

A. Grant Data

Title: *Threshold-based Cover Cropping Strategies for Weed Management*

Proposal No. 2003-04415; USDA Award Nos. 2003-34103-13197 and 2003-41530-01605

Lead Investigator:

Eric R. Gallandt, Associate Professor of Weed Ecology and Management, University of Maine, Department of Plant, Soil and Environmental Sciences, 5722 Deering Hall, Orono, ME, 04469-5722. Phone: 207/581-2933; fax: 207/581-2999; email: gallandt@maine.edu

Team Members:

William S. Curran, Professor of Weed Science and Agronomy, Penn State University; Chris Reberg-Horton, former University of Maine Cooperative Extension Sustainable Agriculture Specialist; David A. Mortensen, Associate Professor of Weed Ecology, Penn State University; Mary E. Barbercheck, Professor of Sustainable Agriculture, Dept. of Entomology, Penn State University; Ronald J. Hoover, agronomist and On-Farm Research Coordinator, Penn State University.

States Involved: Maine, Pennsylvania

Project Duration: 07-01-2003 through 06-30-2006

Funding Amount: \$174,989

B. Nontechnical 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 seedbank occur or, if already small, management to maintain a low equilibrium density. This project has identified single-season cover cropping practices that will lower the density of the germinable weed seedbank, offering an effective means for managing the weed seedbank while maintaining or improving soil health. Specifically, field experiments in Maine and Pennsylvania have demonstrated that soil disturbance events associated with cover cropping encouraged germination and seedling establishment thereby reducing the density of germinable seeds in the weed seedbank. Of notable importance, however, are the disturbance events that preempt weed seed rain. If weeds are permitted to reach reproductive maturity in cash or cover crops, the “debits” to the seedbank resulting from early season disturbance will likely be overwhelmed by the resulting seed rain “credits.”

C. Introduction

Because cultivation and post-emergence herbicide applications generally kill a constant proportion of established weed seedlings, and the density of seedlings is proportional to the density of germinable seeds, high levels of weed control require a low density of germinable seeds in the weed seedbank. Seedbanks in agricultural systems may be managed by maintaining

low densities of weeds, by enhancing the competitive advantage of the crop, by increasing seed mortality, and by manipulation of the soil environment to reduce the probability of weed establishment. Cover cropping practices may be useful in this regard, contributing soil disturbance events that preempt weed growth and stimulate germination of additional weeds, establishing a competitive environment thereby reducing the reproductive potential of surviving weeds, permitting flexible management that can prevent weed seed rain, and producing residues that reduce weed establishment. A further advantage of cover cropping practices is their potential beneficial contribution to soil quality.

D. Objectives

This project evaluated cover cropping practices, varying in intensity, for their ability to directly or indirectly reduce the density of germinable seeds in the weed seedbank.

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

We hypothesized that: (i) The decline in the germinable weed seedbank would be proportional to the intensity of cover cropping; and (ii) that the activity-density of invertebrate weed seed predators would 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 seedbank densities on the efficacy of weed control and yield loss in a subsequent test crop.

We hypothesized that: (i) 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; and that (ii) incorporated green manure residues would impact the weed seedbank to a greater extent than nonincorporated residues (no-till). With uniform weed management across treatments this effect would 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.

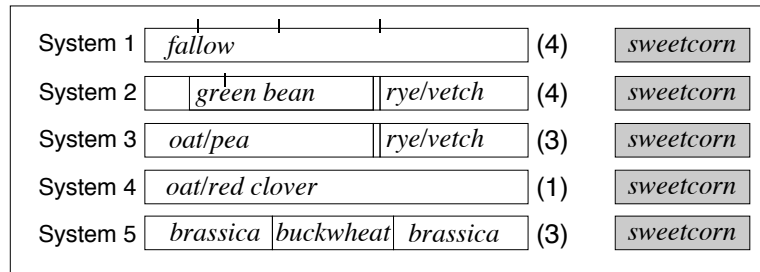
E. Approach

Cover Cropping Systems

To evaluate the contribution of cover cropping practices to the management of the weed seedbank, the three objectives and four associated hypotheses described above were 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 were established in the spring of 2004 and repeated in the spring of 2005, in a split-plot, randomized complete block design with four replications. Main plot treatments were a factorial cross of two factors. First were four cover crop systems representing different levels of intensity and a fallow control. The second factor was the 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. We considered the intensity of cover cropping to be based on the length of time a field is kept in a living cover crop, the biomass production of the cover crop

and, the number of tillage or mowing events before the next cash crop (Figure 1). Back-to-back cover cropping involves more soil disturbance and was therefore hypothesized to decrease the soil seedbank faster.

Figure 1. Cover cropping systems established in 2004 and repeated in 2005 the Maine and Pennsylvania Experiment Station research sites. Numbers in parentheses indicate major disturbance events that would preempt weed growth. Residues were either incorporated or killed and left on the soil surface prior to planting the uniform test crop of sweet corn. The Pennsylvania site included System 6, organic soybean.



Synthetic Weed Seedbanks

The influence of weed seedbank size was assessed by establishing a range of seedbank densities at the start of the experiment in the areas to be planted to the cover crop systems (Figure 2). Weeds were dispersed at specific densities the fall (PA) or early spring (ME) prior to cover crop establishment. The synthetic seedbanks included a 2 m² area seeded with an equal number of each of each of *Setaria sp.*, *Chenopodium album*, and *Abutilon theophrasti* seed at the following four seedbank densities: 60, 200, 450 and 2100 m⁻². Ceramic beads, similar in size and density to *C. album*, were included to evaluate the efficiency of recovery.

Figure 2. Synthetic weed seedbanks were established prior to the cover crop phase of the field experiments. Velvetleaf, yellow foxtail and common lambsquarters were sown at four densities within permanently marked areas in each plot.

Quantifying Seedbank Decline

Greenhouse germination was used to estimate the readily germinable (non-dormant) fraction of the seedbank. Direct extraction using specialized wet sieving equipment was used on sub-samples to enumerate dormant seeds and ceramic beads.

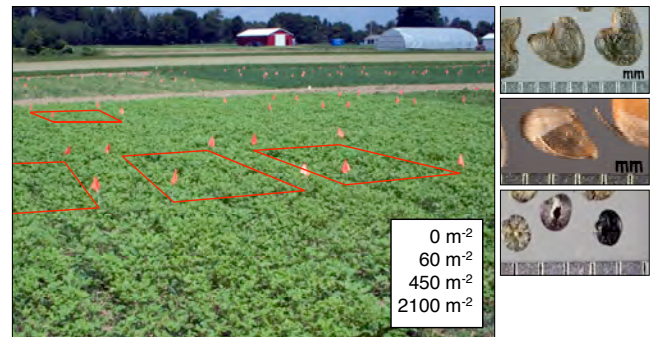
Density-Activity of Invertebrate Seed Predators

For surface active arthropods, pitfall trapping was conducted to compare relative numbers and activity of arthropods on the soil surface in the treatment plots.

F. Progress

Field experiments were concluded in 2006, and analysis of the central data sets from both Maine and Pennsylvania are complete but have not yet been evaluated for possible combined analyses over sites. The seedbank data sets include both resident species and species sown in the synthetic seedbanks. Changes in the germinable seedbank density reflect the relative success of the systems, data sets supported by measurements of weed density in the “test crop” phases of

Synthetic seedbanks



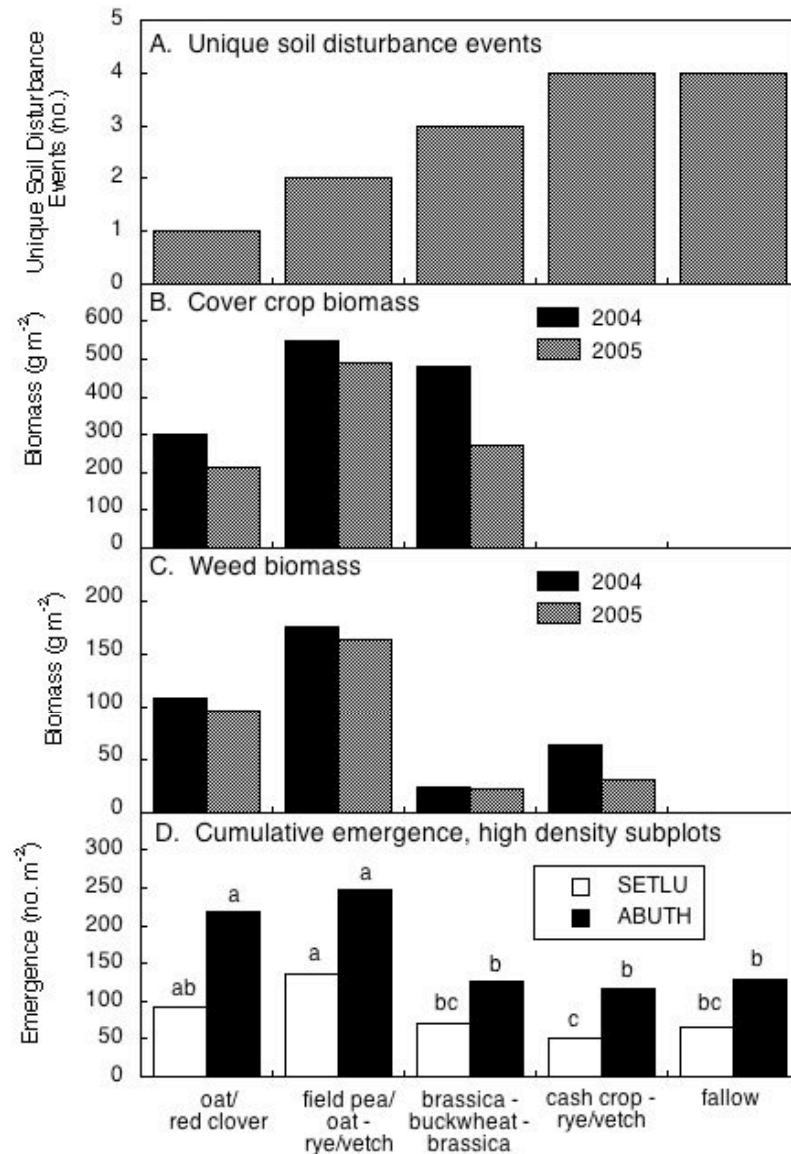
the experiment. Further analysis and modeling efforts will be used to conduct a partial budgeting analysis of the performance of the cover cropping systems; these data are not included in this final report.

G. Results

Systems Characteristics

The cover cropping systems differed in the number of unique soil disturbance events, i.e., temporally unique so as to possibly encourage successive flushes of weed emergence (Figure 3 A), and in the amount of cover crop and weed biomass produced cumulatively over the cover crop year of the experiment (Figure 3, B, C).

Figure 3. Selected characteristics of the four cover cropping systems and fallow treatment evaluated in Maine and Pennsylvania over the period of 2004 through 2006, including temporally unique soil disturbance events (A), cumulative cover crop biomass (B), cumulative weed biomass (C), and cumulative emergence of yellow foxtail (SETLU) and velvetleaf (ABUTH) in the high density synthetic seedbank subplots, averaged over years. Means labeled with common lower case letters within a weed species are not significantly different ($P > 0.05$).



Weed Seedling Recruitment

Because germination is the foremost mechanism by which weed seeds leave the seedbank, recruitment was measured within the cover cropping systems prior to each field disturbance from May through August of 2004 and 2005. In Maine, recruitment (weed seedling densities) within the cover crop phase of the experiments was unexpectedly greater in low disturbance systems compared to systems with more unique soil disturbance events (Figure 3 D).

The high level of recruitment in these systems, however, failed to contribute a net reduction in the germinable seedbank because weeds in these systems were able to set seed (see e.g., Figure 4 A, N t+1).

Weed Seedbank Deline

In both Maine and Pennsylvania, the background populations of common lambsquarters in the seed bank prohibited us from detecting an effect of initial density; this was also the case for foxtail species in Pennsylvania. However, in 2004/2005 and 2005/2006, the velvetleaf populations responded similarly, decreasing 15 to 67% in all cropping systems except in the organic soybean crop rotation where they increased about 30% due to successful reproduction (Table 1). Foxtail species and common lambsquarters germinable seedbanks responded similar to one another in 2005/2006, increasing in population density only in the cropping systems where weed maturity and subsequent seed rain were observed (oats/clover and soybean crop phases) (Table 1).

Table 1. Pennsylvania data from 2005-2006 showing the proportional change in weed density from the initial seedbank population (N_t) to the final weed seedbank population (N_{t+1}) prior to planting the sweet corn cash crop (% change in plant density = $(N_t - N_{t+1}) / 100 * N_t$).

| Cropping system | Weed species* | | |
|---------------------------------|---------------------------------------|------------|----------------------|
| | Foxtail spp. | Velvetleaf | Common lambsquarters |
| | ----- % change in plant density ----- | | |
| Fallow | -49a | -36a | -23a |
| Cash crop – rye/vetch | -52a | -15a | -49a |
| Field pea/oat – rye/vetch | -69a | -46a | -32a |
| Oat/red clover | 913c | -33a | 517b |
| Brassica – buckwheat - brassica | -68a | -67a | -41a |
| Organic soybean | 49b | 30b | 253b |

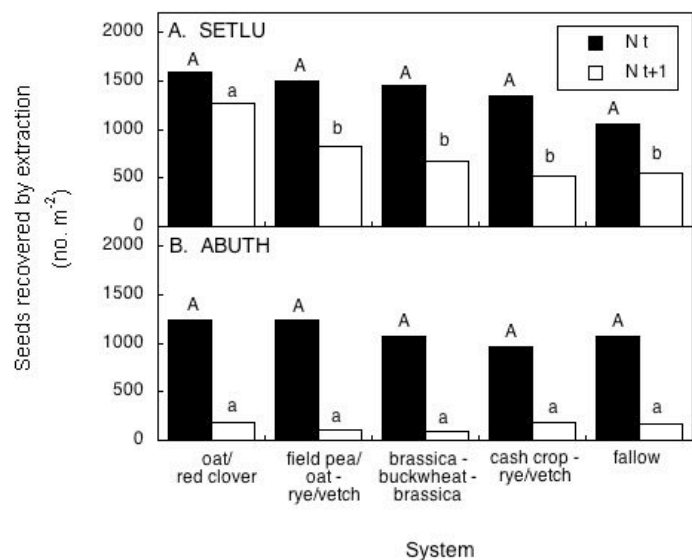
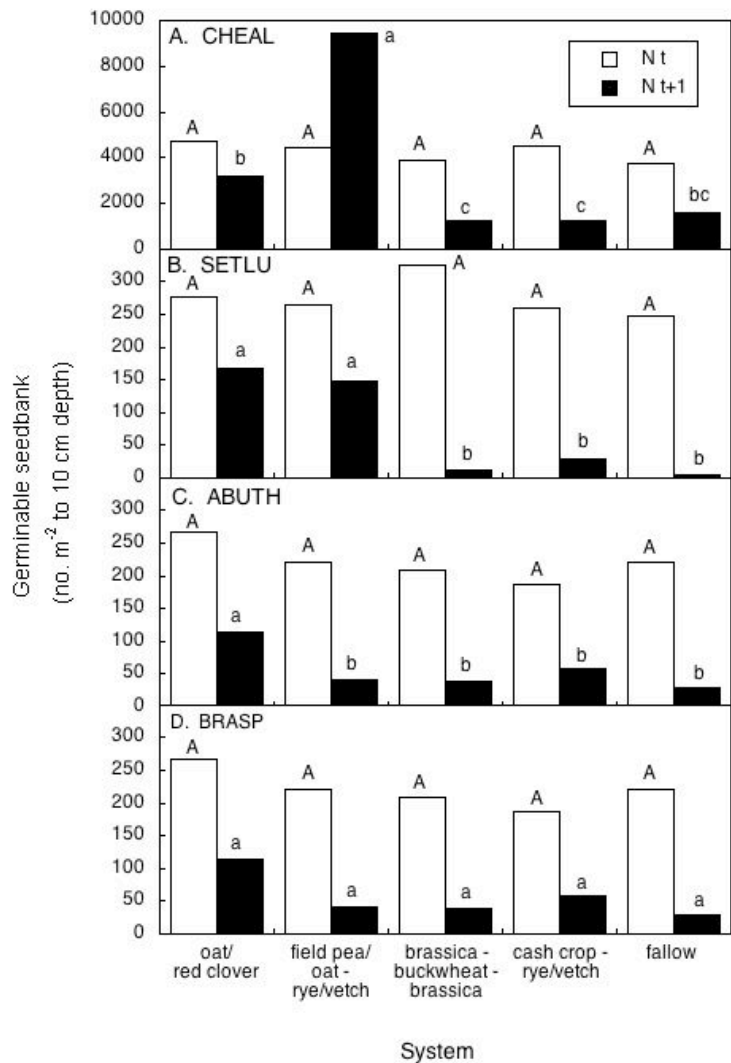
*Means within a given weed species that have the same lower case letter are not significantly different (p= 0.05).

In Maine, the initial germinable seedbank densities were, as expected, unaffected by System (Figure 4). Similar to the problem observed in the Pennsylvania oat/red clover system (Table 1), poor timing of late-season disturbance resulted in considerable common lambsquarters seed production and an increase in the seedbank in the Maine field pea/oat-rye/vetch system (Figure 4 A). Other treatments responded remarkably similar over time and species, demonstrating that systems with more soil disturbance events result in greater depletion of the seedbank over a single season (Figure 4). Notable is the consistently dramatic single-season reduction in common lambsquarters, yellow foxtail and velvetleaf in the systems that included three or more unique disturbance events (Figure 4 A-C).

Figure 4. Density of germinable seeds sampled in the spring following establishment of high density synthetic seedbanks, prior to implementing cover cropping systems (N t), and sampled the following spring (N t+1), in Maine. Species included common lambsquarters (A), yellow foxtail (SETLU), velvetleaf (C), and several brassica species (D), including primarily *Sinapis arvensis*, *Brassica rapa*, and *Raphanus raphanistrum*. Means labeled with common letters within year (N t or N t+1) are not significantly different ($P > 0.05$).

In Maine, direct extraction of 83 cm² of soil (between 1.6 and 1.8 kg of soil), recovered 39% of the sown “surrogate” seeds (ceramic beads), averaged over years, in the spring following sowing (T0), and 25% in the following spring (T1). The density of yellow foxtail seeds remained the greatest in the oat/red clover system (Figure 5, A), and was lower and similar in the remaining systems. This is consistent with the theory that season-long cover crops may act to preserve the preceding years seedbank compared to systems managed with more frequent disturbance events.

Figure 5. Density of all yellow foxtail (A) and velvetleaf (B) seeds recovered by direct extraction in the spring following establishment of high density synthetic seedbanks, prior to implementing cover cropping systems (N t), and sampled the following spring (N t+1), in Maine. Means labeled with common letters within year (N t or N t+1) are not significantly different ($P > 0.05$). Data were averaged over years.



Seed Predator Research

The more abundant of the ground-dwelling invertebrates observed at Penn State was *Harpalus pensylvanicus*, a known weed seed predator found in much of the northeastern United States. *H. pensylvanicus* had peak activity density in the five cropping systems beginning in August for both the 2004 and 2005. In the spring and early summer, *H. pensylvanicus* showed little preference between crops, while in late summer and early fall, activity density was highest in the cropping systems with little soil disturbance. This corresponds to when adult carabids are in one of their most vulnerable stages (breeding and reproducing) and probably prefer habitats with low disturbance. The activity density in the soybean in September, also a low disturbance treatment, increased slightly or stayed the same. These results suggest that cropping systems with little or no late summer tillage or mowing should encourage *H. pensylvanicus* populations.

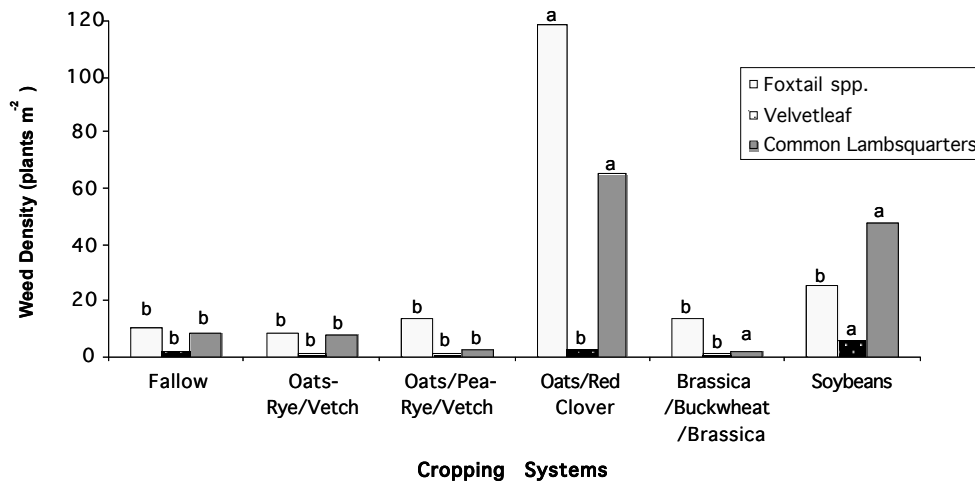
Maine's dominant invertebrate weed seed predator was the ground beetle *Harpalus rufipes* which was three times more abundant in fields planted with a pea-oat cover crop than in fallow fields. Pea-oat fields acted as refuges for beetles released in fallow fields. Within one week, greater than half of all beetles released in fallow fields moved into pea-oat fields. Over 90% of beetles released in pea-oat fields did not move into other fields. This result supports the use of vegetated refuges as a way to preserve *H. rufipes* during periods of intense disturbance. In contrast, the presence or absence of a cover crop did not affect the abundance of *H. rufipes* adults emerging from pupation in the soil during June and July. This suggests that other factors are responsible for determining where immature *H. rufipes* develop.

We also compared *H. rufipes* abundance in four additional cover crop-based weed management systems (buckwheat/brassica/buckwheat rotation, pea-oat/rye-vetch rotation, snap beans/rye-vetch rotation, and a clover-oat mix) to a fallow control. Significantly more beetles were found in the pea-oat/rye-vetch rotation than in the other cover crop and fallow systems. In comparison with the other systems, the pea-oat system is intermediately disturbed. In contrast, the fallow control and buckwheat/brassica/buckwheat rotation endure greater soil disturbance while the snap beans/rye-vetch rotation and clover-oat mix receive less. This suggests that while the presence of vegetation alone encourages adult *H. rufipes* populations, some level of soil disturbance is needed to achieve even higher densities.

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

Reduction in weed populations through recruitment in the first year of the crop rotation generally resulted in lower weed population densities in the subsequent sweet corn cash crop. Cropping systems with weed populations achieving fecundity during the recruitment phase in the crop rotation resulted in increased weed densities during the sweet corn cash crop. Successful weed seed production in foxtail spp. and common lambsquarters during the soybean and oats/clover recruitment crop phase, resulted in reduced weed control efficacy and increases in seedling density during the sweet corn crop phase (Figure 6). Velvetleaf density also increased in the soybean system due to successful seed production.

Figure 6. Density of foxtail species, velvetleaf, and common lambsquarters four weeks after planting sweet corn for the 2005/2006 study site Means within a given weed species that have the same lower case letter are not significantly different ($p = 0.05$).



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.

An evaluation of regionally-available descriptions of innovative cover cropping strategies used by growers indicated that case studies are available, or are being published, that feature some of the farms participating in this research project. Thus, instead of farm-centered case studies we have focused our outreach efforts on field days and grower talks featuring the theoretical basis for our field experiments with cover crops, preliminary results from these experiments, and focused educational materials on weed seed predators.

In 2005 and 2006, a total of 6 educational field days were held in Pennsylvania that focused on the role of cover crops for ecologically-based weed management. Research and/or demonstration plots were utilized at each location to help communicate the educational message. Field days took place at the PSU Russell E. Larson Agricultural Research and Education Center near Rock Springs, PA and on three farms in different regions of the state. A total of about 475 individuals attended one or more of the events. Attendees included farmers, vo-ag teachers, cooperative extension personnel, and other ag professionals. In addition to the financial support from USDA NE Region IPM, field days were co-hosted by the Pennsylvania Association of Sustainable Agriculture (PASA). USDA NE-SARE also provided some financial support for the field day activities. Preliminary results from the threshold-based cover crop project were presented at the field days and attendees had an opportunity to view field experiments. Of particular interest to the group was the seed predation work and the potential impact of ground beetles. Evaluations were conducted at all locations and participants responded very positively about the educational activities. A portion of the evaluation asked individuals to gage their understanding of several concepts before and after attending the educational program. As

specific examples, 70% of the participants at a PSU field day increased their understanding of 4 to 5 concepts in ecological weed management. At a farmer hosted field day, 61% of the participants increased their understanding of 4 to 5 topics in cover crop management and soil quality including the role of seed predators in suppressing weeds. The evaluation results will be summarized and included in extension program impact reports and in other appropriate venues. Several extension publications dealing with various aspects of this project are in development.

Educational field days associated with this project:

1. Ecological weed management field day, Rock Springs - June 13, 2005 – 60 attending
2. Cover cropping to improve soil quality, manage weeds, and improve production, Charlestown Cooperative Farm – Oct. 7, 2005 – 15 attending
3. Ecological weed management field day, Rock Springs – June 13, 2006 – 50 attending
4. Integrating cover crops and tillage to manage weeds and build better soil quality, Village Acres Farm – June 28, 2006 – 70 attending
5. Integrating no-till practices and cover crops to build soil quality and manage pests, Cedar Meadow Farm – July 14, 2006 – 250 attending.
6. Ecological weed management for teachers, Rock Springs – July 17, 2006 – 30 attending

In Maine, two field day activities featured this project in 2005. The first was an educational program for eighteen urban high school students from Maine and New York City. This three- hour program featured a presentation on ecological weed management (Shearin, A. and E.R. Gallandt) and field exercises in which the students recovered invertebrate pitfall traps and weed seed feeding stations that had been previously placed in the field. The second event, a more traditional grower field day held on July 27, 2005, included presentations on the preliminary seed bank results from the project, a tour of the plots, and a second presentation on invertebrate seed predators by John Shearin, a University of Maryland undergraduate who developed our “Seed Predator Test Kits.” Approximately 85 growers and agricultural professionals attended these presentations. In 2006 field days were held again at the University of Maine Rogers Farm, and at the Peacemeal Farm in Dixmont, Maine; 40 growers attended these presentations.

H. Impacts

The foremost impact of this project is the demonstration that single-season cover cropping practices including three or more unique soil disturbance events result in a marked reduction in the germinable weed seedbank. Secondly, despite their apparent competitive ability, and likely benefits to soil quality, full season cover crops lacking soil disturbance may result in considerable weed seed rain resulting an increasing weed problem in subsequent years. While we do not discourage growers from considering these full-season cover crops, they must be monitored carefully so that they are terminated prior to production of viable weed seed. Invertebrate seed predators may be conserved in cover crops, and late-season management must balance the need to preempt weed seed rain while minimizing disturbance to ground beetle populations. Lastly, through our outreach efforts we have delivered these salient points to 600 growers.

I. Appendices

Publications, Peer-reviewed

1. Gallandt, E. R. (2006). "How can we target the weed seedbank?" *Weed Science* **54**: 588-596.

Grower Publications

1. Gallandt, E.R., and R. Kersbergen. Ecologically-based weed management; Managing weeds without herbicides. [copy attached]
2. Seed Predator Test Kit: Materials List [copy attached]
3. Seed Predation Field Day Lesson Plan [copy attached]

Presentations

1. Gallandt, E.R. How can we target the weed seedbank? North Central Weed Science Society Annual Meeting. *Invited presentation*. December 15, 2004 (40 attending).
2. Gallandt, E.R. Soil-improving practices for ecological weed management. Biology Department, Colby College, Waterville, ME. *Invited presentation*. November 19, 2004 (55 attending).
3. Gallandt, E.R. Managing the weed seedbank. Northeast Organic Farming Association. *Invited presentation*. August 13, 2005 (40 attending).
4. Mirsky, S., D. Mortensen, and W. Curran. 2006. Implications of managing weed seedbanks at increasing weed seed densities. Abstr. 46:246.
5. Mirsky, S., M. Murray, W. Curran, D. Mortensen, and M. Barbercheck. 2005. Incorporating cover crops for weed management. Abstr. WSSA 45:259.
6. Mirsky, S., W. Curran, and D. Mortensen. 2005. Evaluating effects of increasing cover crop intensity on weed seedbank dynamics: a systems approach. Proc. NEWSS 59:127.
7. Murray, M., S. Mirsky, W. Curran, and E. Gallandt. 2006. Threshold-based cover cropping strategies for weed management. 5th National IPM Symposium, April 4-6, St. Louis, MO.
8. Murray, M., W. Curran, M. Barbercheck, and D. Mortensen. 2006. Weed seed predation by ground beetles. Proc. NEWSS60:55.
9. Murray, M., W. Curran, D. Mortensen and M. Barbercheck. 2005. Ecological weed management: the role of ground beetles in weed seed predation. Proc. NEWSS59:126.
10. Reberg-Horton, S.C. New England Vegetable & Berry Conference, "Managing weed seedbanks", Manchester, New Hampshire, December 17, 2003
11. Reberg-Horton, S.C. Sustainable Agriculture Field Day, "Weed Seed Predator Test Kits for Your Farm", July 27, 2005.
12. Shearin, A. and S.C. Reberg-Horton. 2005. Cover crop management impacts on the weed seed predator *Harpalus rufipes*. Proceedings of the Annual Meeting – Northeastern Weed Science Society 59: 77.
13. Shearin, A. F., S.C. Reberg-Horton, E.R. Gallandt, and F.A. Drummond. 2005. Cover crop and cultivation impacts on the weed seed predator *Harpalus rufipes*. Programs and Abstracts of the Annual Meeting – American Society for Horticultural Science. Hortscience 40(1): 1102.

Manuscripts in preparation

1. Shearin, A.F., S.C. Reberg-Horton, E.R. Gallandt. Tillage impacts on carabid (Coleoptera: Carabidae) weed seed predator abundance in Maine.
2. Shearin, A.F., S.C. Reberg-Horton, E.R. Gallandt. Cover cropping and soil disturbance impacts on the invertebrate weed seed predator *Harpalus rufipes* Degeer (Coleoptera:Carabidae).

Ecologically-Based Weed Management

Strategies for Managing Weeds Without Herbicides

Eric Gallandt (581-2933; gallandt@maine.edu)

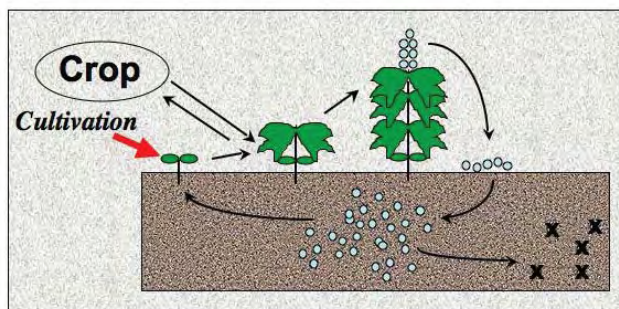
Rick Kersbergen (800-287-1426; richardk@umext.maine.edu)

“Many Little Hammers”

—A systems approach to weed management

Annual weeds depend on the seedbank, seeds on and in the soil, to disperse their offspring over time. Because cultivation generally controls a fixed proportion of germinated weeds, which in turn is directly proportional to the abundance of seeds in the seedbank, weed management efforts should include strategies that (1) reduce seed inputs, (2) increase seed losses, and (3) reduce the probability of establishment for the seeds that remain.

Early season weed control, crop competition, and late season weed control to preempt seed production contribute to reducing seed rain.

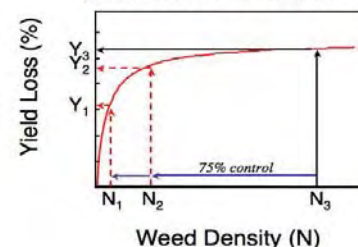


Vertebrate and invertebrate seed predators may consume a considerable proportion of the seed rain, but burial by tillage or rain events may limit

this source of loss. Shallow tillage events, timed based on soil temperature and moisture conditions to encourage germination losses is an effective means of preparing a “false seedbed.” Lastly, incorporated cover crop residues often reduce the probability of establishment of small-seeded weeds, and may be a useful means of reducing the “effective” seedbank prior to growing large-seeded or transplanted crops; larger plants better tolerate the physical and chemical environment following incorporation of green manures.



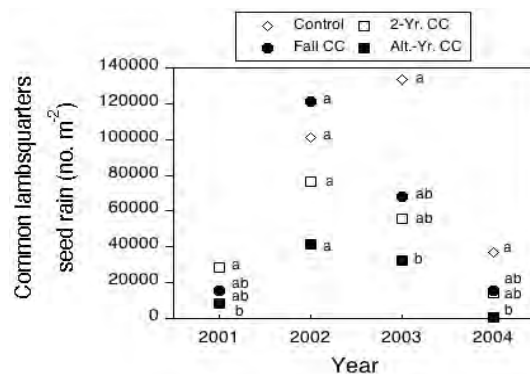
Cultivation controls a constant proportion of weeds



Managing Weed Seed Rain

Effect of four vegetable/cover cropping systems on common lambsquarters weed seed rain. The experiment, conducted at the University of Maine’s Rogers Farm in Stillwater, included: (1) a “control” system (Control), a conventionally-managed 2-year rotation of broccoli and winter squash; (2) Fall cover crop system (Fall CC), an organic, “land limited” system, also a 2-year rotation of broccoli and winter squash, but with winter cover crops (e.g., rye/hairy vetch and winter rye alone) planted following harvest of the cash crops; (3) Perennial cover crop system (2-Yr. CC), an organic, 4-year rotation of broccoli, winter squash, oats/red clover, red clover sod; and (4) Alternate year cover crop system (Alt-yr CC), an organic, 4-year rotation of broccoli/winter rye, winter rye/summer fallow/oat-hairy vetch.

Over the four years, common lambsquarters increased in each of the systems. However, compared to a system without cover crops, common lambsquarters increased only slightly in the disturbance-intensive, alternate year cover crop system which both debited the seedbank by encouraging germination, and minimized “deposits,” i.e., “seed rain.” The perennial cover



crop system, despite an abundance of invertebrate seed predators, experienced no net reduction in the germinable weed seedbank over the four-year period.

False Seedbed

Early tillage. Make the first cultivation the deepest so germinable seeds aren't brought to the surface.

Repeat shallow cultivation as conditions allow to encourage multiple "flushes" of weed germination.

Three to five days after planting blind cultivate with rotary hoe or spring-tine harrow.

Cultivate 3 to 4 times until canopy closes.

Germination losses account for the majority of debits to the seedbank.

Stale Seedbed

Delayed or no primary tillage.

Early planting to get a jump on weeds.

Preemergence flaming to kill emerged seedlings without stimulating germination.

Begin cultivating once crop has maximal size advantage.

Seed Predation

Seed losses due to predation may be considerable. Birds, rodents, and numerous invertebrates including ants and ground beetles, are all potential post-dispersal weed seed predators. We recently examined seed predation by invertebrates in contrasting cover cropping systems and found *Harpalus rufipes* a ground-dwelling beetle and well-known seed predator (eating a velvetleaf seed in the photo, right), to be particularly abundant in red clover plots. Predation rates averaged over cover crop treatments and six weed species were 56% over 11 d in 2002 and 58% over 4 d in 2003; enclosure treatments indicated that invertebrates were responsible for the majority of predation in both years.



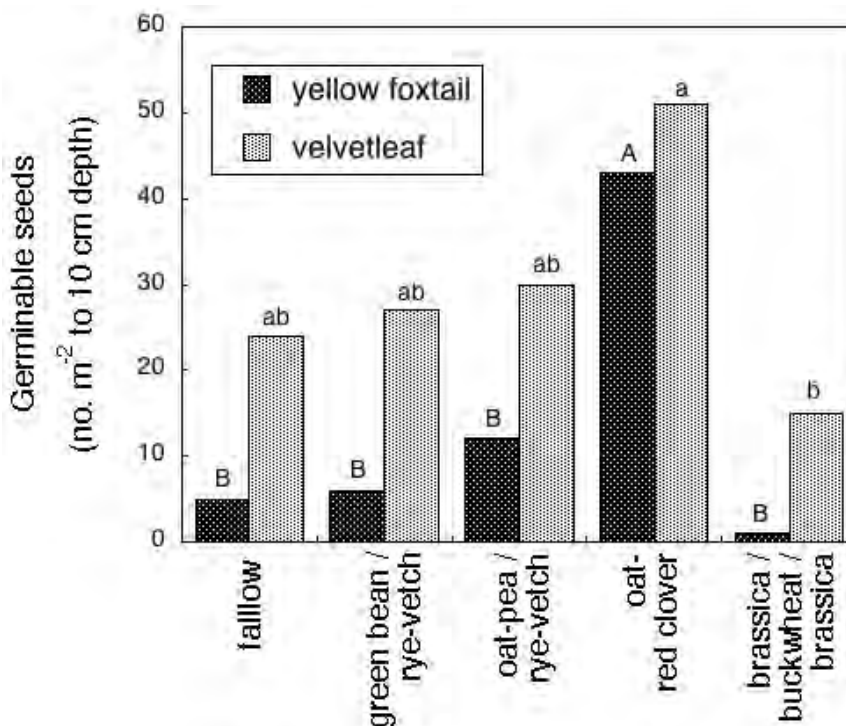
Cover Cropping

—The Importance of Disturbance Events

While cover cropping may contribute to weed management through multiple mechanisms, disturbance events associated with establishment and termination of cover crops is perhaps most important.

The data, right, show the effect of 2004 cover cropping systems on the density of germinable yellow foxtail and velvetleaf seeds in spring 2005 samples. Note that yellow foxtail was chosen to represent a species with a relatively short-lived seedbank whereas the hard seed coat of velvetleaf, with associated antimicrobial agents, enables this species to persist many years in the soil.

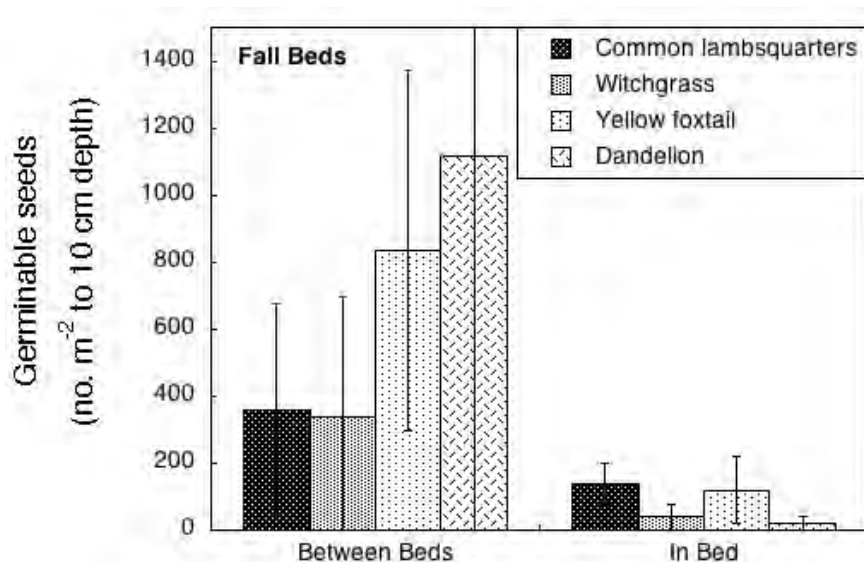
Yellow foxtail seed density was greatest following oat/red clover, which included only a single disturbance event. Yellow foxtail density was lower, and equivalent, in the remaining systems. Density of germinable velvetleaf seeds was likewise greatest in the oat/red clover system, and least in the highly disturbed brassica/buckwheat/brassica system, with intermediate density in the remaining treatments.



Fall Bed Project

A field trial comparing fall-made “permanent” beds with repeatedly established (in the same locations) spring-made beds, was established at the Rogers Farm in Stillwater, ME, in late September 2002. Each bed treatment consisted of three beds; the area between the fall beds was sown to perennial ryegrass which, overtime, became a mixture of ryegrass and white clover. This sod area was managed by mowing with a side discharge mower to distribute clippings onto the plastic in an effort to protect the plastic from UV degradation. Key points from this preliminary study include:

1. Germinable weed seed bank was similarly very low within beds of both Fall and Spring bed treatments.
2. Attention to weed management along plastic edges, i.e., by hand pulling, and timely mowing are needed to reduce likely seed rain between beds.
3. Benefits of longer-term plastic mulching regarding weed seedbank depletion are likely obscured when plastic is removed and tillage homogenizes the relatively weedy between bed area and the relatively weed-free bed area.
4. The plastic must be protected from animal foot traffic by fencing
5. Crop yield and quality were not measured; competition from the perennial ryegrass, inter-bed cover crop could be intense



For more information on Ecologically-Based Weed Management:

Liebman, M., C. L. Mohler, and C. P. Staver. 2001. *Ecological Management of Agricultural Weeds* Cambridge University Press, Cambridge, UK.

Integrated weed management: One year's seeding.... Davis, Renner, et al., (2005). Michigan State University Extension Publication E2931. (<http://www.emdc.msue.msu.edu/viewitem.cfm?INVKEY=E2931>)

HDRA Organic Weed Management website:

http://www.hdra.org.uk/organicweeds/weed_management/index.php

“A review of non-chemical weed management” by Bond and Grundy

“Organic weed management” by Merfield

National Sustainable Agriculture Information Service

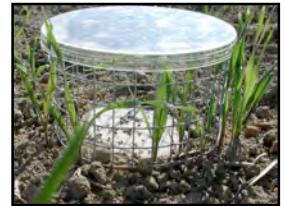
<http://www.attra.org/> >Pest Management>Weed Management

Gallandt, E. R. 2004. Soil improving practices for ecological weed management, 267-284, in Inderjit, ed. *Principles and Practices in Weed Management: Weed Biology & Weed Management*. Dordrecht, The Netherlands: Kluwer academic publishers.

Seed Predator Test Kit

Contents:

- **15 pitfall traps, incl. 15 specimen cups with lids**
- **1 box of beetle specimen cards**
- **5 beetle ID cards**
- **1 bulletin**
- **1 Lesson Plan**
- **Seed predation testing supplies**
 - 15 small (15 x 100 mm) petri dishes covered with double-sided mounting film
 - 30 extra pieces of double-sided mounting film
 - packet of seeds— ~1200 common lambsquarters seeds
~1200 redroot pigweed seeds
- **Set of enclosures**
 - 5 vertebrate with petri dish (15 x 150 mm) covers
 - 5 vertebrate/invertebrate with petri dish (15 x 100 mm) covers
 - 5 open (15 x 100 mm petri dishes with legs)
- **30 marking flags**



Alternative Materials for Constructing Additional Supplies

Many of the materials in our Seed Predator Test Kits, such as specimen cups and petri dishes, must be purchased from a laboratory supply company. The following alternatives to these materials may be more practical when constructing small quantities of additional testing supplies:

- ✓ **Enclosure covers:** Use margarine/ice cream/yogurt tub lids or lids from similar containers
- ✓ **Specimen cups:** Individual size yogurt cups or small plastic/paper disposable cups will work
- ✓ **Double-sided mounting film:** Use double-sided outdoor carpet tape, 3M Spray Mount®, etc.
- ✓ **Small Petri dishes:** Use lids from individual size yogurt cups or from small margarine tubs; small squares of heavy sandpaper can also be sprayed with 3M Spray Mount® before being sprinkled with weed seeds and then held in the ground with nails



Lesson Plan: Planning Your Own Field Day

Preparation:

There are two options for placing the testing supplies in the field. The simplest option is to place all traps and exclosures in the same field, preferably in five different sets that are spaced evenly apart. For example, each set should include one open exclosure, one vertebrate exclosure, one vertebrate/invertebrate exclosure, and three pitfall traps; one set can be placed in each corner of the field and one in the center of the field. This option works best for smaller groups (15-20 people) and if time is limited (less than one hour). With larger groups and more time available, the demonstration can be expanded to multiple fields/plots that include several different tillage types or crop rotations (i.e. one set of traps and exclosures in each of five differently managed fields). This option allows the audience to see the effect of tillage and cover crops on ground beetle populations in addition to demonstrating how seed predation works, but requires at least one hour in order to fully discuss the implications of what is found in these traps and exclosures. This option also works best if there are several leaders to guide the participants through checking the traps and exclosures.

Exclosures should be placed in the field at least 48 hours before the field day/workshop is to take place in order to allow seed predators time to locate and consume seeds. 25 seeds of each weed type should be counted out (or estimated) from the seed containers for each of the 15 small petri dishes. The protective paper covering the sticky side of the petri dishes should be peeled off and the appropriate number of weed seeds sprinkled on each of the 15 petri dishes.

Pitfall traps should be placed in the field at least 24 hours before the field day/workshop is to take place in order to capture a greater number and variety of ground beetles, and should be buried flush with the soil surface.

The Field Day:

The audience should first be given background information on seed predation, including the importance of weed seed predation, information on weed seedbanks, seed removal rates, and the effects of seed burial on predation. Participants should be familiarized with the pitfall traps and exclosures and what they should be looking for when checking them in the field. This portion should take about 10 to 15 minutes.

The participants should be split up into five groups, and each group should be assigned to a different set of traps and exclosures. Participants can either determine seed predation in the field (and share their findings with the full group later) or retrieve the exclosures and bring them to a determined meeting spot. The specimen cups from the pitfall traps can be retrieved and brought back to the determined meeting spot for identifying beetles as a group, using both the beetle ID card and the beetle specimen cards. This portion can take between 10 and 30 minutes, depending on time available.

After the small groups return to the larger group, the beetles captured should be identified, paying particular attention to the number of seed predators versus non-seed predators. Each group's estimates of seed predation by invertebrates should be shared and discussed. If multiple tillage types or crop rotations were used, the number of beetles captured in each field should also be determined and discussed.