1. Title: Estimating weed seed banks for improved monitoring and management of weeds

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4. Abstract

The major objectives of this project were (i) to develop a low-cost method for estimating weed seed banks, and evaluate its potential as a fee-based service for growers, (ii) to assess the effects of winter cover crops on weed seed banks using this method. A simple weed seed bank estimation procedure was established in which soil samples from growers' fields were mixed with potting soil, spread thinly in flats in a greenhouse and monitored for emerged weed seedlings. To reduce costs, only the top 10-15 summer annual weed species were identified by species, and emergence counts occurred for only 4 weeks. Samples from 21 fields and two replicated long-term field studies were taken and their seed banks estimated. The simple method was compared to a more intensive method previously developed for research purposes. For two sites, weed seed bank estimates were compared to emergence of weeds in the field. In addition, weed seed bank estimates from treatments involving four years of winter cover crops (rye and hairy vetch) were compared to bare-soil treatments. The simple seed bank assessment was estimated to cost approximately $10 per sample. Seed bank estimates using this method correlated reasonably well with field emergence, and provided similar information to more intensive methods of estimating weed seed banks. Contrary to expectations, treatments with a history of winter cover crops had equal or higher estimated weed seed banks than those without winter cover crops. Ongoing research will assess the effects of fall versus spring sampling, and evaluate the potential value of these seed bank estimates for guiding crop-rotation and weed management decisions on farms.

5. Background and Justification

Alternative weed management is consistently ranked at or near the top of IPM priority lists for virtually every commodity group. For vegetable growers, top priorities include "alternative weed management" and "development of rotational strategies… for improved soil quality and weed control". In a recent survey of 244 NY vegetable growers, conducted by the Soil Health PWT, "large weed seed bank" had by far the highest rating (3.4) among all soil quality problems, outranking soil borne insects (2.7), soil compaction (2.5), soil borne disease (2.5), low soil organic matter (2.5) and soil nutrient availability (2.1) (Wolfe, unpublished).

Knowledge of the density and composition of weed seeds in the soil is an important component of successful integrated weed management programs and may be helpful for crop rotation planning, for improving the efficiency of weed management, and for reducing herbicide use (Wiles and Schweizer 2002). Although weed maps based on above ground observation of weeds are potentially useful, especially for perennial species, weed seed bank estimates provide a much more complete indicator of past and future problems with annual weed species.

Given the importance growers place on managing weeds, it is surprising how little research has been conducted to develop cost-effective methods of monitoring the weed seed bank. Methods for estimating weed seed banks have been developed which rely either on physically separating seeds from the soil and counting them (e.g. elutriation) or placing soil in a greenhouse and monitoring emergence. However, due in part to their high costs, the use of these methods has been limited. By providing a centralized service linked to soil health monitoring conducted by the CCE Soil Health PWT, and by simplifying the methods of weed seed bank estimation, it may be possible to lower costs and expand the use of weed seed bank estimates. The framework developed by the Soil Health PWT should facilitate efficiencies in (i) development of weed seed bank estimation protocol (ii) implementation of a fee-based service and (iii) promotion of awareness of weed seed banks as part of the continued effort to improve soil health literacy.

Mounting evidence suggests that winter cover cropping practices may have a profound impact on weeds by influencing rates of decay and predation of weed seeds, yet the importance of those effects within NY climate and cropping systems has not been extensively studied. An existing long-term vegetable cropping experiment at the Gates Farm in Geneva, as well as a newly initiated experiment at the Harford farm, provide a unique opportunity to monitor these effects, while simultaneously evaluating alternative estimation procedures.

6. Objectives

1) Develop a cost-effective method for estimating summer weed seed banks.
2) Estimate winter cover crop effects on weed seed bank density and composition.
3) Evaluate (i) potential for implementation of a fee-based weed seed bank estimates and (ii) optimal uses of winter cover crops for suppression of annual weeds.

7. Procedures

Weed seed bank estimation. Weed seed bank estimates were conducted using soil from a variety of sites including a tillage x winter cover crop trial at the Gates Farm in Geneva; a five-year vegetable crop rotation x weed management intensity trial at the Homer Thompson Research Farm in Freeville, NY; a winter cover crop x snow removal experiment recently established at the Harford Teaching and Research Center; and selected fields from Peacework Organic, Pedersen, Iron Kettle, Giles, Smith, and Hanson farms.

Altogether, soil samples were taken from 21 different fields. At the Freeville and Gates farms, samples were taken from four replicates of 2 (Freeville) or 6 (Gates) treatments within the same field. At the Gates farm, samples were taken both in the spring and fall, while for all other locations, samples were taken only in the spring. Within each location or experimental plot, a composite soil sample consisting of 12 subsamples was collected following an M pattern. Soil was thoroughly mixed, and stored at 5 C until further testing. Immediately before testing, 500 mL of field soil was mixed with potting soil (50:50 Peat:Vermiculite with nutrients) in 50:50 V:V ratio, and spread 3 cm deep in plastic flats containing a 5 cm layer of potting soil. Two flats were prepared for each sample, using a total of 1 L of field soil per sample. Flats were placed in a greenhouse (25/20 C), watered daily, and monitored for emergence at 2 week intervals for 1 month. For soil sampled in the spring, greenhouse emergence was monitored as soon as possible following field sampling. Emerged weeds were identified by species, counted, and removed. Unidentified weeds were potted and allowed to grow until identification was possible. For soil samples collected in the fall, emergence was monitored following a 1 month storage period at 5 C (to break dormancy of summer annuals). Additional storage intervals of 3 or 5 months will be tested on fall samples to determine the importance of storage duration on results. At the time of this report, these subsequent testing dates had not been conducted.

For soil from the Freeville site, additional samples, taken on the same day from the same plots were used to estimate the weed seed bank using a more intense method, previously established for research purposes. In this method, 1 kg of dry soil (approximately 1.3 L) is mixed with 9 oz of potting soil, placed in metal pie-tins, watered, and monitored for emergence for 4-5 weeks (until emergence subsides). Following these initial counts, the soil is dried, stirred, re-watered and the process repeated 3 or 4 times. Soil disturbance, wet-dry cycles, and time all help break dormancy of some weed species. In addition, seeds are separated from soil using high volume column eleutriation (this part will not be done until January, 2007). At the Freeville site, field emergence of weeds in early spring was conducted in _ m^2 plots within each plot. This field emergence data was compared to seed bank estimates to assess the adequacy of estimation procedures.

For each duration and intensity of seed bank estimation, the costs of greenhouse space, supplies, and labor was calculated. Greenhouse, soil, and watering fees were based on current greenhouse charges at the Gutterman greenhouse facility. The time to train someone in weed ID and soil sample preparation was included in the cost estimates. The time to complete each step of the estimation procedure was recorded and used to estimate labor costs on a per sample basis.

Effects of winter cover crops on weed seeds. The weed seed bank estimation procedure outlined above was used to test the hypothesis that winter cover crops reduce the density of summer annual weed seeds, and to characterize effects of cover crops on particular weed species. At the Gates site, weed seed bank density and composition were estimated from treatments differing in their historic tillage (conventional vs reduced tillage) and winter cover cropping (none, rye or vetch) practices. The effects of winter cover crops on weed seed bank density and composition, and their interactions with tillage practices were assessed using ANOVA procedures of SAS.

Baseline summer annual weed seed estimates were also taken from bare soil and cover crop treatments in newly established experimental sites at the Harford Farm, as well as Iron Kettle Farm. These sites will be sampled again in the future on an annual basis to assess cover crop effects.

Project evaluation. A project focus group consisting of researchers, growers, and extension educators has been established to discuss (i) the feasibility of implementing a fee-based service to estimate weed seed banks and (ii) the implications of results from the winter cover crop-weed seed bank estimates. To facilitate discussion, members of the group will be provided with (i) estimates of costs associated with different methods of weed seed bank estimation and correlations between seed bank estimates and emergence in the field and (ii) a summary of the effects of winter cover crops on important weed species. Following review of these materials, individuals from this group will be contacted to get feedback.

Table 1. Estimated costs per sample for estimating germinable weed seed bank.

	Top ten species		All summer species		All species	
Activity	Time (min)	Cost ($)	Time (min)	Cost[4] ($)	Time (min)	Cost[5] ($)
Training costs[1]	4.8	0.80	24	4.00	48	8.00
Watering and greenhouse fees[2]		1.48		2.96		2.96
Sample storage	5	0.83	5	0.83	10	1.67
Potting soil[3]		0.71		0.71		0.71
Flat soil preparation	15	2.50	15	2.50	30	5.00
Weed counts 2 wk	6	1.00	12	2.00	24	4.00
Weed counts 4 wk	3	0.50	6	1.00	12	2.00
Weed counts 6 wk			3	0.50	6	1.00
Weed counts 8 wks			1	0.17	2	0.33
Clean up	2	0.33	2	0.33	4	0.67
Data entry	3	0.50	6	1.00	12	2.00
Report preparation and mailing	5	0.83	10	1.67	20	3.33
Labor/sample	43.8	7.30	84	14.00	168	28.00
Total cost/sample		9.49		17.67		31.67

Notes

[1] Assumes that each season a new person would be trained and 50 samples processed.

[2] Based on $0.37/ft^2$ per month fee for Cornell greenhouse basic care; includes watering, pest control, maintanance and cost of plastic flats. Assumes each sample requires $4ft^2$ (2 flats plus spacing and idle bench space).

[3]Assumes $3.50/bushel ($2.82ft^3$) x $0.25ft^3$/sample

[4]Assumes increased training costs for ID, and two month duration for more complete testing

[5]Assumes additional fall sampling and counting required to assess winter annual seed bank.

8. Results and discussion

Estimates of cost of weed seed bank estimation procedure. Table 1 summarizes the costs associated with the weed seed bank estimation procedures. The estimated cost of the simple method used in this study was $9.49/sample. This procedure is limited to the top 10-15 summer annual weeds, and utilizes a 4 week monitoring procedure. The major cost associated with this method is labor for sample preparation and monitoring, which accounted for about 77% of the total estimated cost. Watering and greenhouse fees accounted for about $1.50 (16%) per sample. More intensive sampling to identify and count all summer annual species would cost almost $18 per sample. Estimates of costs required to estimate both summer and annual weed species could easily run $30 or more. These more intensive methods would require increased costs (i) to train employees to identify hundreds of weed species, (ii) additional greenhouse charges for longer duration monitoring and (iii) increased labor costs associated with monitoring more species over a longer duration.

Preliminary evaluation of weed seed bank estimation method.

Seed bank estimates using the simple method (4 week estimation procedure for major summer annuals) were similar to those from the more intensive method (4 months with drying and disturbance) (Table 2). The total number of seedlings emerging in both methods was very similar. The simple method resulted in higher estimates for hairy galinsoga and ragweed, but lower estimates for annual grasses (especially barnyardgrass). The reasons for these discrepancies are not clear. One possibility is that the more intense method involved drying and storing the soil for 1 month at air temperature before testing. This treatment may have contributed to dormancy breaking of annual grasses or induction of secondary dormancy of ragweed. In January and February of 2007 more intensive estimates of the same Freeville soil samples will be conducted using high volume column eleutriation. These estimates will be useful for further assessing potential limitations of the simple estimation procedure.

Each of the major weed species observed in the field were also detected in the simple estimation procedure in the greenhouse (Table 2). In addition, the relative proportions of weed species estimated by the simple procedure were similar to those observed in the field. For example, galinsoga represented 62% of the estimated germinable seed bank, and 74% of weeds emerging in the field. The estimated seed bank for pigweed (16 or 27% of all seeds) was somewhat higher than emergence in the field (2-7% of all seedlings). This difference is most likely due to warmer temperatures in the greenhouse than the field. Pigweed species have a higher base temperature of germination than the other species observed, and hence generally have peak emerge later in the spring. Actual emergence of summer annual weeds in the spring was generally between 30 and 50% of the estimated germinable weed seed bank. This is not surprising given suboptimal temperature and moisture conditions in the field compared to the greenhouse.

The simple estimation procedure clearly distinguished between weed seed banks in plots where intensive weed management (herbicide + cultivation) had taken place for the previous 5 years, from those relying on cultivation alone for weed management (Table 2). However, the ability of this method to distinguish more subtle differences in weed seed banks may be more limited.

For practical application of the seed bank estimation procedure, samples will have to be taken at least 2 months before to the anticipated planting date. Ideally, a fall soil sample would be submitted and tested in the greenhouse during the winter. However, because seeds of many summer annual species are dormant in the fall, immediate testing would underestimate the germinable seed bank in the spring. Therefore, testing is underway to assess the duration of cold storage (stratification) required to break dormancy of summer annual species.

Summary of weed seed bank estimates from 20 fields.

Seed bank estimates from 21 fields sampled in the spring revealed significant variation in both

Table 2. Comparison of weed seed bank estimates and weed emergence in two management systems, Freeville farm, 2006.

	Cultivation[5] seeds/seedlings (#/m²)	(%)	Herbicides +Cultivation[5] seeds/seedlings (#/m²)	(%)
Total				
Greenhouse simple[1]	4,200	100	728	100
Greenhouse intense[2]	4,148	100	1,010	100
Field emergence[4]	1,399	100	401	100
Galinsoga				
Greenhouse simple[1]	2,610	62	360	49
Greenhouse intense[2]	1,800	43	450	45
Field emergence[4]	1,037	74	334	83
Lambsquarters				
Greenhouse simple[1]	345	8	15	2
Greenhouse intense[2]	127	3	23	2
Field emergence[4]	50	4	7	2
Pigweed				
Greenhouse simple[1]	668	16	195	27
Greenhouse intense[2]	635	15	121	12
Field emergence[4]	103	7	10	2
Ragweed				
Greenhouse simple[1]	113	3	23	3
Greenhouse intense[2]	6	0	0	0
Field emergence[4]	42	3	16	4
Annual grasses				
Greenhouse simple[1]	255	6	8	1
Greenhouse intense[2]	1,229	30	237	23
Field emergence[4]	69	5	1	0

Notes

[1] Greenhouse emergence for 4 wks as described in methods. Estimate is number of germinable seeds in top 3 cm of soil.

[2] Greenhouse emergence for 8 wks with stirring.

[3] Actual emergence in field in early spring.

[5] Soils were collected from two treatments within a rotation study differin in their weed management intensity for the previous 5 years. The cultivation treatment relied on cultivation and hand-weeding, while the herbicide + cultivation treatment used herbicides in combination with cultivation as needed

[4] Separation of seed from soil with high volume column eleutriator and sieves. Separation not complete at time of report.

the distribution and abundance of species across sites (Table 3). Estimates of the total germinable weed seed bank ranged from 150 to almost 6,000 seeds/m^2 with a median value of 1,110 seeds/ m^2. Not surprisingly, the distribution of species also varied substantially. The ten common summer annual species (or genera) listed in Table 3 accounted for between 0 and 100% of all weeds identified with an average of 53%. Broadleaf weeds were dominant, accounting for 82% of all weeds counted. The number of different weed species identified on individual farms ranged from 1 (Johnson field #11 had only lambsquarters) to 13 (multiple farms). Lambsquarters was found on the most fields (76%), followed by purslane (48%), *Panicum* species (48%) and pigweed (*Amaranthus*) species (38%).

Table 3. Summary of weed seed bank estimates for 2006 spring sampling.

Farm	Field ID	# of spp.	Total (#/m^2)	Top 10 Total (#/m^2)	Top 10 Broadleaf (#/m^2)	Top 10 Broadleaf (%)	Top 10 Grass (#/m^2)	Weed species[1] PW (#/m^2)	LQ	PL	RW	GA	VL	SW	BG	FX	PN
Gates	1	8	570	120	90	(75)	30	0	0	60	30	0	0	0	0	0	30
Gates	2	13	1,110	210	120	(57)	90	0	30	60	30	0	0	0	30	30	30
Gates	3	12	990	210	120	(57)	90	0	30	60	30	0	0	0	30	30	30
Henderson	4	10	1,230	720	720	(100)	0	0	270	450	0	0	0	0	0	0	0
Henderson	5	9	810	300	270	(90)	30	0	180	90	0	0	0	0	0	0	30
Henderson	6	13	3,060	2,670	1,770	(66)	900	0	600	1,140	30	0	0	0	0	60	840
Henderson	7	12	1,050	540	510	(94)	30	0	60	450	0	0	0	0	30	0	0
Freeville	8	13	5,940	5,430	4,710	(87)	720	360	30	0	450	3,780	0	90	0	0	720
Freeville	9	7	540	510	480	(94)	30	120	30	0	90	210	0	30	0	0	30
Freeville	10	9	2,100	1,500	1,500	(100)	0	390	30	270	0	810	0	0	0	0	0
Johnson	11	1	630	630	630	(100)	0	0	630	0	0	0	0	0	0	0	0
Iron Kettle	12	9	1,140	330	270	(82)	60	240	30	0	0	0	0	0	0	30	30
Iron Kettle	13	4	870	510	510	(100)	0	420	90	0	0	0	0	0	0	0	0
Giles	14	3	1,350	1,290	0	(0)	1290	0	0	0	0	0	0	0	0	0	1,290
Giles	15	7	3,300	2,880	2,550	(89)	330	960	1,590	0	0	0	0	0	0	30	300
Pederson	16	7	900	180	180	(100)	0	0	30	0	90	60	0	0	0	0	0
Pederson	17	5	1,140	480	480	(100)	0	360	60	0	0	0	0	60	0	0	0
Pederson	18	7	2,310	1,170	1,170	(100)	0	1,110	60	0	0	0	0	0	0	0	0
Hanson	19	11	2,280	450	450	(100)	0	0	0	360	0	30	0	60	0	0	0
Smith	20	3	240	120	120	(100)	0	0	0	30	0	0	90	0	0	0	0
Smith	21	4	150	0	0	NA	0	0	0	0	0	0	0	0	0	0	0

Notes

[1] PW = pigweed species (*Amaranthus* spp); LQ = lambsquarters (*Chenopodium album)*; PL = purslane (*Portulaca oleracea*); RW = ragweed (*Ambrosia artimiisifolia*); GA = hairy galinsoga (*Galinsoga ciliata*); VL = velvetleaf (*Abutilon theophrasti)*; SW = smartweed species (*Polygonum* spp); BG = barnyardgrass (*Echinochloa crus-gali*); FX = foxtail spp (*Setaria* spp); PN = *Panicum* spp. (e.g. witchgrass; fall panicum)

Cover crop effects on weed seed bank estimates

Weed seed bank estimates from the Gates farm experiment did not reveal major effects of winter cover crops on the germinable weed seed bank (Table 4). Estimates from samples taken in the spring showed lower total weed seed numbers in plots that historically had bare soil, compared with those which had a rye winter cover crop. No significant differences in major summer annual weed species were detected between winter cover crop treatments. Estimates from samples taken in the fall did not vary significantly by cover crop treatment, although there was a trend towards reduced seed number in cover crop treatments.

Seed bank estimates for field pennycress (the dominant species) correlated well with observed emergence in the fall (Table 4). As with the seed bank estimate, field pennycress emergence in the fall was not significantly lower in cover crop versus bare soil treatments. However, the observed density of mature field pennycress plants in the spring (over-wintering plants) was significantly lower in cover crop plots. This result suggests that both rye and vetch can significantly reduce the survival of winter annuals like field pennycress, but the effects of these cover crops on the weed seed bank may be relatively small. For example, in 2006, field pennycress plants were killed prior to producing seeds in the spring, so the suppressive effect of cover crops did not result in reduced inputs of field pennycress to the weed seed bank.

As expected, fall sampling and testing resulted in lower estimates of summer annuals, and higher estimates for winter annual species like field pennycress (Table 4). This is likely due in large part to the dormancy cycles of weed seeds: Summer annual seeds are often dormant in the fall, while winter annuals are often dormant in the spring. Particularly striking was the absence of field pennycress detected in spring samples. This result highlights the importance of targeting sampling timing to the species of interest.

Table 4. Cover crop effects on germinable weed seed bank, and field pennycress density, Gates Farm, 2006.[a]

	Seed bank estimates						Observed plant density	
	Total		Summer annuals		Field Pennycress		Field Pennycress	
Cover crop[b]	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
	#/m^2							
None	570 a	1,020 a	120 a	60 a	0 a	150 a	13 a	119 a
Rye	1,020 b	690 a	180 a	30 a	0 a	30 a	1 c	53 a
Vetch	930 ab	1,080 a	180 a	90 a	0 a	60 a	3 b	61 a

Notes: [a]Means within the same column followed by the same letters are not significantly different (P = 0.05).
[b] Cover crop treatments had been in place for four years prior to sampling. Cover crop treatments varied not only in cover crop, but also in tillage and herbicide practices.

Summary and future plans.

Results from this study indicate that (i) estimates of the density of major summer annual weeds can be obtained from soil samples for as little as $10 per sample (Table 1), (ii) these estimates correlate reasonably well with field emergence (Tables 2 and 4), and therefore may have value in both crop rotation planning and weed management decision making and (iii) these estimates can be helpful in assessing the long term weed management effects of different management choices.

The usefulness of seed bank estimation for growers, and their willingness to pay a fee for this service needs further investigation. A copy of this report will be provided to project cooperators for their feedback. Preliminary discussion with vegetable growers suggest some limitations and concerns. Some growers may already know what species are present in their fields. In addition, one grower pointed out that given the limited herbicide options for most vegetable crops, knowledge of the weed species present is unlikely to change his management decisions. On the other hand, many growers do not have the training to correctly identify weed species and might benefit from this service, particularly if it were linked to management information specific to the species identified (e.g. weed fact sheets; herbicide efficacy charts). A centralized testing service would also allow growers to compare their weed seed bank densities to all farms tested in order to better evaluate how they are doing and help in setting realistic goals. In addition, testing of the same field over time using a standard protocol, can help growers assess the effectiveness of their management choices, and identify trends of potentially problematic weed species.

9. Project location(s)

Soil samples from the project came from multiple counties in North Central NY. Development of a fee-based weed seed bank assessment service could ultimately be beneficial to growers and homeowners throughout the Northeastern U.S.

10. Samples of resources developed

Weed seed bank estimation result forms are currently under development. They will include information like that shown in Table 3. In addition, photos of seedlings of weed species found, and fact sheets for key species may be included.