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Seedbanks: Determination, Dynamics & Management

Cropping system effects on *Setaria faberi* seedbank dynamics

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Summary

Green manure and compost effects on *Setaria faberi* seed survival, recruitment and fecundity were studied in 2000 and 2001 within the wheat *Triticum aestivum*-corn *Zea mays* transition of a wheat-corn crop sequence in Iowa, USA. Wheat was grown as a sole crop (W) or underseeded with red clover *Trifolium pratense* (R). Composted swine manure, applied in late fall of the wheat phase, did not affect *S. faberi* seedbanks. Green manure did not affect *S. faberi* seed survival, but recruitment was 21% lower, and fecundity was 38-120% greater, respectively, in the R treatment than in the W treatment. Bioassays of soil collected from the corn phase on 10 May showed reductions of 22-25% and 16-47%, respectively, for *S. faberi* germination and radicle elongation in the R treatment compared to the W treatment. To prevent weed seedbank increases, green manure residues should be managed to avoid reduced early crop growth.

Key words: Seed survival, recruitment, fecundity, compost, green manure

Introduction

Weed seedbanks buffer weed population dynamics against temporal variations in environmental conditions and management practices (Cousens & Mortimer, 1995). Because of the close association between weed seeds and soil in weed seedbanks, management practices that affect soil properties have the potential to alter weed seedbank dynamics. Better understanding of cropping system effects on weed seedbank dynamics will promote integrated weed management strategies in which weed control complements weed suppressive qualities of the cropping system.

Soil amendment with organic materials such as green manure and compost is an important practice for maintaining and improving soil quality that may also influence weed seedbank dynamics through effects on soil fertility, phytotoxicity and soil physical properties (Liebman & Davis, 2000). Green manure N contributions to soil are limited by residue biomass, whereas compost N contributions vary with application rate. Compost applied at high rates may stimulate growth and fecundity of certain weed species, such as common waterhemp *Amaranthus rudis* (Menalled *et al.*, 2004). Timing and amount of N mineralisation by soil organic amendments is dependent upon their composition and handling, but may be delayed compared to N release by synthetic N fertilisers applied at planting, and therefore less likely to stimulate weed recruitment and growth (Liebman & Davis, 2000).

Incorporation of organic amendments into soil can cause temporary phytotoxicity of the amended soil volume, resulting in chemical and pathogenic inhibition of seedling recruitment

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and growth (Conklin *et al.*, 2002) and increased fungal attack of weed seeds (Pitty *et al.*, 1987). Bioassays have detected phytotoxicity from immature compost (Tiquia *et al.*, 1996) and freshly incorporated green manure residues, including those of small grains (Weston, 1996), crucifers (Vaughn & Boydston, 1997) and legumes (Chung & Miller, 1995). Amendment phytotoxicity decreases as decomposition of the material progresses, with little or no phytotoxicity 4 to 6 wk after residue incorporation (Breland, 1996; Dabney *et al.*, 1996) or 5 wk after initiation of the composting process (Tiquia *et al.*, 1996). As composts mature, they may become sources of compounds that promote plant growth (Chen & Aviad, 1990) and suppress damping-off diseases of seedlings (Craft & Nelson, 1996).

Soil organic amendments can affect soil physical properties by stimulating microbial formation of soil aggregates, but such effects depend on the stability of amendment decomposition products (Tate, 1987). Soil amendment with small grain residues promotes greater aggregate stability than does soil amendment with legumes (Martens & Frankenberger, 1992). Composts, which are rich in humic acids, may have pronounced, long-lasting effects on water stable aggregates and water holding capacity of soils, even after a single application (Tester, 1990). Soil water content and aggregate size can influence seedbank dynamics through effects on recruitment and seed survival (Benech-Arnold *et al.*, 2000; Reuss *et al.*, 2001).

Through differential effects on soil properties, green manure and compost may have different impacts upon weed seedbank dynamics. In previous work, wild mustard *Sinapis arvensis* growth and interference with sweet corn were found to be reduced in soils amended with red clover green manure and composted dairy manure, compared to unamended soils (Davis & Liebman, 2001). The objectives of the present study were to characterise the effects of red clover green manure and composted swine manure on *Setaria faberi* seedbank dynamics within a wheat-corn crop sequence. Two hypotheses were tested: first, that compost would have a neutral or stimulatory effect upon *S. faberi* seedbank dynamics, due to its low phytotoxicity and high nutrient value; and second, that freshly-incorporated green manure would exhibit phytotoxicity, with negative effects upon all aspects of *S. faberi* seedbank dynamics.

Materials and Methods

A field study of soil organic amendment effects on *Setaria faberi* seedbank dynamics was begun in 1999 on a Nicollet clay loam (Aquic Hapludolls) near Boone, Iowa USA. This experiment was conducted within a spring wheat-corn crop sequence. Both entry points of the wheat-corn crop sequence were grown in 1999, 2000 and 2001 so as to have wheat-corn transition environments to study over multiple years.

The experiment consisted of a two by two factorial of *Green manure* (+/- red clover in the wheat phase) and *Compost* (+/- compost applied in fall of the wheat phase), arranged in randomised blocks replicated four times. Each experimental unit was 3.8 m wide by 6.1 m long. Spring wheat was sown in April either as a sole crop ('W') or underseeded with red clover ('R'). In late October, composted swine manure (matured for 6 months prior to application) was applied to each plot in the wheat phase at 0 t C ha^{-1} ('NC') or 25 t C ha^{-1} ('C'). Due to variation in compost C and N content between years, total N application rate from compost was greater in 2000 (220 kg N ha^{-1}) than in 1999 (180 kg N ha^{-1}). Residues and compost from the wheat phase were incorporated to a depth of 20 cm in early April with a power takeoff-driven rototiller. Corn was planted in these plots on 27 April of each study year in 0.76 m wide rows at 64,500 seeds ha^{-1}. Urea was banded 2.5 cm from the corn row at 90 kg N ha^{-1} on 5 June of each study year. Wheat and corn were harvested in mid July and early September, respectively.

Two sets of synthetic seedbanks were used to measure *S. faberi* seed survival on the soil surface from October of the wheat phase through March of the corn phase (σ_w), and seed survival in the top 5 cm of soil from March of the corn phase through October of the corn phase (σ_s). In late October, sections of PVC pipe 5 cm long and 30.5 cm in diameter were driven flush

with the soil surface in plots transitioning from wheat to corn. Four hundred *S. faberi* seeds per PVC ring were sprinkled onto the soil surface beneath wheat and red clover residues. Seeds were recovered using a seedbank elutriator (Wiles *et al.*, 1996) and viability determined with tetrazolium tests (Peters, 2000). During spring tillage, seedbanks for the determination of σ_s were exhumed, bagged and moved to the side, after which they were hand mixed and re-interred between future corn row locations.

Seed survival was calculated as $[N_{MAR}/N_{OCT}] \times 100$ for σ_w, and $[N'_{OCT}/(N'_{MAR} - N_g)] \times 100$ for σ_s, where N_{OCT} represented the 400 seeds placed in the ring, N_{MAR} was the number of viable seeds recovered from the seedbank in March, N'_{MAR} was equal to the treatment mean of viable seeds recovered in March from seedbanks used to determine σ_w, N_g was emerged seedlings (see below) and N'_{OCT} was the number of viable seeds recovered in October after the corn phase.

Seedling recruitment per m^2 from synthetic seedbanks was measured weekly from 27 April through 21 June in 2000 and 2001. Emerged seedlings were counted and removed with sharp forceps. Fecundity and biomass were determined in early September for *S. faberi* planted on 28 April of each study year at 50 plants per m^2 in rows parallel to, and offset 4 cm from, the corn row. Prior to seed rain, 30 *S. faberi* panicles per experimental unit were enclosed in fine mesh bags. Mature panicle length was regressed on seed number for bagged panicles, and this regression applied to giant foxtail panicle length in the rest of the plot to give seeds per plant (ϕ) and per m^2 (f). Weed species not in the study were removed by hand on a weekly basis.

Soil phytotoxicity during seedling recruitment was assessed with bioassays (Dabney *et al.* 1996). Forty *S. faberi* seeds were spaced in a line 10 cm from the top edge of two 25 cm by 38 cm sheets of germination paper moistened with 20 ml H_2O. The field-moist equivalent of 100 g dry weight soil, collected from each plot on 10 May, was spread in a 1 cm deep band starting 2 cm above, and extending 12 cm below, the line of seeds. A third sheet of germination paper was placed on top of the soil layer, and the entire assembly rolled along the short axis, wrapped in plastic film and secured with rubber bands. Units were incubated vertically for 96 hr at 25°C in the light (16 hr) and 15°C in the dark (8 hr). Germinated seedlings were then counted and radicle length measured.

Arcsine and square root transformations were necessary to meet ANOVA assumptions of normality and homogeneity of error variance for seed survival and fecundity data, respectively. Seed survival, fecundity and bioasssay data were analysed with ANOVA models that included *Year*, *Red clover* and *Compost* main effects and interaction terms. Means were separated by Fisher's Protected LSD test at $P<0.05$. Seedling recruitment was analysed by repeated measures ANOVA models that included *Year*, *Red clover* and *Compost* main effects and interaction terms. Path analysis was used to examine direct and indirect effects of *Red clover* on f (Mitchell, 2001). Data were analysed across years since model variables, including corn height on 5 June, *S. faberi* biomass on 9 September, and f did not fail tests for homogeneity of error variances, nor were there year by treatment interactions for these variables.

Results

Compost

There were no main effects of *Compost* on *Setaria faberi* seed survival, seedling recruitment or fecundity in either 2000 or 2001 (Table 1, Fig. 1). Bioassays of soil collected on 10 May within the corn phase also showed no effect of *Compost* on *S. faberi* germination or radicle length (Table 2). Interactions between *Year*, *Compost* and *Green manure* ($P < 0.05$) were observed for seed survival from October through March (σ_w) and March through October (σ_s) (Table 1). These interactions appeared to reflect the large amount of interannual variability in seed survival data, rather than any clear effect of *Compost* in modifying *Green manure* impacts on seed survival. In 2000, σ_w was 5% lower in the R/C treatment than in the other three

treatments, which were the same. In 2001, there was no amendment-related variation in σ_w. The pattern of treatment means for σ_s was nearly opposite in 2000 and 2001. In 2000, σ_s was 17% lower in the R/NC treatment than in the other three amendment treatments, which were the same. In 2001, σ_s was lowest in the W/NC and R/C treatments, intermediate in the R/NC treatment and greatest in the W/C treatment. Despite the large pulse of nutrients contained in the compost amendment, there was no tendency towards greater *S. faberi* fecundity, measured either as seeds per plant (ϕ) or seeds per m^2 (f), in soils amended with compost (Table 1).

Green manure

Year by *Compost* by *Green manure* interaction effects were observed for both σ_w and σ_s, but *Green manure* did not have a clear relationship to either seed survival parameter. Within levels of *Compost*, values of σ_w and σ_s were the same, or lower, in the R treatment compared to the W treatment (Table 1).

In contrast to the lack of *Compost* effect on *S. faberi* seedling recruitment from 27 April through 21 June, a strong *Green manure* effect on recruitment was observed in both 2000 and 2001 (Fig. 1). Across years, there was a 21% reduction in seedling recruitment in the R treatment (713 seedlings m^{-2}) compared to the W treatment (903 seedlings m^{-2}). The reduction in seedling emergence in the R treatment was significant at all census dates. Moreover, the effect of *Green manure* on seedling recruitment was not subject to interactions with either *Compost* or *Year*. Bioassays of the phytotoxicity of soil collected from the corn phase on 10 May showed main effects of *Green manure* on both *S. faberi* radicle length and percent germination (Table 2). Radicle length of *S. faberi* seedlings was 47 and 16% lower in the R treatment than in the W treatment, in 2000 and 2001, respectively. Germination of *S. faberi* was 22 and 16% lower in the R treatment than in the W treatment, in 2000 and 2001, respectively.

Green manure main effects were observed for *S. faberi* fecundity on both a per plant (ϕ) and per m^2 (f) basis (Table 1). Although *Green manure* interacted with *Year* in its effect on *S. faberi* fecundity (especially for f, which was an order of magnitude greater in 2001 than in 2000) the pattern of *Green manure* main effects was consistent. Therefore, only main effects of *Green manure* on *S. faberi* fecundity will be considered here. In 2000 and 2001, ϕ was 120 and 38% greater, respectively, in the R treatment than in the W treatment. Despite reductions in plant

Table 1. Setaria faberi *seed survival and fecundity within a corn crop grown in soils amended with compost, green manure, or both, in Boone, Iowa, USA*[1]

	Seed survival				Fecundity			
	[Oct.-Mar.(σ_w)]		Mar.-Oct.(σ_s)]		[ϕ		f]	
	[2000	2001]	[2000	2001]	[2000	2001]	[2000	2001]
	%				10^3 seeds $plant^{-1}$		10^3 seeds m^{-2}	
W/NC [2]	84 b	54 a	57 b	67 a	1.2 a	1.2 a	4.1 a	51 a
R/NC	86 b	51 a	45 a	74 ab	4.0 c	1.4 ab	9.5 b	59 b
W/C	86 b	46 a	52 b	80 b	1.5 a	1.3 a	6.2 ab	54 ab
R/C	81 a	52 a	53 b	66 a	2.2 b	1.8 b	8.2 b	62 b
SE	2	5	4	4	0.3	0.1	1.8	3

[1]Within columns for each year, means followed by different lower case letters were different as determined by Fisher's Protected $LSD_{0.05}$ multiple comparison test.
[2]W = wheat sole crop prior to corn phase, R = wheat + red clover green manure prior to corn phase, NC = no compost prior to corn phase, C = compost added prior to corn phase.

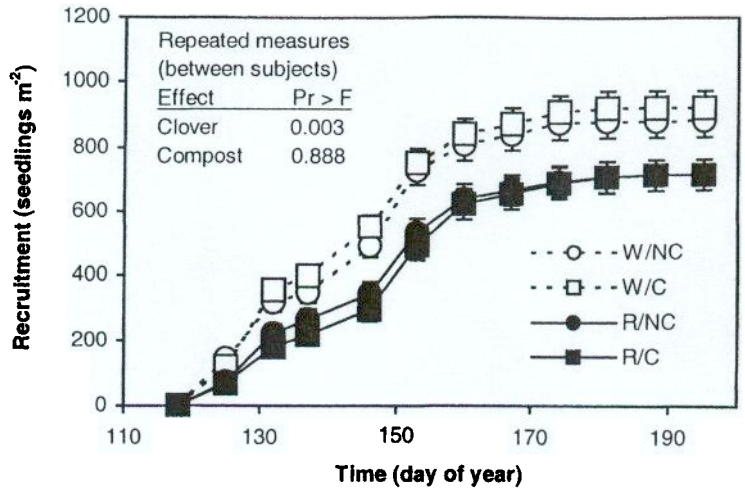

Fig. 1. *Setaria faberi* seedling recruitment within a corn crop grown in unamended soil (W/NC), or soil amended with compost (W/C), green manure (R/NC), or compost and green manure (R/C). Data were analysed across 2000 and 2001.

density associated with the R treatment, *f* was 71 and 15% greater in the R treatment than the W treatment in 2000 and 2001, respectively.

A path analysis of the relationship between red clover green manure, corn height at June 5, *S. faberi* biomass and *S. faberi* fecundity in seeds per m^2 was used to test two alternative explanations for the increase in *f* associated with the R treatment (Fig. 2). We were interested in knowing whether the green manure 1) directly stimulated *S. faberi* growth and seed production, or 2) inhibited early corn growth, thereby reducing the competitive effect of corn upon *S. faberi* growth and seed production. An examination of the path coefficients showed only one

Table 2. *Bioassay of soil organic amendment effects on phytotoxicity of soil collected on 10 May, 2000 and 2001, within a corn crop in Boone, Iowa, USA*[1]

	S. faberi radicle length		*S. faberi* germination	
	[2000	2001]	[2000	2001]
	mm		%	
W/NC[2]	21 c	17 b	38 c	59 c
R/NC	11 a	15 a	28 b	36 a
W/C	17 b	20 c	36 c	46 b
R/C	9 a	16 a	21 a	44 b
SE	1.3	0.9	2.5	2.1

[1] Within columns for each year, means followed by different lower case letters were different as determined by Fisher's Protected $LSD_{0.05}$ multiple comparison test.
[2] Treatment abbreviations follow the pattern described in Table 1.

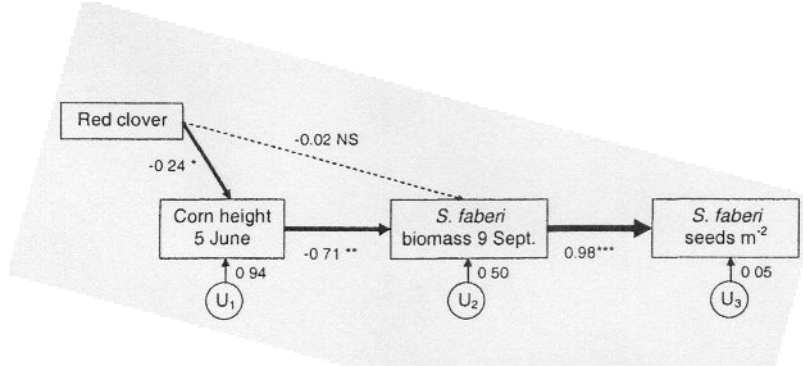

Fig. 2. Path analysis of red clover green manure effects on S. faberi fecundity. The symbols *, ** and *** represent the significance of path coefficients at the $P < 0.05$, 0.01, and 0.001 levels, respectively. Non-significant pathways are represented by dashed arrows. U_n = unexplained variation.

significant causal pathway from the red clover green manure to *S. faberi* fecundity, via green manure effects on early corn growth and interference with *S. faberi* growth. Therefore the latter explanation of green manure effects on *S. faberi* fecundity fit the available data better than the former one.

Discussion

Interannual variation in all seedbank parameters greatly exceeded variation related to soil amendment practices. These results are consistent with the work of Ullrich (2000), who found that weather affected weed seedbanks in Maine potato cropping systems much more strongly than did crop sequence, cultivation or tillage.

In support of hypothesis 1, soil amendment with composted swine manure had a neutral effect on weed seedbanks, with no main effects of *Compost* on any parameter, or meaningful interactions with *Green manure*. As bioassays showed, the compost applied in this study had matured to the point that it did not create phytotoxic effects in the amended soil volume. The lack of weed suppression by the mature compost is in agreement with previous work showing that organic wastes composted for longer than 6 wk do not have negative effects on seedling germination and growth (Tiquia *et al.*, 1996). It was somewhat suprising that compost did not stimulate *Setaria faberi* seedbank dynamics, given its potential to supply plant macronutrients at high rates (Eghball & Power, 1999).

Two lines of evidence may help explain why compost amendments did not stimulate *S. faberi* seedbank dynamics in this study. First, levels of NO_3-N in the soil on 12 June, prior to a side-dress application of N fertiliser, did not differ between compost-amended treatments (10 ppm) and unamended treatments (8 ppm). Compost amendments contained between 180 and 220 kg N ha^{-1}, but the N was in organic forms, and therefore not immediately available for plant uptake. Eghball & Power (1999) estimated that 20% of the total N from composted beef manure should become available to plants during the first year of decomposition. Because the compost that was applied in this experiment had already decomposed for over six months prior to application, it is possible that the mineralisation rate had already slowed down substantially, leading to less NO_3-N accumulation than would have been obtained with a less decomposed material. Second, although many the growth of many grass weeds is stimulated by N fertiliser (DiTomaso, 1995), *S. faberi* may be less responsive to N than other grass weeds. In subplots sidedressed with urea at 0, 90 and 200 kg ha^{-1}, N rate had no effect on *S. faberi* seed survival, recruitment or fecundity (data not shown).

When the weed flora of a farm is dominated by *S. faberi*, soil amendment with mature compost may present little risk of weed seedbank increases. Other work, however, indicates that

soil amendment with compost may have differential effects on weed species, with potential stimulation of *Amaranthus rudis* and velvetleaf *Abutilon theophrasti* (M Liebman, unpublished observations). Therefore, in cropping systems receiving compost applications, weed growth should be monitored closely and additional weed control employed, if necessary.

Green manure effects on *S. faberi* seedbank parameters varied from negative to stimulatory, therefore hypothesis 2 was not supported by the results of this study. Seedbank persistence was unaffected by green manure during either the winter (σ_w) or summer (σ_s) months. Little published information exists on this topic, but one previous study suggests that the potential for seed decay due to fungal infection is increased due to soil amendment with plant residues (Pitty *et al.*, 1987). In addition to the possibility that green manure residues simply do not affect weed seedbank persistence, the lack of effect observed in this study may have been due to delaying incorporation of green manure residues and weed seeds into the soil until spring. For seeds overwintering on the soil surface, where seed mortality factors such as weathering and predation operate most strongly (Cousens & Mortimer, 1995), the presence of green manure residues may have been relatively insignificant as a mortality factor. In contrast, when wheat/red clover green manure residues were incorporated in late November in a parallel study (Davis & Liebman, 2003), there was a 65% increase in mortality of *S. faberi* seeds compared to seeds in an unamended treatment in one of two years. For seeds remaining in the seedbank during the growing season, spring-incorporated green manure may have had little effect on survival for two reasons. First, legume residues decompose very quickly when ploughed under in warm, moist conditions, with fleeting effects on soil properties (Tate, 1987). Green manure effects on soil conditions may not have lasted long enough to affect seed survival. Second, because *S. faberi* seeds do not persist for long in the seedbank (Buhler & Hartzler, 2001), a large proportion of the seeds remaining in the seedbank after germination may already have been fated for decay, masking variability in seed decay due to green manure. Further work is necessary to understand how residue management affects weed seed survival through changes in the soil environment.

Green manure effects on *S. faberi* recruitment were consistent with previous studies indicating that weed seedling emergence may be reduced, delayed, or both, in response to soil amendment with legume residues (Dyck & Liebman, 1994; Davis & Liebman, 2001). Such suppression has been shown to have both chemical (Ohno *et al.*, 2000) and pathogenic components (Conklin *et al.*, 2002). To our knowledge, the indirect stimulation of weed fecundity through reductions in crop-weed interference caused by green manure phytotoxicity has not been observed before. Given the potential for suppression of crop seedling emergence and growth by green manure residues (Hammond & Cooper, 1993; Davis & Liebman, 2003), altering cultural practices to avoid crop damage is an important consideration for growers who include green manures in their cropping system. Some options include the use of treated seed and allowing sufficient time between residue incorporation and crop planting for phytotoxicity to diminish (Hammond & Cooper, 1993; Dabney *et al.*, 1996). Other approaches for benefiting from green manure suppression of weed emergence while avoiding the chance of increased weed fecundity include 1) using green manures in transplanted vegetable crops, where large seedings should be able to resist residue-mediated suppression, and 2) incorporating green manure residues more shallowly for rapid decomposition and reduced overlap with the crop seed zone.

Manipulation of weed seedbank dynamics through cropping system effects on soil characteristics offers the possibility of more fully integrated weed management systems, in which cultural and weed management practices have complementary effects on overall weed population size. Success will depend on identifying soil and crop management practices that reduce weed seed survival, emergence and fecundity without negative effects on the crop.

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