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Weed Suppression by Annual Legume Cover Crops in No-Tillage Corn

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ABSTRACT

Cover crops often reduce density and biomass of annual weeds in no-till cropping systems. However, cover crops that over-winter also have the potential to reduce crop yield. Currently, there is an interest in annual medics (*Medicago* spp.) and other annual legumes that winter-kill for use as cover crops in midwestern grain cropping systems. A 2-yr study was conducted at East Lansing and the Kellogg Biological Station, Michigan, to investigate the influence of annual legume cover crops on weed populations. Two annual medic species [burr medic (*M. polymorpha* cv. Santiago) and barrel medic (*M. truncatula* Gaertn. cv. Mogul)], berseem clover (*Trifolium alexandrinum* L. cv. Bigbee), and medium red clover (*Trifolium pratense* L.) were no-till seeded as cover crops into winter wheat (*Triticum aestivum* L.) stubble in a winter wheat/corn (*Zea mays* L.) rotation system. Density of winter annual weeds were between 41 and 78% lower following most cover crops when compared with no cover control in 2 out of 4 site years, while dry weight was between 26 and 80% lower in all 4 site years. Impact of cover crops on the density of summer annual weeds was infrequent; however, weed dry weights were reduced by 70% in 1995 following burr medic and barrel medic. Dry weight of perennial weeds before corn planting were 35 to 75% lower following annual legumes compared with the control, while weed density was not affected. This study indicated a potential for annual legumes to reduce weed density and growth in no-till corn grain systems.

THE USE of cover crops in no-till corn production can provide a variety of benefits, both to a following corn crop and to the long-term health of the cropping system. Legume cover crops can replace fertilizer N (Blevins et al., 1990; Hesterman et al., 1992), minimize soil erosion (Hargrove et al., 1984), maintain soil organic matter and improve soil structure (Frye et al., 1988; Smith et al., 1987), as well as reduce weed density and biomass (Teasdale et al., 1991). Hairy vetch (*Vicia villosa* Roth), crimson clover (*Trifolium incarnatum* L.) and subterranean clover (*T. subterraneum* L.) have been shown to reduce weed density and dry weight of early season weeds (Johnson et al., 1993; Teasdale et al., 1991;Yenish et al., 1996).

There are a number of mechanisms responsible for the effect of cover crops on weeds. The living cover crop can reduce light (Teasdale and Mohler, 1993) and moisture available to fall germinating seeds. Weeds attempting to establish along with a cover crop would be in competition for resources and may not develop sufficiently to survive the winter. Cover crop residue can modify the conditions under which weeds germinate or regrow in the spring. Such effects could be due to changes in soil temperature, increase in soil moisture, release of allelopathic chemicals, and physical impediments to weed seedlings (Facelli and Pickett, 1991; Teasdale, 1996; Teasdale and Mohler, 1993).

Many legume species that are used as cover crops in no-till corn production are winter annuals or short-lived perennials. In northern regions of the USA, over-wintering species are normally established in the summer or fall and accumulate most of their biomass when they regrow in the spring. Despite the positive effects often produced by winter annual cover crops in corn production, there is also a potential for reduction in corn yield. Spring regrowth of legumes can lower available water in the subsoil creating conditions of moisture stress for corn in years of low precipitation (Badaruddin and Meyer, 1989; Frye et al., 1988; Hesterman et al., 1992; Tiffin and Hesterman, 1998). In addition, winter annuals require some form of control, either chemical or mechanical, before or at the time of corn planting. Contact herbicides are most commonly used; however, these can result in incomplete control of weeds and cover crops (Worsham and White, 1987; Yenish et al., 1996). Although herbicide options for cover crop control have improved, variability of spring conditions can still lower their effectiveness. Field and weather conditions can delay application as well as reduce uptake of herbicides into plant tissue.

In contrast to winter annuals, summer annual legume species will not over-winter in northern regions of the USA or other areas with prolonged freezing temperatures. When these species are fall-planted and allowed to winter-kill, they may be able to provide the benefits of winter annuals without reducing available soil moisture and eliminate the need for chemical or mechanical control in the spring.

Currently, there is interest in annual species of *Medicago* (annual medics) and other annual legumes for use as cover crops in midwestern grain cropping systems. Originating in North Africa and the Middle East, annual medics have adapted to a range of environmental conditions (Lesins and Lesins, 1979). Annual medics were introduced for grazing purposes into Australia and New Zealand, and are now a common component of sheep pastures. In southern Australia, annual medics are used in ley cropping systems, where they are rotated with cereal crops (Puckridge and French, 1983). In these systems, medics provide high quality forage, contribute N to the soil and nonlegume pasture species and improve physical structure of the soil (Crawford et al.,

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Abbreviations: EL, East Lansing; KBS, Kellogg Biological Station; NIS, non-ionic surfactant; COC, crop oil concentrate.

1989). Annual medics have also been tested as forages in Michigan (Shrestha et al., 1998) and in Minnesota (Zhu et al., 1996). Berseem clover is an annual legume used as a forage plant in India and in areas with Mediterranean climates. It has the potential to produce large amounts of biomass rapidly and can be cut several times a year (Shrestha et al., 1998; Westcott et al., 1995).

Recent investigations have indicated the potential for annual legumes to reduce weed populations. DeHaan et al. (1997) found that weed populations were reduced where annual medics were interseeded with corn. However, in this same study corn yield was also reduced, due to competition for nutrients or moisture when medic and corn were planted at the same time. Annual medics interseeded several weeks after corn planting did not affect corn yield; however, weed dry weight was not reduced compared with a no-cover control either. Moynihan et al. (1996) reported a 65% reduction in fall weed biomass compared with no-cover control following a grain barley (*Hordeum vulgare* L.) and medic intercrop.

Winter wheat–corn is a common rotation in the Midwest USA. The period between wheat harvest and corn planting is an ideal time for establishing a cover crop. Annual medics and berseem clover planted after wheat harvest have been shown to accumulate aboveground biomass of between 2.1 and 5.3 Mg ha^{-1} and increase no-till corn yields (Fisk, 1997). Our objectives were to investigate the impact of legume cover crops in a winter wheat–legume cover–corn cropping sequence on: (i) winter annual and perennial weed populations prior to no-till corn planting; (ii) summer annual and perennial weeds before application of postemergence herbicides; and (iii) to determine the role of legume residue on summer annual and perennial weeds in this cropping sequence.

MATERIALS AND METHODS

Experiments were conducted in the 1994–1995 and 1995–1996 growing seasons at the Michigan State University Crop and Soil Sciences Research Farm in East Lansing (EL), MI, and at the Kellogg Biological Station (KBS) in Hickory Corners, MI. Separate but nearby sites were used in each year at each location. Soils were a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualf) at EL and a Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalf) at KBS. Soil pH, available P, and available K were 6.7, 162 kg ha^{-1}, and 245 kg ha^{-1}, respectively, for EL averaged across both years and 6.4, 115 kg ha^{-1}, and 240 kg ha^{-1}, respectively, for KBS averaged across both years.

Four cover crop treatments and a no-cover control were arranged in a randomized complete block design with four replications at each location. Cover crop treatments included two annual medic species (Santiago burr medic and Mogul barrel medic), Bigbee berseem clover, and medium red clover. The cropping system in this study was a sequence of winter wheat/cover crop/ and no-till corn. Legume cover crops were planted after wheat harvest.

Cover crops were no-till drilled into a wheat stubble field (straw removed) on 8 Aug. and 9 Aug. 1994 at EL and KBS, respectively, and on 9 Aug. and 11 Aug. 1995 at EL and KBS, respectively, with a drill with 20-cm row spacing to a depth of 1 to 2 cm. Santiago burr medic and Mogul barrel medic were seeded at a rate of 269 live seeds m^{-2} or 13.4 kg ha^{-1} and 15.7 kg ha^{-1}, respectively. Red clover and berseem clover were planted at 16.8 kg ha^{-1}, which is the common seeding rate in Michigan. Legume seeds were inoculated with the appropriate *Rhizobia* spp. before planting. Berseem clover did not establish at EL in 1995 because of equipment malfunction and when reseeded several weeks later, it failed to produce consistent stands.

Before cover crop planting, each field received an application of glyphosate (*N*-(phosphonomethyl)glycine) at 1.68 kg a.i. ha^{-1} with 0.1% nonionic surfactant (NIS). In addition, sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclo-hexen-1-one) was applied at a rate of 0.32 kg a.i. ha^{-1} with 2.31 L ha^{-1} crop oil concentrate (COC) at EL on 19 Aug. 1994 to control volunteer wheat, large crabgrass (*Digitaria sanguinalis* L.), and quackgrass [*Elytrigia repens* (L.) Nevski].

Annual legumes winter-killed and the red clover was killed with herbicide in the spring before planting no-till corn. Each field received an application of glyphosate at 1.68 kg a.i. ha^{-1} with 2,4-D ester (2,4-dichlorophenoxyacetic acid, butoxyethylester) at 0.532 kg a.i ha^{-1} and 0.5% NIS prior to corn planting to control established weeds and the red clover cover crop. In 1994 at both locations, red clover was not killed by the herbicides. Therefore, red clover plots were mowed by hand at EL (avoiding the corn seedlings) and followed by an application of dicamba (3,6-dichloro-2-methoxybenzoic acid) at 0.56 kg a.i. ha^{-1}. This resulted in complete control of the red clover. Also in 1994 at EL, bentazon (3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one2,2-dioxide) at 0.84 kg a.i. ha^{-1} with 2.31 L ha^{-1} COC was spot-sprayed for purple nutsedge (*Cyperus esculentus* L.) control on 3 June.

'Pioneer 3751' corn was planted no-till in mid-May of each year at 62 220 seeds ha^{-1} at a row spacing of 76 cm. Fertilizer P and K were broadcast before corn planting according to soil test results. This study was a part of another experiment that measured no-till corn response to N following cover crops; however, in this study weed samples were taken before side dress N application. Postemergence herbicide applications were made 45 and 60 d after chemical kill in 1995 and 1996, respectively. Nicosulfuron (2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino] carbonyl]amino] sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide) at 0.035 kg a.i ha^{-1}, and bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at 0.28 kg a.i. ha^{-1} with 0.25% NIS were applied at EL in 1995. At KBS, sethoxydim at 0.21 kg a.i. ha^{-1} with 2.31 L ha^{-1} COC was applied in 1995. In 1996 at EL, bromoxynil was applied at 0.28 kg a.i. ha^{-1} with 0.25% NIS.

Sampling for weed density and dry weight was done twice: before corn planting and before postemergence herbicide application. The effect of cover crops on winter annual and existing perennial weed density and dry weight was determined at first sampling. In early May, just prior to spring herbicide application, the area within four randomly placed 0.25 m^2 quadrats was sampled for weed density and dry weight. These samples were removed, separated by species, dried at 60°C for 72 h, and weighed. Common chickweed (*Stellaria media* L.) was sampled only for dry weight, since it was difficult to determine actual plant density because of its growth habit.

The effect of cover crops on summer annual and perennial weed populations and growth (weeds that germinated or otherwise initiated growth after application of the herbicide) was determined at second sampling. This sampling was done as described above on spots adjacent to the initial sampling within the treatment plots approximately 45 d after chemical kill of cover crops in 1995. In 1996, weed populations were slow to initiate growth because of dry soil surface conditions. As a result, sampling was delayed until approximately 60 d after chemical kill.

Also, at this time the effect of the cover crop residue on weed populations and growth was measured. This was done by comparing data from plots in which cover crop residue had been removed to data from plots in which residue had not been removed. After sampling in early May, the legume residue was removed from the soil surface in the 0.25 m^2 quadrats, leaving legume roots behind, and the spots were marked. Approximately 45 or 60 d later, weeds were sampled in these areas for density and dry weight and separated by species. These results were compared to measurements taken at the same time in adjacent, but previously unsampled, quadrates in the same cover treatment.

Soil temperatures were measured on selected dates in 1995 and 1996 to a 5-cm depth with a soil thermometer. The thermometer was inserted into five randomly chosen spots in each treatment and these values were averaged.

Data were combined across years and locations and subject to analysis of variance using a randomized complete block model with a split-split-plot treatment arrangment. The main plot was the random effect of years, the subplot was location, and the sub-subplots were the five cover crop treatments. Where interactions with year and location were significant ($P < 0.05$), data were separated accordingly and reanalyzed.

Weed density and dry weight data taken after chemical kill of cover crops was transformed by taking the square root and log, respectively, to correct for heterogeneity of variance. Nontransformed data are presented with statistical interpretation based on transformed data. Means of each cover crop treatment were compared with the no-cover control with a single degree of freedom *F* test. Data describing the residue effect within cover crop treatment were compared using a *t* test.

RESULTS AND DISCUSSION

Winter Annual Weed Density and Dry Weight

Winter annual weed density was reduced following cover crop treatments in 2 out of 4 site years (Table 1). A year × location × cover interaction occurred for weed density and dry weight. Therefore, data are presented by site year. The greatest reduction in weed density by cover crops as compared with the no cover control was observed at EL in 1995. The dominant weed species in this site year were shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.], common chickweed, field pennycress (*Thlaspi arvense* L.), and volunteer wheat. In 1996 at KBS, weed density was reduced following Santiago medic and red clover. In contrast, there were no observed effects of the cover crop treatments on weed density at KBS in 1995 or at EL in 1996.

Dry weights of winter annual weeds were lower following most cover crop treatments in all site years (Table 1). The greater impact on dry weight than on weed density was, in part, due to the inclusion of common chickweed in dry weight analysis but not in weed density. Common chickweed accounted for 30 to 63% of dry weights in the no cover crop treatments.

Winter annual weeds germinate and begin growth in the fall, reinitiate growth in the spring, and complete their life cycle by midsummer (Stubbendieck et al., 1995). However, some winter annual species may also germinate in the spring. The observed reduction in weed density could have resulted from the effect of the cover crop on weed seedlings in the fall. Such effects could have been due to a multitude of factors, which include reduction in light interception, changes in soil temperature, increase in soil moisture, release of allelopathic chemicals, and physical impedance to weed seedlings. In our study, soil temperature was not affected by annual legume residue (Table 2). Therefore, weed density and dry weight reduction resulted from factors other than soil temperature.

The amount of cover crop biomass present at each site year may help explain some of the observed results. In fall of 1994 at EL, biomass for Santiago, Mogul, Berseem clover, and red clover was 3.1, 5.3, 4.1, and 1.9 Mg ha^{-1}, respectively. In fall of 1995 at EL, biomass was 2.2, 1.8, and 1.3 for Santiago, Mogul, and red clover, respectively. Cover crop biomass was lower in 1995 than in 1994 at EL for each species ($P \leq 0.05$). Cover crop biomass at KBS in 1994 for Santiago, Mogul, Berseem clover, and red clover was 2.0, 2.3, 2.2, and 1.4 Mg ha^{-1}, respectively. In 1995, at KBS biomass was 2.8, 2.4, 1.6, and 1.7 Mg ha^{-1}, for Santiago, Mogul, Berseem clover, and red clover, respectively. Except for Santiago medic, which had greater biomass in 1995 than in 1994 ($P \leq 0.05$), there was no difference in the amount of cover crop biomass at KBS between 1994 and 1995. This may indicate that greater levels of cover crop biomass reduce germination or establishment of winter annual weeds.

The growth habit of red clover differs from that of other cover crops used in this study in that it reinitiates growth in the spring from crowns established the previous year. At the time of sampling for winter annual weeds, red clover had grown to between 16 and 24 cm in height, while the annual legumes had left a desiccated residue on the soil surface. Differences in soil temperature, however, were observed in the treatments with a red clover cover crop (Table 2). Soil temperature at

Table 1. Density and dry weight of winter annual weeds following legume cover crops and a no cover control before corn planting in 1995 and 1996 at East Lansing (EL) and Kellogg Biological Station (KBS).

	Weed density				Weed dry wt.			
	1995		1996		1995		1996	
Cover crop	EL	KBS	EL	KBS	EL	KBS	EL	KBS
	no. m^{-2}				g m^{-2}			
Santiago medic	53.0*	21.0	19.5	29.3*	65.7**	70.8*	19.9**	9.4**
Mogul medic	29.0**	19.5	39.5	57.5	52.5**	51.7**	35.1	41.1**
Red clover	20.3**	20.5	17.3	27.8*	51.4**	42.4**	12.5**	26.3**
Berseem clover	29.0**	22.5	–	77.3	46.2**	74.4*	–	56.6*
No cover	91.0	26.8	30.5	81.8	234	124	43.0	76.3

* Values are significantly different than the no cover control within a year and date at $P \leq 0.05$, with a single degree of freedom *F* test.
** Values are significantly different than the no cover control within a year and date at $P \leq 0.01$, with a single degree of freedom *F* test.

Table 2. Soil temperatures at a 5-cm depth on selected dates following legume cover crops and a no cover control in 1995 and 1996 at East Lansing (EL) and Kellogg Biological Station (KBS).

Cover crop	EL 21 Apr.	EL 15 May	EL 26 May	EL 22 June	KBS 11 Apr.	KBS 24 Apr.	KBS 12 May
	°C						
1995							
Santiago medic	8.5	21.0	22.2	31.0	10.6	9.4	23.2
Mogul medic	8.6	21.0	21.6	32.4	10.9	9.0	22.5
Red clover	7.9	15.6*	18.6*	30.9	11.5	7.8*	15.9**
Berseem clover	8.3	20.6	22.4	30.0†	11.8	9.9	22.2
No cover	8.5	20.3	22.2	32.2	11.3	9.3	21.9
		16 May	22 May	11 June	17 May	31 May	14 June
1996							
Santiago medic	–	16.8	22.2	24.7	18.5	24.4	30.8
Mogul medic	–	16.7	22.0	24.5	18.1	24.8	30.7
Red clover	–	12.9**	19.3	24.0	15.6**	23.6	30.6
Berseem clover	–	–	–	–	18.3	25.1	31.0
No cover	–	17.0	21.9	24.3	17.9	24.7	30.8

* Values are significantly different than the no cover control within a year and date at $P \leq 0.05$, with a single degree of freedom F test.
** Values are significantly different than the no cover control within a year and date at $P \leq 0.01$, with a single degree of freedom F test.
† Values are significantly different than the no cover control within a year and date at $P \leq 0.10$, with a single degree of freedom F test.

seven different sampling events was lower in the red clover treatments than in the no-cover control. This may have influenced weed density and weed dry weight. Also, competition for light and nutrients by the red clover regrowth may have further influenced weed density.

The differential response to cover crop treatments among weed species was small. At EL in 1995, the density and dry weight of shepherd's-purse was lower in all cover crop treatments compared with the no cover control ($P \leq 0.05$). This was the case for volunteer wheat as well, except in the Santiago medic treatment where populations were no different than the control. Dry weight of chickweed was lower following all cover crops in 1995 at EL ($P \leq 0.05$) and at EL and KBS in 1996 ($P \leq 0.1$ or 0.05). Following red and berseem clover, dry weights of field pennycress were lower at EL in 1995 ($P \leq 0.05$). In 1996 at KBS, density of henbit (*Lamium amplexicaule* L.) was lower in all cover treatments except berseem clover ($P \leq 0.05$). In 1996 at KBS, dry weights of volunteer wheat in Santiago medic and red clover treatments were lower than in the control ($P \leq 0.05$); however, they were not lower in mogul medic or berseem clover treatments.

The effects of legume cover crops on weed populations that are present before crop planting have not been adequately documented. Most cover crop species used in north central USA are still alive prior to corn planting and require either mechanical or chemical control. However, annual legume cover crops may permit the reduction of herbicide use before crop planting and enable a shift toward postemergence herbicide options (Teasdale, 1996). Our study indicated this may be possible because cover crops reduced winter annual and early spring germinating weeds.

Summer Annual Weed Density and Dry Weight

Cover crops had inconsistent effects on summer annual weeds. There was a year × location × cover interaction for summer annual weed density and a year × cover interaction for weed dry weight (Table 3). Weed density was reduced following Santiago medic compared with the no-cover treatment in 1995 at EL, but there was no effect in other site years. Weed density following red clover was reduced only in 1996 at EL, whereas berseem clover had no effect on summer annual weed density or dry weight.

Soil temperatures measured just before or after corn planting indicate that red clover reduced temperatures during the time of summer weed germination (Table 2). However, red clover reduced weed density only in one site year when compared with the no cover control (Table 3). This suggested that soil temperatures may have played a limited role in suppression of summer annual weeds.

The effect of cover crops on summer annual weeds was more pronounced on dry weight than on density. Dry weight of summer annual weeds following annual medics was reduced in 1995 compared with the no cover treatment (Table 3). However, this effect was not observed in 1996. Aboveground growth of medics was greater in 1994–1995 at EL than in 1995–1996, and this may have contributed to the difference between years (Fisk, 1997). Dominant weeds in 1995 included common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), giant foxtail (*Setaria faberi* Herrm.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and smooth crabgrass [*Digitaria ischaemum* (Schreb. ex Schweig.) Schreb]. In 1996, however, the dominant weed species were common purslane (*Portu-*

Table 3. Density and dry weight of summer annual weeds following legume cover crops and no cover control in 1995 and 1996 at East Lansing (EL) and Kellogg Biological Station (KBS).

Cover crop	Weed density 1995 EL	Weed density 1995 KBS	Weed density 1996 EL	Weed density 1996 KBS	Weed dry wt. 1995	Weed dry wt. 1996
	no. m^{-2}				g m^{-2}	
Santiago medic	4.0*	22.5	29.8	5.8	2.2*	4.7
Mogul medic	4.8	14.0	36.3	15.5	2.4*	12.2
Red clover	46.5	17.3	10.5*	13.0	2.3	4.5
Berseem clover	7.8	24.5	–	9.8	2.9	–
No cover	42.1	18.8	37.8	12.3	8.6	7.9

* Values are significantly different than the no cover control within a year and date at $P \leq 0.05$, with a single degree of freedom F test.

laca oleracea L.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), and barnyardgrass [*Echinochloa crusgalli* (L.) Beauv.]. In 1995, the dry weight of pigweed was lower in Santiago medic and Mogul medic treatments ($P \leq 0.05$). Our results are similar to the finding of Yenish et al. (1996), who reported that biomass of weeds sampled 45 d after corn planting was reduced by winter annual legume cover crops.

It has been suggested that weed biomass may be less influenced than weed density by the residue of overwintering cover crops (Teasdale, 1996), because weeds will compensate for lower density by increasing biomass. In our study, such effects were not observed. This may be because of the mechanisms of annual legumes to limit weed growth, which at this point are unknown. However, reduction in weed growth may have resulted from allelopathic chemicals released by the legumes or from microbial metabolic activity on the residue (Worsham, 1991).

Effect of Cover Crop Residue on Summer Annual Weeds

Annual medic residues reduced the density and dry weight of summer annual weeds (Table 4). Data for all cover crop species were combined over year and location because there was no year × location by cover interaction. Summer annual weed density and dry weight were consistently reduced from 27 to 60% following annual medics and red clover (Table 4). Berseem clover residue, however, had no effect on weed density or dry weight. Some differential response of weed among cover species was observed. Density of common lambsquarters was lower in Santiago and Mogul medic treatments ($P \leq 0.1$). Dry weight of common purslane ($P \leq 0.05$), Pennsylvania smartweed, and barnyardgrass ($P \leq 0.1$) was lower in the Santiago medic treatment. Pennsylvania smartweed density was lower in the Mogul medic treatment ($P \leq 0.05$) and the Santiago treatment ($P \leq 0.01$). Density of giant foxtail was lower in the red clover treatment ($P \leq 0.05$).

The effect of cover crops on weed density and dry weight of summer germinated weeds was measured in two different ways: by comparing these measurements between a cover treatment and a no cover control; and by comparing between adjacent sampling plots within cover crop treatments where residue was removed or left in place. The effect of annual legumes on weed density was more consistent when tested in adjacent sampling plots within a cover treatment plot. Naturally occurring weed populations as used in this study have high spatial heterogeneity (Cardina et al., 1997; Forcella et al., 1992), making it more difficult to see treatment effects between cover and no-cover plots. This would have been exacerbated by the size of the cover treatment plots (30 m in length). The size of the cover treatment plots was much less important where density and dry weight were measured in adjacent plots within a cover treatment. These conditions may have provided for a better comparison of cover treatment effects on weed densities.

Effect of Cover Crops on Perennial Weeds

Cover crops had no effect on density but did affect dry weight of perennial weeds before corn planting (Table 5). For the first sampling date, data for weed density were combined across all site years since no interaction was found. However, an interaction occurred for weed dry weight so data are presented by site year. The failure of cover crop residues to affect weed density was expected because most of the weeds present before corn planting probably established in the fall when the cover crops were just beginning to grow. However, dry weight of perennial weeds was reduced by 30 to 75% following most of the cover crop treatments when compared with the no-cover control (Table 5). Dominant perennial weeds included broadleaf plantain (*Plantago major* L.), dandelion (*Taraxacum officinale* Weber in Wiggers), white clover (*Trifolium repens* L.), and quackgrass [*Elytrigia repens* (L.) Nevski]). Among perennial weed species, dandelion dry weight was most consistently impacted. Dandelion dry weight was lower in Mogul medic and red clover treatments in 1995 at EL ($P \leq 0.05$), in Santiago ($P \leq 0.01$), and red clover ($P \leq 0.05$) at EL in 1996, and in Santiago ($P \leq 0.05$), red clover and berseem clover ($P \leq 0.01$) at KBS in 1996. Reduced

Table 4. Density and dry weight of summer annual weeds with and without legume residue present combined over years (1995 and 1996) and location (East Lansing and Kellogg Biological Station).

Cover crop	Residue	Weed density	Weed dry wt.
		no. m^{-2}	g m^{-2}
Santiago medic	Without residue	34.1**	8.1**
	With residue	15.7	3.2
Mogul medic	Without residue	29.2†	9.8*
	With residue	18.4	7.1
Berseem clover	Without residue	28.2	5.7
	With residue	15.3	3.4
Red clover	Without residue	30.8*	7.2*
	With residue	21.9	3.3

* Values are significantly different than the no cover control within a year and date at $P \leq 0.05$, with a *t* test.
** Values are significantly different than the no cover control within a year and date at $P \leq 0.01$, with a *t* test.
† Values are significantly different than the no cover control within a year and date at $P \leq 0.10$, with a *t* test.

Table 5. Perennial weed density and dry weight following legume cover crops and a no cover control just before corn planting in 1995 and 1996 at East Lansing (EL) and Kellogg Biological Station (KBS).

		Weed dry wt.			
		1995		1996	
Cover crop	Weed density	EL	KBS	EL	KBS
	no. m^{-2}	g m^{-2}			
Santiago medic	12.6	2.3†	1.9**	2.6**	3.2**
Mogul medic	19.0	6.4*	2.4**	5.4**	10.3
Red clover	9.8	1.5*	0.1**	2.8**	5.0*
Berseem clover	13.8	5.5	17.4**	–	6.6*
No cover	15.8	8.0	8.4	9.9	13.1

* Values are significantly different than the no cover control within a year and date at $P \leq 0.05$, with a single degree of freedom *F* test.
** Values are significantly different than the no cover control within a year and date at $P \leq 0.01$, with a single degree of freedom *F* test.
† Values are significantly different than the no cover control within a year and date at $P \leq 0.10$, with a single degree of freedom *F* test.

Table 6. Perennial weed density and dry weight following cover treatments and no cover control 45 or 60 d after corn planting in 1995 and 1996 at East Lansing (EL) and Kellogg Biological Station (KBS).

	Weed density				Weed dry wt.			
	1995		1996		1995		1996	
Cover crop	EL	KBS	EL	KBS	EL	KBS	EL	KBS
	no. m^{-2}				g m^{-2}			
Santiago medic	5.5†	22.5	5.8†	10.5	1.1	2.9	0.7†	1.1
Mogul medic	5.3*	14.0	9.3	19.8	0.4	2.7	2.1	4.0†
Red clover	9.5	17.3	7.8	32.5*	1.9	2.3	1.1†	4.2*
Berseem clover	13.0	24.5	–	11.8	1.2	3.7	–	1.0
No cover	10.3	18.8	11.5	16.5	0.8	2.6	4.1	0.8

* Values are significantly different than the no cover control within a year and date at $P \leq 0.05$, with a single degree of freedom F test.
† Values are significantly different than the no control cover within a year and date at $P \leq 0.10$, with a single degree of freedom F test.

dry weights of perennial weeds may have resulted from the competition for resources during the establishment of cover crops or allelopathic chemicals released from cover crop residues.

The effect of legume cover crops on perennial weeds that emerged at the time of, or after, corn planting measured approximately 45 or 60 d after existing weeds were killed showed a year × location by cover interaction and hence, results are presented by site year (Table 6). Annual medics affected density and dry weight of perennial weeds. Santiago medic reduced perennial weed density at EL both years and weed dry weight at EL in 1996. However, Mogul medic reduced weed density at EL in 1995 only.

Red clover was not effective in reducing weed density and dry weight of perennial weeds. In 1996 at KBS, perennial weed density and dry weight were in fact greater following red clover than following the no-cover control (Table 6). Dry soil conditions in this year may have been ameliorated by red clover residue that can conserve surface soil moisture and thereby enhance weed growth. Similarly, berseem clover was not effective in reducing weed density or dry weight. In this study, dry weight or density of white clover, quackgrass, and dandelion were lower in the Santiago medic treatment for several site years. In 1995 at EL, density of white clover and quackgrass was lower in the Santiago treatment than in the control ($P \leq 0.05$). In 1996 at EL dry weight of dandelion was less in the Santiago treatment than in the control ($P \leq 0.01$).

Previous research has found little effect by hairy vetch residue, at common planting rates, on the density of perennial weeds such as dandelion, curly dock (*Rumex crispus* L.), and quackgrass (Mohler and Teasdale, 1993; Curran et al., 1994). Our results, however, indicated that a potential of annual medics to reduce perennial weed dry weight prior to corn planting existed and an ability to reduce weed density during corn growth existed.

Table 7. Density and dry weight of perennial weeds with and without legume residue present combined over year (1995 and 1996) and location (East Lansing and Kellogg Biological Station).

Cover crop	Residue	Weed density	Weed dry wt.
		no. m^{-2}	g m^{-2}
Santiago medic	Without residue	10.8**	4.3**
	With residue	7.1	1.0
Mogul medic	Without residue	17.5**	5.5**
	With residue	11.6	1.8
Red clover	Without residue	19.9**	7.2**
	With residue	12.5	1.8
Berseem clover	Without residue	13.0*	4.7**
	With residue	8.7	0.8

* Values are significantly different than the no cover control within a year and date at $P \leq 0.05$, with a t test.
** Values are significantly different than the no cover control within a year and date at $P \leq 0.01$, with a t test.

Perennial weed density and dry weight were 35 and 75% lower, respectively, following cover crops when residue was left on the soil surface compared with where it had been removed (Table 7). Data were combined over site years for both weed density and dry weight since no interactions were observed. Similar to annual weeds, the impact of the cover crops on perennial weeds was more pronounced when measured in adjacent plots within treatments than by comparing cover treatment with a no cover control.

Several investigators have established that winter annual legume cover crops reduce weed density and biomass of summer annual weeds in corn cropping systems (Yenish et al., 1996; Teasdale et al., 1991; Johnson et al., 1993). However, the effect of summer annual legume cover crops on weed density and biomass appears to vary depending on the cropping system in which they are used. Squire (1997) found no suppression of weeds by annual medics or berseem clover interseeded into corn. Tharp (1997) reported a reduction of annual grass weeds when annual rye (*Lolium multiflorum* L.) or an annual rye–crimson clover (*Trifolium incarnatum* L.) mixture was interseeded into sweet corn; however, crimson clover alone did not reduce grass weed densities. Moynihan et al. (1996) reported lower fall weed biomass where annual medics were interseeded with barley.

In our study, annual legumes reduced weed density and dry weight in many cases. However, any effect this may have had on corn grain yield was not assessed because of the application of a postemergence herbicide after the final sampling. Studies on weed–crop competition have demonstrated that the relative time of weed emergence with respect to the crop is as, or more, important than weed density in predicting the impact on corn yield (Knezevic et al., 1994; Bosnic and Swanton, 1997). Bosnic and Swanton (1997) reported that barnyardgrass at 39 plants m^{-2} reduced corn yield by 14% when they emerged at the 3-leaf corn stage as compared with 4% at the 7-leaf stage. In Michigan, Fausey et al. (1997) reported that corn grain yields were reduced by up to

14% by 13 giant foxtail plants m^{-2} germinating 2 d after corn emergence.

We cannot use these examples to predict the effect of weeds in our study because we do not have data on time of emergence. However, weed densities in this study were in the same range as those in the cited studies where yields were reduced when germination was close to corn emergence. Other researchers have found cover crops reduced weeds, but not enough to eliminate the need for chemical control (Yenish et al., 1996; Teasdale, 1996; Curran et al., 1994; Johnson et al., 1993).

SUMMARY AND CONCLUSIONS

Annual medics and red clover planted after wheat harvest reduced density and dry weight of winter annual weeds before planting no-till corn. Similarly, annual medics and red clover reduced summer annual weed dry weight; however, weed density was only occasionally reduced. The suppressive effect of annual medic residue on summer annual weed density and dry weight was consistent across all site years. Berseem clover had no effect, whereas the effect of red clover was not consistent.

Dry weight of perennial weeds before corn planting was consistently reduced by both annual legumes and red clover; however, density was unaffected. The annual medics suppressed perennial weeds 45 to 60 d after chemical kill, but this effect was not as strong as the effect observed before corn planting. Residue of all legumes reduced both density and dry weight of perennial weeds. This study indicated an excellent potential for annual medics to reduce weed density and growth in no-till corn grain systems. Further research is needed to quantify if chemical control can be reduced or eliminated by the use of annual legume cover crops.

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