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Weed Management in a Legume-Cereal Cover Crop with the Rotary Hoe[1]

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Abstract: Substantial weed growth often occurs in legume-cereal cover-crop mixes commonly grown on organic vegetable farms. A 2-yr study at the USDA-ARS in Salinas, CA, was conducted to test the effect of zero, one, and two passes with a rotary hoe on weed control in a mixed cover crop of 10% rye, 15% common vetch, 15% purple vetch, 25% peas, and 35% bell bean. Rotary hoeing occurred 14–15 days after planting (DAP) in the one-pass treatment, and 14 and 28 DAP in the two-pass treatment. Rotary hoeing did not affect total cover-crop density or biomass in either year, but reduced rye density and biomass in year 2. One pass reduced total weed density by 69% in year 1 and 49% in year 2. A second pass did not affect weed density in year 1 but reduced weed density an additional 33% in year 2. One pass decreased weed biomass in year 1, whereas two passes were required to reduce weed biomass in year 2. Rotary hoeing reduced seed shed by chickweed and shepherd's-purse seeds, the two predominant weed species, by 80 to 95% in both years. Rotary hoe efficacy depended on weather conditions directly before and after cultivation. The decision to repeat rotary hoeing should be based upon field scouting and weather conditions following the initial pass with the rotary hoe.

Nomenclature: Chickweed, *Stellaria media* (L.) Vill. #[3] STEME; shepherd's purse, *Capsella bursa-pastoris* (L.) Medic. # CAPBP; rye, 'Merced' *Secale Cereale* L.; common vetch, *Vicia sativa* L.; purple vetch, *Vicia benghalensis* L.; peas 'magnus', *Pisum sativum* L.; bell bean, *Vicia faba* L.

Additional index words: Weed seed, organic, *Senecio vulgaris*, *Lamium amplexicaule*, *Solanum sarrachoides*, *Poa annua*.

Abbreviations: GDD, growing degree days

INTRODUCTION

Cover crops are essential components of crop rotations on organic farms. They can reduce nitrate leaching (Wyland et al. 1996), provide nitrogen to following crops (Singogo et al. 1996), improve soil structure (McVay et al. 1989), and impact weed populations (Akemo et al. 2000). Weed seed production during cover-crop growth can be substantial and may increase weed problems in subsequent vegetable crops (Brennan and Boyd 2004; Brennan and Smith 2005). This issue is extremely important on organic farms, where weed management is particularly expensive and poorly competitive legumes are often included in cover-crop mixes.

The rotary hoe has been shown to effectively reduce weed density in agronomic crops (Bowman 1997), but, to our knowledge, has not been evaluated in a mixed planting or on a cover crop. In some crops like oats (*Avena sativa* L.), the rotary hoe is as effective as herbicides at controlling weeds (Mohler and Frisch 1997). Rotary hoeing is most effective just before or shortly after weeds emerge (Gunsolus 1990; Oriade and Forcella 1999). A 50 to 80% drop in weed density following rotary hoeing has been reported (Buhler et al. 1992; Forcella 2000; Hooker et al. 1998; Lovely et al. 1958). Weed size and hoeing frequency determine implement efficacy. Small weeds are more easily uprooted and desiccated compared to larger, more established weeds. Weeds at the white-thread stage are especially sensitive to uprooting by the rotary hoe. Lovely et al. (1958) reported a 70 to 80% reduction in weed infestations when multiple passes with the rotary hoeing occurred just as the weeds were germinating but not emerged. However, they only achieved 50% weed control when they delayed rotary hoeing until all weeds had emerged. Multiple passes facilitate control of weeds that germinate and emerge over an extended period of time.

Rotary hoeing is typically done after crop emergence when the plants are small. Crop density, but not yield, generally declines up to 10% with rotary hoeing (Le-

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

Table 1. Cover-crop planting, treatment application, and data-collection dates as well as cumulative growing degree days (GDD), cumulative precipitation (precip), and irrigation regime.

	Year 1			Year 2		
	Date	GDD	Precip	Date	GDD	Precip
		°C	mm		°C	mm
Cover-crop planting	Nov. 6, 2003	0	—	Oct. 25, 2004	0	—
Pass 1 with the rotary hoe	Nov. 20, 2003	138	10	Nov. 9, 2004	131	25
Pass 2 with the rotary hoe	Dec. 4, 2003	228	13	Nov. 22, 2004	238	29
Plant counts	Dec. 12, 2003	283	23	Dec. 6, 2004	304	33
Harvest 1	Feb. 19, 2004	708	190	Feb. 23, 2005	889	259
Harvest 2	Mar. 19, 2004	993	246	Mar. 19, 2005	1131	295
Weed seed retrieval	Mar. 19, 2004	—	—	Mar. 19, 2005	—	—
First irrigation	Nov. 11, 2003	—	9	Nov. 5, 2004	—	6
Second irrigation	Nov. 26, 2003	—	8	—	—	—

Blanc and Cloutier 2001a; Lovely et al. 1958). Leblanc and Cloutier (2001b) found that multiple passes with the rotary hoe up to the fourth trifoliate soybean leaf stage decreased soybean density, but not yields. In fact, yields were sometimes greater with rotary hoeing than the noncultivated control. They suggest that the increase in soybean yields following rotary hoeing in the absence of weed competition could be attributed to the breakage of soil crusts, improved soil aeration, increased nutrient mineralization, or reduced soil moisture losses.

The objective of this study was to evaluate the impact of one and two passes with the rotary hoe on cover-crop density and biomass, weed density and biomass, and weed seed shed in a mixed legume-cereal cover crop.

MATERIALS AND METHODS

The experiment occurred on a 4-ha transitional organic field on adjacent areas at the USDA-ARS in Salinas, CA, during the fall and winter of 2003 to 2004 (year 1) and 2004 to 2005 (year 2). The field was mowed, disked, and chiseled before the experiment began, and between years 1 and 2, to incorporate winter cover-crop biomass. The field was fallow in the summer between years 1 and 2. The soil is a Chualar series sandy loam (fine–loamy, mixed Thermic Typic Argixerolls) with 77% sand, 16% silt, 7% clay, and 1% organic matter. A mixed cover crop[4] of 10% 'Merced' rye, 15% common vetch, 15% purple vetch, 25% 'Magnus' peas and 35% bell bean was planted on November 6, 2003, and October 25, 2004 (Table 1). The cover crop was planted with a Great Plains grain drill[5] with 15 cm between seed lines at a seeding rate of 228 kg/ha. Sprinkler irrigation was applied after planting as needed to promote germination of the cover crop (Table 1).

Three treatments were tested: (1) no rotary hoeing (weedy check, 0 passes), (2) one pass with the rotary hoe[6] 14 or 15 DAP, and (3) two passes with the rotary hoe with the first at 14 or 15 DAP, and the second at 28 DAP. Weed emergence had just begun when the first rotary hoeing occurred. A 4.6-m-wide rotary hoe with 7.6-cm spacing between rotary wheels was used at speeds of 13 to 16 km/h. The rotary hoe was raised and lowered as the tractor moved across the field to create adjacent treatment plots that were 4.6 m wide and at least 3 m long. All sampling occurred in the center of each plot between tractor tire tracks. Cover-crop growth stages at the first rotary hoeing were rye (two leaves), common and purple vetch (first true leaf emerging), peas (first true leaf), and bell bean (first true leaf emerging). Cover-crop growth stages at the second rotary hoeing were rye (one to two tillers), purple vetch (four to six nodes with the bottom one branching), common vetch (four to five nodes with the bottom two branching), peas (three to four true leaves), and bell beans (two to three true leaves).

Weed and cover-crop plants were counted in a 50 by 50-cm quadrat in each plot following the final rotary hoeing (Table 1). Aboveground cover-crop biomass was harvested in one 50 by 100-cm quadrat in each plot, and divided into cereal and legume components. Weed biomass was harvested from the same quadrat on the first harvest date. Biomass was oven dried at 65 C for at least 48 h and then weighed. The number of shed chickweed and shepherd's-purse seeds was measured on the same day as the final biomass harvest by vacuuming the soil surface of the area harvested. The hose of a wet/dry

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[4] L. A. Hearne Co., 524 Metz Road, King City, CA 93930. The percentage of each component in the mix was by seed weight, and the cover crop was inoculated with *Rhizobium*.

[5] Great Plains Mfg., Inc., 1525 East North Street, Salina, KS 67401.

[6] Yetter Farm Equipment, 109 South McNonough, Colchester, IL 62326.

Table 2. Rye, vetch, pea, bell bean, and total cover-crop plant counts (plants/m^2) in 2003, and 2004, after zero, one, or two passes with the rotary hoe.

	Rye	Vetch	Pea	Bell bean	Total
Year 1					
Zero passes[a]	90 a[b]	84 a	18 a	15 a	207 a
One pass	77 a	82 a	16 a	10 a	185 a
Two passes	78 a	80 a	20 a	13 a	191 a
Year 2					
Zero passes	46 a	105 a	25 a	21 a	197 a
One pass	30 ab	102 a	30 a	22 a	184 a
Two passes	24 b	101 a	33 a	23 a	181 a

[a] Weedy check.

[b] Means within columns and year followed by different letters are significantly different at $P < 0.05$.

vacuum[7] was moved slowly over the entire area harvested just above the soil surface. A crust on the soil surface facilitated removal of plant residue, including weed seeds, with minimal soil disturbance. The contents of the vacuum were emptied into paper bags and taken to the lab, where a 212-µm sieve was used to wash clay from the sample. Sand and organic matter were separated by flotation in water. The organic matter was dried, put through a 1.7-mm sieve to remove large particles, and in year 2 placed in a custom-designed air column blower to remove additional organic debris. Chickweed and shepherd's-purse seeds were visually separated from the remaining organic matter and counted under a dissecting microscope.

Temperature and rainfall data reported in the article were obtained from the California Irrigation Management Information System Web site[8]. The accumulated growing degree days (GDD) were calculated with the use of the formula:

$$\text{GDD} = \Sigma([T_{\max} + T_{\min}]/2) - T_{\text{base}} \qquad [1]$$

where $T_{\max}$ is the daily maximum temperature, $T_{\min}$ is the daily minimum temperature, and T_{base} was set at 0 C.

The experiment was a randomized complete block design with 9 and 10 blocks in years 1 and 2, respectively. Data were analyzed in SAS[9] with the PROC GLM procedure. Weed and cover-crop plant counts were done in all blocks both years. Biomass was harvested from separate blocks for Harvest 1 and 2 each year. Four and five blocks were harvested at each sampling date in years 1 and 2, respectively. Weed seed was collected from 3 blocks in year 1 and from 4 blocks in year 2. Square root or $\log(x + 1)$ transformations were used as needed to homogenize the variance, but arithmetic means are presented. Data from each year were analyzed separately because the effect of year was significant for all variables. Fisher's protected LSD test was used for mean separations with a significance level of $P < 0.05$ based on a comparisonwise error rate.

RESULTS AND DISCUSSION

Cover-Crop Density and Biomass. Cover-crop density and biomass production was similar across years (Tables 2 and 3). In the weedy check, biomass increased by 40% between harvests 1 and 2 in year 1. The earlier planting date in year 2 hastened GDD accumulation earlier in the season and may explain why cover-crop biomass did not change in the weedy check between harvests in year 2. The percentage of rye plants in the mix prior to rotary hoeing was 43% in year 1 and 23% in year 2. Total cover-crop plant density and biomass, and legume density and biomass, were not affected by one or two passes

Table 3. The effect of zero, one, or two passes with the rotary hoe on the rye component, legume component, and total cover-crop biomass as well as weed biomass (all in kg/ha).

	Year 1				Year 2			
	Rye	Legume	Total[a]	Weed	Rye	Legume	Total	Weed
Harvest 1								
Zero passes[a,b]	2,274[c]	1,650	3,924	727 a	3,406 a	3,108	6,514	67 a
One pass	2,134	1,790	3,924	169 b	2,304 ab	3,902	6,206	47 ab
Two passes	2,252	1,996	4,248	167 b	1,662 b	3,837	5,499	34 bc
Harvest 2								
Zero passes	3,162	3,842	7,004	—	2,298	4,308	6,606	—
One pass	3,217	3,459	6,676	—	2,016	3,938	5,954	—
Two passes	3,588	2,780	6,368	—	2,084	3,331	5,415	—

[a] The total of the rye and legume biomass.

[b] Weedy check.

[c] Means within a column and harvest date followed by different letters are significantly different at $P < 0.05$.

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[7] Craftsman, Sears, Roebuck and Co., Hoffman Estates, IL 50179.

[8] www.cimis.water.ca.gov/cimis/welcome.jsp

[9] SAS, Statistical Analysis System Software, Version 9.1, SAS Institute Inc., SAS Campus Drive, Cary, NC 27513-2414.

Table 4. Weed counts (weeds/m^2) in 2003 and 2004 following zero, one, and two passes with the rotary hoe.

	CAPBP[a]	LAMAM	POAAN	SENVU	SOLSA	STEME	Total
Year 1							
Zero passes[b]	124 a[c]	68 a	5 a	20 a	9 a	217 a	474 a
One pass	12 b	27 b	4 ab	5 b	5 ab	79 b	148 b
Two passes	13 b	24 b	2 b	7 b	1 b	68 b	143 b
Year 2							
Zero passes	43 a	25 a	—	6 a	—	55 a	154 a
One pass	7 b	15 b	—	2 b	—	51 a	78 b
Two passes	2 c	8 b	—	0 b	—	18 b	28 c

[a] Abbreviations: CAPBP, *Capsella bursa-pastoris*; LAMAM, *Lamium amplexicaule*; POAAN, *Poa annua*; SENVU, *Senecio vulgaris*; SOLSA, *Solanum sarachoides*; STEME, *Stellaria media.*

[b] Weedy check.

[c] Means within columns and year followed by different letters are significantly different at $P < 0.05$.

with the rotary hoe either year (Tables 2 and 3). Two passes with the rotary hoe decreased rye density by 20% and rye biomass by 28% in year 2. A similar, but statistically insignificant decline in rye density also occurred in year 1. Others have shown that rotary hoeing can reduce crop density but not yield (Boerboom and Young 1995; Leblanc and Cloutier 2001b) and that effects on crop density depend on crop growth stage at the time of rotary hoeing (Leblanc and Coutier 2001a).

Weed Density, Biomass, and Shed Weed Seed. A single pass with the rotary hoe reduced weed populations by 69%, from 474 to 148 weeds/m^2 in year 1 (Table 4). The weed density in the weedy check was substantially smaller in year 2 (154 weeds/m^2) and a single pass reduced weed density by 49% to 78 weeds/m^2. The second pass only had a significant impact on weed density in year 2, where it further reduced weed density by 33%. The second pass in year 1 was probably ineffective due to heavy cloud cover and 4–5 mm of rain received in the 3 d following rotary hoeing. Rainfall and cloud cover prevent seedling desiccation following cultivation and permit seedling survival (Boerboom and Young 1995). Relatively small amounts of precipitation before or after rotary hoeing reduce weed control as much as delaying rotary hoeing until all weeds have emerged (Lovely et al 1958). Multiple passes are appropriate if weather conditions shortly after the initial rotary hoeing prevent rapid desiccation of the weed seedlings or crop scouting reveals an additional emerging seedling population or a large number of seedlings that survived.

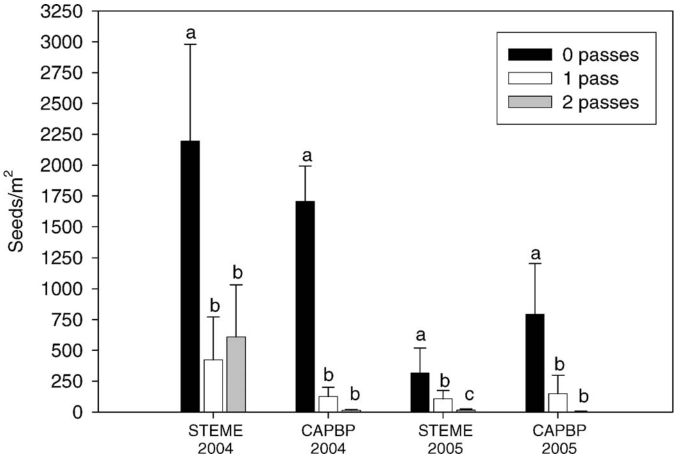

Figure 1. Chickweed (STEME) and shepherd's-purse (CAPBP) seed shed following zero, one, and two passes with the rotary hoe. Bars topped by different letters within a given weed species and year are significantly different at $P < 0.05$. Vertical bars represent standard errors of the means.

The two predominate species, chickweed and shepherd's-purse, together comprised 72 and 64% of the weed population in years 1 and 2, respectively (Table 4). The rotary hoe reduced shepherd's-purse density more than chickweed density. The effect of one versus two passes varied with years and species. For example, maximum control of chickweed and shepherd's-purse occurred with one pass in year 1, but with two passes in year 2 for the reasons discussed above.

Aboveground weed biomass comprised 16 and 1% of the total biomass production without rotary hoeing in years 1 and 2, respectively (Table 3). A single rotary hoe pass reduced weed biomass by 77% in year 1 with no additional affect of the second pass. In contrast, two passes were required to reduce weed biomass in year 2.

Rotary hoeing reduced the number of seeds shed by the two most predominant weed species in both years (Figure 1). For example, one pass with the rotary hoe in year 1 reduced seed shed of chickweed and shepherd's-purse by 72% and 93%, respectively. This reduction is similar to that obtained with more weed-suppressive winter cover crops like rye and mustard (Brennan and Boyd, 2004). A second rotary hoe pass further reduced seed shed of chickweed in year 2, and the same trend, though not significant, occurred with shepherd's-purse in both years. The data suggest that the shepherd's-purse population may decrease slightly over time if emergence continues to exceed seed production.

This study is unique because it is the first report of rotary hoeing a cover crop composed of multiple species at various growth stages. Despite this variability, the rotary hoe reduced weed populations and weed seed shed without significantly affecting total cover-crop plant counts or biomass production. Therefore, the rotary hoe is an effective implement for managing weed populations in poorly competitive legume-cereal cover crops. Efficacy depends on careful timing of rotary hoeing relative to weed emergence and weather conditions. Multiple passes are required when weather conditions inhibit rapid desiccation of seedling following rotary hoeing or crop scouting identifies the presence of a new population of emerging weed seedlings.

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