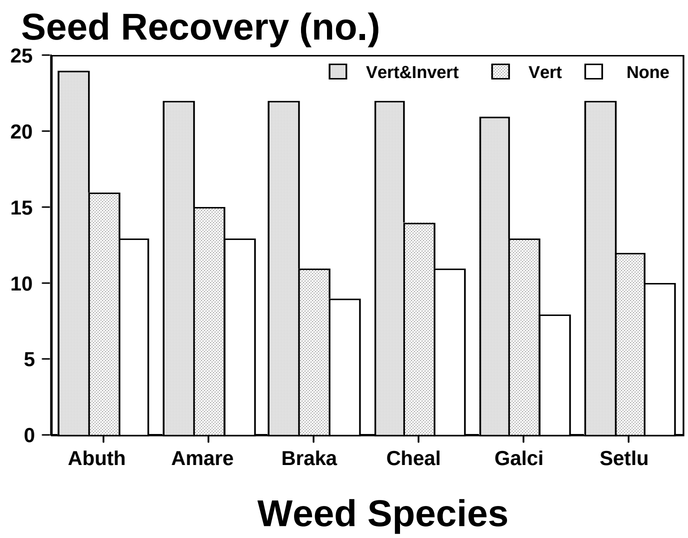


Figure 2. Seed predation over a 10 day period in August, 2002. Twenty-five seeds of each weed species were placed on "feeding stations" of washed sand in Petri dishes, placed in the field 9 August and recovered on 18 August. Seed recovery is reflected in treatments receiving complete exclosure (Vert&Invert). Predation by invertebrates measured by excluding vertebrates (Vert), and the combined predation by vertebrates and invertebrates measured by feeding stations without exclosure (None). Species included *Abutilon theophrasti*, Abuth; *Amaranthus retroflexus*, Amare; *Brassica kaber*, Braka; *Chenopodium album*, Cheal; *Galinsoga ciliata*, Galci; and *Seteria lutenscens*, Setlu. Source: Gallandt, E.R. and F. Drummond, unpublished.

exclosure). Averaged over weed species (interaction P = 0.441), seed recovery was 89% with the vertebrate + invertebrate exclosures, intermediate at 55% with the vertebrate exclosures, and least at 43% with no exclosure ($P < 0.001$; Figure 2). Invertebrates were therefore likely responsible for 45% loss of seeds over this 10-day interval. Predators preferred *G. ciliata* with *A. theophrasti* being the least preferred and the other species lying in preference between these extremes ($P < 0.001$). The lack of species by exclosure interaction suggests that vertebrate and invertebrate predators had a similar preference for the species included in this experiment.

Research efforts should continue to focus on no-till practices thereby eliminating the detrimental effects that tillage has on soil quality. However, the combination of tillage and green manure crops may offer a much needed intermediate cropping strategy that can function with reduced reliance on or without herbicides, minimize deleterious effects on soil quality, and with the potential of rapidly reducing the equilibrium density of the germinable weed seed bank.

B. Objectives

This project aims to evaluate the intensity of cover cropping to directly or indirectly reduce the density of germinable seeds in the weed seed bank.

Objective 1. Evaluate the impact of increasing cover cropping system intensity on weed seed bank dynamics.

Hypothesis 1-1. Decline in the germinable weed seed bank will be proportional to the intensity of cover cropping.

Hypothesis 1-2. Activity-density of invertebrate weed seed predators will be positively correlated with the amount of time live cover crop biomass is present in a system, and negatively correlated with the frequency of disturbance (tillage/mowing).

Objective 2. Determine the effect of varying germinable seed bank densities on the efficacy of weed control and yield loss in a subsequent test crop.

Hypothesis 2-1. To preserve acceptable levels of weed control with minimal herbicide and cultivation inputs, the intensity of cover cropping must increase as the density of germinable seeds increases.

Hypothesis 2-2. Incorporated green manure residues will impact the weed seed bank to a greater extent than nonincorporated residues (no-till). With uniform weed management across treatments this will be manifest in lower weed densities and less crop yield loss where residues are incorporated.

Objective 3. Assemble innovative cover cropping systems concepts or techniques into case studies and conduct on-farm research that demonstrates key pest and soil management benefits.

C. Approach and Procedures

Objective 1. Evaluate the impact of increasing cover cropping system intensity on weed seed bank dynamics.

Cover Cropping Systems

To evaluate the contribution of green manuring practices to the management of the weed seed bank, three objectives and four associated hypotheses will be addressed in field experiments conducted at the University of Maine Rogers Farm in Stillwater, Maine and the Russell E. Larson Agricultural Research Center near University Park, Pennsylvania. The experiments will be established in the spring of 2004 and 2005 in a split-plot, randomized complete block design with four replications. Main plot treatments will be a factorial cross of two factors. First will be four cover crop systems representing different levels of intensity and a fallow control. The second factor is method of handling the cover crop residue when the cash crop is planted the following year, either incorporated or left as a surface mulch for no-till or zone tillage. The intensity of cover cropping is determined by multiple factors. The length of time a field is kept in a living cover crop is first factor. Second is the biomass production of the cover crop and finally, the number of tillage or mowing events before the next cash crop (Table 1). Back-to-back cover cropping involves more soil disturbance and is therefore hypothesized to decrease the soil seed bank faster.

Table 1. Cover crops and intensity criteria targeted for the field experiment.

		Intensity of Cover Cropping			
Cover Crop System	Target seeding date	Time cover crop is alive (months)	Biomass (kg/ha. $^{-1}$yr^{-1})	# of tillage/ mowing events	Comments
none	--	--	--	--	fallow control
rye/vetch	Aug.15	9-10	4,500-9,000	1	winter hardy
pea/oats followed by rye/vetch	May 1 Sept 1	4 9-10 12-13	2,200-4,500 4,000-9,000 9 -13,000	2	pea/oats incorporated and then rye/vetch planted
red clover/ perennial ryegrass	April/ May 1	12-13	3,400-4,800	2	winter hardy
brassica	May 15	1.5	2500	2	tillage/ fallowing between cover crops
buckwheat	July 15	1	2000	2	
brassica	Aug 25	2-3	3500-4000	2	

Main plots will be 16.5 m by 16.5 m. Cover crop treatments will be established as soon as soil conditions permit in the spring of 2004, and repeated in the spring of 2005. All legumes will be inoculated with appropriate strains of *Rhizobium* prior to planting. Cover crops will be planted with either a conventional grain drill or, in the case of the small-seeded clover and brassica, a Brillion seeder.

Synthetic Weed Seed Banks

The influence of weed seed bank size will be assessed by establishing a range of seed bank densities at the start of the experiment in the areas to be planted to the cover crop systems. Weeds will dispersed at specific densities the fall prior to cover crop establishment. The change in seed bank density will be assessed at several critical times over a period of 18 months. Four seed bank densities will be established as subplots within each of the cover crop plots. Within a cover crop by tillage plot, a 2 m^{-2} area will be seeded with an equal number of each of each of *Setaria sp*., *Chenopodium album, and Abutilon theophrasti* seed at the following four seed bank densities: 60, 200, 450 and 2100 m^{-2}.

Test of Hypothesis 1-1. Decline in the germinable weed seed bank will be proportional to the intensity of cover cropping.

Quantifying Seed Bank Decline

Greenhouse germination will be used to estimate the readily germinable (non-dormant) fraction of the seed bank (Gallandt *et al*., 1998). Direct extraction, in which organic materials including weed seeds are separated from soil using concentrated salt solution and centrifugation, will be used on sub-samples to enumerate dormant seeds. Viability will be subsequently tested using tetrazolium or GA-induced germination tests (Simpson *et al*., 1989), depending on seed size. Alternatively, viability will be estimated by applying pressure to seeds with forceps or a dissecting needle (‘firm’ seeds are assumed to be viable) (Ball and Miller, 1989; Forcella, 1992), recognizing that intact but dead seeds may result in overestimation of seed bank densities. Difficulties in detecting small or cryptically colored seeds, or in distinguishing among species with similar seeds, may underestimate densities and distort estimates of community composition (Gross, 1990), hence the necessity for the greenhouse germination data set.

For all plots, twenty 8.3 cm-diam. by 10 cm-deep cores (1080 cm^2 surface area) will be collected and pooled at each sampling time. Accurate estimates of the weed taxa present require sampling a minimum of 1000 cm^2 (Forcella, 1984) whereas coefficients of variation across large (270-fold) differences in seed density are stabilized by collecting $\geq$ 15 cores per experimental unit (Forcella *et al*., 1992). Spring soil samples will be sieved to remove coarse fragments and spread over a 2.54 cm layer of fine vermiculite in plastic trays. Tray size and/or number for each sample will be adjusted to result in a soil depth $\leq$ 1.5 cm to eliminate effects of vertical stratification within samples. Trays will be placed in the a greenhouse Emerged seedlings will be identified to species and counted thereby providing an estimate of the germinable seed bank.

Test of Hypothesis 1-2. Activity-density of invertebrate weed seed predators will be positively correlated with the amount of time live cover crop biomass is present in a system, and negatively correlated with the frequency of disturbance (tillage/mowing).

Density-Activity of Invertebrate Seed Predators

For surface active arthropods, periodic pitfall trapping will be used to compare relative numbers and activity of arthropods on the soil surface in the treatment plots. Each pitfall trap will consist of a 500 ml plastic cup buried in the ground flush with the soil surface, with another 500 ml plastic cup placed inside the first to allow specimens to be removed easily without having to displace the entire trap. Each cup will contain 125 ml propylene glycol as a killing/preserving agent (Weeks & McIntyre 1997). Each treatment will receive 6 traps, placed randomly in the crop rows and each trapping event will last three days. Location of the traps will remain constant throughout the duration of the experiment. Traps will be checked and specimens collected daily for identification. Carabid beetles will be identified to species. All specimens will be identified at least to genus and placed in a trophic group category (e.g., chewing herbivore, sucking herbivore, omnivore, predator) for analysis. Data from the traps will be numbers and diversity of surface active arthropods in the treatment plots.

We hypothesize that cover crops in a vegetative stage during June, July, and August will encourage the activity of invertebrate seed predators as demonstrated by pitfall trapping and the resultant activity-density parameter (Carmona and Landis, 1999). Furthermore, disturbance associated with summer fallowing will reduce opportunities for seed predation (Brust and House, 1988). Quantification of seed predation in these cover cropping systems will guide decisions related to soil disturbance and the management of reproductive weeds on organic and diversified vegetable farms.

Objective 2. Determine the effect of varying germinable seed bank densities on the efficacy of weed control and yield loss in a subsequent test crop.

<u>*Test of Hypothesis 2-1.* Incorporated green manure residues will impact the weed seed bank to a greater extent than nonincorporated residues (no-till). With uniform weed management across treatments this will be manifest in lower weed densities and less crop yield loss where residues are incorporated.</u>

Management of the Cover Crops and Test Crop

In May of 2005 and 2006, prior to planting the sweet corn “test crop,” above ground cover crop biomass will be measured in each plot by clipping all plant material $\geq$ 1-cm in height from two 0.5-m^2 quadrats per plot. The material will be bulked, sorted to categories of stubble, green manure, by species, and weeds, by species, and then dried and weighed.

Prior to planting the sweet corn "test crop", the cover crops will either be tilled under with an appropriate tillage implement or killed with a burndown herbicide. If necessary, the cover will be mowed prior to tillage to help reduce cover crop particle size and enhance soil incorporation. The sweet corn will be planted 3.8 cm deep in rows spaced 91-cm apart. Main plots will consist of 18 row of sweet corn by 16.5 m long. P and K will be applied prior to corn planting based on soil tests. N will be applied at planting time and rates will be based on sweet corn requirements and residual N supplied by the cover crop and tillage system. Approximately four weeks after planting, weed seed density by species will be determined by counting four 0.5 m^2 quadrats per plot. Weeds will be suppressed in all treatments with a nonresidual postemergence herbicide after weed density determinations have been taken. Weed escapes will be quantified at the end of the season by quadrat sampling for density and biomass. Monitoring for arthropod pests will be conducted on a weekly basis, and appropriate management treatments will be applied if necessary. Marketable ears (yield) will be collected from the center 8 rows of corn at harvest.

Test of Hypothesis 2-2. To preserve acceptable levels of weed control with minimal herbicide and cultivation inputs, the intensity of cover cropping must increase as the density of germinable seeds increases.

Partial Budget Analysis

The economic performance of the contrasting crop and cover crop/tillage 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," in this case sweet corn, as compared to the "fallow" control treatment. The added benefits of the alternative systems are expected to be manifest in better weed control and higher yields.

Expected Results. Field studies are expected to provide strong evidence for or against the hypothesis that seed bank density can influence the frequency of "safe sites" and therefore the efficacy of more or less intensive cover-cropping systems. Conducting the study under conditions as close as possible to those practiced by farmers will enhance the likelihood that results quantifying the relationship between cover cropping intensity 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.

Objective 3. Assemble innovative cover cropping systems concepts or techniques into case studies and conduct on-farm research that demonstrates key pest and soil management benefits.

Grower case studies.

A number of innovative farmers that participated in the Department of Crop and Soil Sciences *Producer Seminar Series* at Penn State University in 2001 and 2002 have expressed the strong need for both research and education with cover crop integration (see support letter). This project addresses the educational need by developing case studies featuring farmers who are using innovative cover cropping systems. The case studies will focus on the impact of cover crops on pest management (weed, insect and disease), soil quality (organic matter, soil structure, soil and water conservation) and their utility for managing animal manure. Case study farmer participants will be selected from a pool of farmers who have been leaders in cover crop research and outreach on their farms in Maine and Pennsylvania. A target of at least 10 case studies will be developed. The case studies will span the diversity of grain, forage/livestock, and vegetable production systems. Participants will also reflect the emphasis of this research project, reducing reliance on herbicide inputs. Since most cover crop recommendations are vague, emphasis will be placed on the specific details of how these farmers manage their cover crops. Multiple visits will be made to each farm throughout the season to elicit the details that are often overlooked during an end of season interview. Farmers will be asked to describe the benefits as well as the challenges or limitations of their cropping system. They also will be asked to identify critical gaps in current knowledge that could be areas of future research. The case studies will be made available through Cooperative Extension as bulletins, and will serve as a resource for farmers, extension educators, crop advisors, and university instructors. Results will be distributed to at least 1500 farmers via Cooperative Extension channels. Case study interviews will be conducted during the second year of the project.

On-farm demonstrations.

Case-study farms will then serve as on-farm sites to demonstrate the concepts and techniques underpinning the practices. An area on each farm with the cropping sequence necessary for the demonstration will be selected. Site selection will also take into consideration the ease with which a well-attended field day can be facilitated. Two or three treatments will be included in most on-farm trials. Innovative treatments will be compared to more traditional techniques. These trials will consist of field-length strips that are sized in widths to accommodate the host farmer’s equipment. The trials will be replicated three or four times and will be laid out as randomized complete blocks. When applicable, pest and soil quality data will be collected to help support the educational mission. Field days will be conducted at times when the educational message is most clearly seen in the field. Both the University of Maine and Penn State have active on-farm research programs. Mr. Ron Hoover, the on-farm coordinator in the Department of Crop and Soil Sciences at Penn State will assume a major role in these activities. In addition, we will work closely with Maine and Pennsylvania Cooperative Extension personnel, the Pennsylvania Association for Sustainable Agriculture (PASA) and the Maine Organic Farmers and Gardeners Association (MOFGA) in coordinating farm days and educational events. PASA and MOFGA have generated a track record of producing and publicizing farmer field days that have been extremely well attended. Each field day will serve as a forum to show first-hand the opportunities and benefits available to farmers when cover crops are included into crop production systems. Outreach activities will reach at least 1500 individuals.

D. Cooperation and Institutional Units Involved

This project brings together complimentary expertise from the University of Maine, the lead state, and The Pennsylvania State University. Located in the north and in the center of the Northeastern Region, the work spans ecoregions representing a significant portion of the region and agricultural management types that span the integrated vegetable cropping systems of northern New England to dairy-based cropping systems representative of the region broadly. The concurrent field studies outlined herein will advance our understanding of mechanistic relationships between pest population size and cover crops, information that will be packaged and extended to growers. The published case studies and field days will reach a significant number of growers and will likely strongly shape their impressions of the feasibility of these practices. The PD in Maine is presently involved in a complimentary vegetable cover cropping systems comparison supported by the NE SARE program, and is Project Coordinator for NE-1000, a regional project focused on managing residues for weed control benefits. Pennsylvania PDs have extensive experience assessing the weed suppressive effects of cover-crops, linking weed population size to intensity of management and education experience with weed and insect ecology and pest management in diverse cropping systems.

E. Implementation and Evaluation Plans

<u>Evaluation of Alternative Cover Cropping Strategies.</u>

This project will effectively rank alternative cover cropping systems for their ability to reduce germinable weed seed bank densities. Growers working towards reduced reliance on herbicides or, in the case of organic growers, hand labor, will be able to consider cover cropping practices balancing short term cropping needs with longer term seed bank and soil quality management goals.

Pest management tactics and results from Objectives 2 and 3 will be implemented rapidly though the activities in Objective 3 of this project. The on-farm research project will capture general concepts (e.g. intensity of cover crop system on weed seedling emergence) from the 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. PASA and MOGFA) will help disseminate results. Finally, the research results will also be distributed through traditional scientific avenues such as regional and national conferences and through journals and proceedings.

<u>Case studies.</u>

This project will address the need for more education about pest management and soil quality by developing case studies that feature farmers who are using innovative cover cropping systems. The PI's already have established relationships with many of these innovative growers. Successful cropping systems/pest management concepts and techniques will be identified and documented for at least 10 growers. The case studies will be made available through Cooperative Extension as bulletins, and will serve as a resource for farmers, extension educators, crop advisors, and university lecturers. Bulletins will be available electronically as well as in print. Results will be distributed to at least 1500 farmers via Cooperative Extension channels. Indicators of success for the case study portion of the project will include written or oral responses provided by the audience at the field demonstrations and other extension activities (see survey evaluation below) associated with the project, by the number of case study bulletins printed and distributed, and by the number of visits to the case study bulletin website.

<u>On-farm demonstrations</u>

Field days will be conducted at times when the educational message is most clearly seen in the field. Both the University of Maine and Penn State have active on-farm research programs. Each field day will serve as a forum to show first-hand the opportunities and benefits available to farmers with changing or intensifying the cropping systems by including cover crops. Outreach activities will reach at least 1500 individuals. 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 and ability to try something new or different. We will evaluate the success of the educational activities through attendance at the field days and with a survey conducted at each field day 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.

The time-frame for activities for the field research, case studies, and on-farm demonstrations is provided in Table 2.

Table 2. Timetable of activities for Gallandt et al. NE-IPM Project.

Actvity	Fall 03	Spr. 04	Sum. 04	Fall 04	Spr. 05	Sum. 05	Fall 05	Spr. 06	Sum. 06
1st Run	Collect seed	Establish covers	Establish covers	Establish covers	Manage covers	Cash crop			
2nd Run				Collect seed	Establish covers	Establish covers	Establish covers	Manage covers	Cash crop
On-farm					Manage covers	Covers/ education	Manage covers	Manage Covers	Educa-tion
Case studies					Data collection	Data collection	Data collection	Sum-marize	Sum-marize

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