Mechanical versus herbicidal strategies for killing a hairy vetch cover crop and controlling weeds in minimum-tillage corn production

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Abstract. *The development of production systems that provide the benefits of reduced tillage and also reduce or eliminate herbicide inputs presents a challenge to practitioners of sustainable agriculture. This research was conducted to evaluate management approaches for minimum-tillage corn production in a hairy vetch cover crop, specifically, mechanical versus herbicidal methods for pre-plant cover-crop kill and for post-emergence control of emerged weeds. Pre-plant treatments included 2,4-D [(2,4-dichlorophenoxy)acetic acid] plus residual herbicides, 2,4-D alone, flail mower, corn stalk chopper, light disk and heavy disk. The pre-plant herbicide treatments were followed by a post-emergence treatment of dicamba, whereas the pre-plant mechanical treatments were followed by post-emergence cultivation, as needed, for weed control. The mechanical treatments that kept residue on the soil surface (mower, stalk chopper and light disk) killed hairy vetch when it was flowering, but not when vegetative. The herbicide treatment with pre-plant 2,4-D alone, followed by dicamba post-emergence, controlled annual broadleaf weeds (the dominant species in these experiments) similarly to treatment with 2,4-D plus residual herbicides, suggesting that residual herbicides may be eliminated in cover-crop-based no-tillage systems. The pre-plant mechanical treatments followed by cultivation did not control annual broadleaf weeds as well as herbicide treatments, but did maintain final populations below threshold levels in two of four experiments. The stalk chopper and light disk left high levels of vetch residue on the soil surface, and reduced initial broadleaf weed populations compared with the heavy disk that incorporated residue. However, broadleaf weed populations were reduced with less efficiency by cultivation of untilled soil following the stalk chopper or light disk (38–69%) than by cultivation of tilled soil following the heavy disk (87–95%). Thus, although maintaining surface cover-crop residue without tillage initially reduced weed emergence, it also reduced the efficiency of cultivation, leading to similar final weed populations in all mechanical-based, pre-plant treatments.*

Key words: cultivation, integrated weed management, organic farming, smooth pigweed, sustainable agriculture, weed survival

Introduction

Cover crops have the capacity to influence many facets of production systems, including the fertility, quality, radiation exchange, moisture and erosion of soils, as well as weed and pest populations (Sustainable Agriculture Network, 1998). In sustainable production systems, it is well established that legume cover crops can be particularly beneficial to high-nitrogen (N) requiring crops such as corn (*Zea mays* L.), by fixing N and reducing the need for off-farm N inputs. For example, Decker et al. (1994) established that a hairy vetch (*Vicia villosa* Roth) cover crop could reduce N requirements for corn production in Maryland. In addition, hairy vetch residue on the surface of soils benefitted no-tillage corn production, by maintaining soil moisture during periods of drought (Clark et al., 1995). Production was most consistent when hairy vetch was killed before planting, rather than after planting or after corn emergence (Teasdale and Shirley, 1998). Current recommendations for minimum-tillage corn with a cover crop rely on herbicides to kill the cover crop before planting and to control weeds emerging after planting. However, there is a need to develop systems with the benefits of minimum-tillage production with cover crops, but which reduce or eliminate the use of herbicides. Organic field-crop producers would benefit from such a system, since they have identified weed management, as well as tillage systems and soil conservation, among their top ten research priorities (Walz, 1999).

Cover-crop residue can influence biological activity at the soil surface, including the suppression of weed

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emergence (Sustainable Agriculture Network, 1998). The density of emerging weeds is inversely related to the amount of residue present (Teasdale and Mohler, 2000). Specifically, mulch area index and solid volume fraction are the best mulch properties for predicting weed emergence through a variety of mulch types (Teasdale and Mohler, 2000). The success of weed emergence through mulches is associated with larger seed size; small-seeded broadleaf weeds are most sensitive to suppression. Despite suppression of weed emergence, cover-crop residue alone cannot reliably provide full-season weed control (Teasdale et al., 2003). Cover crops must be part of an integrated weed management system to achieve consistent, long-term weed control (Williams et al., 1998).

Mechanical cultivation of weeds has been practiced primarily in plowed soils, but equipment has recently been developed for cultivation in no- or minimum-tillage systems. Cultivation, alone, often does not provide adequate weed control, but the combination of cultivation plus banded herbicide in the crop row has controlled weeds and permitted production of crop yields equivalent to those obtained with broadcast herbicides (Buhler et al., 1994, 1995; Hanna et al., 2000; Hartzler et al., 1993; Mulder and Doll, 1993; Mt. Pleasant et al., 1994). Banding herbicide is required for optimum weed control, because weeds growing within the row are difficult to disturb using mechanical methods, particularly in minimum-tillage systems. In-row weeds must be controlled by burying seedlings with soil moved from the area between rows; however, this can only be done effectively if there is a size differential between crop and weed (Mohler, 2001). The ecological basis for this differential is faster emergence and absolute growth rate of crops, due to the larger seed reserves of crop, relative to weed seeds. However, this may be compensated for by the faster relative growth rate of weed, compared to crop plants, as well as by possible environmental conditions that favor weeds more than the crop. If weeds become too large for adequate burial before the crop reaches sufficient size to withstand aggressive soil movement into the row, mechanical cultivation will fail to control these weeds.

An integrated system, using both cover crops and mechanical cultivation, could improve weed control in comparison with reliance on either strategy alone. Liebman and Gallandt (1997) propose that successful integrated weed management systems can be developed without herbicides by combining several strategies or 'little hammers' that would cumulatively reduce the relative fitness of weeds versus crop. Although not sufficient to provide full-season weed control alone, cover-crop residue may suppress early emergence of weeds sufficiently to reduce in-row weed populations that can be problematic for cultivation-based systems. Thus, if cover crops can be killed, and escaped weeds adequately controlled, using mechanical means, an effective reduced-tillage system without herbicides could be developed. These experiments were conducted to evaluate an integrated strategy for corn production in a hairy vetch cover crop with mechanical, versus herbicidal methods for: (1) pre-plant cover-crop kill; and (2) post-emergence control of emerged weeds.

Materials and Methods

Research was conducted on production fields of the Beltsville Agricultural Research Center, Beltsville, MD, using separate fields in 1997, 1998 and 1999. All fields contained combinations of Elkton (fine-silty, mixed, active, mesic Typic Endoaquults), Keyport (fine, mixed, semi-active, mesic Aquic Hapludults), and Matawan (fine-loamy, siliceous, semi-active, mesic Aquic Hapludults) silt loam soils. Hairy vetch had been planted at 28 kg ha^{-1} in September of the preceding year, following harvest of corn for silage. In spring, hairy vetch was killed, either while vegetative during early May, or while reproductive in late May. Early kill dates were: May 7–9 in 1997, April 28–30 in 1998 and May 2–3 in 1999. Late kill dates were: May 23–28 in 1997 and May 26 in 1998 and 1999. Corn was planted with a no-tillage planter within 1 week after the killing operations, except for the early kill date in 1998, when wet weather delayed planting for 3 weeks.

Five treatments were used for killing hairy vetch each year. Treatment 1 was a mixture of 0.56 kg acid equivalent ha^{-1} of 2,4-D [(2,4-dichlorophenoxy)acetic acid], 0.53 kg active ingredient (a.i.) ha^{-1} of paraquat (1,1′-dimethyl-4,4′-bipyridinium ion), 1.8 kg a.i. ha^{-1} of atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine], 2.2 kg a.i. ha^{-1} of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide], and 0.25% nonionic surfactant. Treatment 2 was 0.56 kg ha^{-1} of 2,4-D. Treatment 3 was flail mowed (model 144BM, 3.6 m width, Loftness Specialized Farm Equipment, Hector, MN) in 1997 but, because this treatment was ineffective, a Buffalo Stalk Chopper (model 52000430, 3.0 m width, Fleischer Manufacturing Inc., Columbus, NE), with cutters set at the most aggressive angle, was used in 1998 and 1999. Treatment 4 was slicing vetch with a light disk (3.6 m tandem disk, Ford Motor Co., Dearborn, MI) set to skim over the surface of the vetch vines and minimize burial of the residue. Treatment 5 was incorporation of vetch with a heavy disk (5.5 m tandem disk, Krause Corp., Hutchinson, KA). Because of continuous rain after the early kill operations in 1998, treatments 4 and 5 required another disking before planting corn. Rotary hoeing (model 1815MT, 4.6 m width, M & W Gear Co., Gibson City, IL) was performed on treatments with exposed soil, shortly after planting corn in 1997 and 1998, but dry weather after planting in 1999 precluded the need for rotary hoeing. Hairy vetch cover ratings were made after planting and rotary hoeing operations were completed by visually estimating the percentage of soil covered by residue.

Each treatment received post-emergence weed management operations when broadleaf weed emergence exceeded

2.3 plants m^{-2}, the threshold level for corn recommended by the University of Maryland IPM Program (undated scouting manual). Post-emergence operations consisted of application of 0.28 kg a.i. ha^{-1} of dicamba (3,6-dichloro–2-methoxybenzoic acid) in treatments 1 and 2, and cultivation with a minimum-tillage cultivator in treatments 3–5. Cultivation was performed with a Krause High Residue Row Crop Cultivator (model 4704-R3 four-row cultivator with 36 cm sweeps, Krause Corp., Hutchinson, KA), except for the first cultivation of untilled soil, which was performed with a Buffalo Cultivator (model 64000430 four-row cultivator with 36 cm sweeps, Fleischer Manufacturing Inc., Columbus, NE). Cultivations were not initiated until corn reached approximately the fourth leaf stage and could sustain some soil movement into the row.

The 1997 experiment was a preliminary exploration of these treatments; consequently, visual estimation of weed cover on September 1 was the only weed data collected. A more intensive collection of weed data was included in the 1998 and 1999 experiments. Weed density was determined approximately once a week, in five 1-m^2 areas within the middle six rows of each 12-row plot, until corn canopy closure. Just before cultivation of selected plots from treatments 3–5, smooth pigweed (*Amaranthus hybridus* L.) plants of different sizes, within 8 cm of the corn row, were identified with plastic labels, color-coded by size. There were 20 smooth pigweed plants within each size group per plot. Approximately 1 week after cultivation, surviving plants at each label were recorded. An experimental unit consisted of the fraction of surviving plants for each 20-plant set. Because of severe drought after weed establishment in 1998 and 1999, corn and weed growth were severely stunted and, unfortunately, no meaningful biomass or yield data could be collected. Therefore, this paper focuses on treatment effects on weed emergence and establishment which occurred before drought conditions became severe.

Treatments were arranged in a split-plot design having four replications, with time of vetch kill as the whole plot and method of vetch kill as the subplot. Subplots were 9.2 m wide and 20, 30 and 18 m long in 1997, 1998 and 1999, respectively. A log transformation was applied to all weed cover and density data to equalize variance before conducting analysis of variance. Means were backtransformed for presentation. Regression analysis was performed on weed survival data, with fraction of surviving weeds as the dependent variable and weed height as the independent variable. Survival data from all treatments at both planting dates in both years were pooled because a similar response was observed across all of these factors.

Results

Hairy vetch management

The soil coverage by hairy vetch residue, and the degree of hairy vetch kill, depended on year, pre-plant operation and timing of pre-plant operations (Table 1). At least 95% of the soil area was covered with desiccated hairy vetch residue following both herbicide treatments, with the exception of the early kill date in 1998. Decomposition of hairy vetch during a rainy 3-week period between hairy vetch kill and corn planting accounted for the lower groundcover seen after early kill in 1998 than in the other years.

The flail mower did not kill hairy vetch when treated in the vegetative stage (Table 1), permitting a dense network of hairy vetch vines to regrow from prostrate stems. These

Table 1. Percentage of the soil covered by hairy vetch residue after pre-plant operations.

		Hairy vetch residue cover (%)[1]		
Stage[2]	Pre-plant treatment	1997	1998	1999
Vegetative	2,4-D + paraquat + atrazine + metolachlor	95 (1)	70 (6)	95 (2)
	2,4-D	95 (3)	79 (4)	98 (2)
	Mow	84 (2)[3]	–	–
	Chop	–	66 (2)[3]	95 (3)[3]
	Light disk	44 (3)	5 (0)	92 (4)[3]
	Heavy disk	5 (1)	0 (0)	9 (4)
Flowering	2,4-D + paraquat + atrazine + metolachlor	97 (1)	100 (0)	99 (1)
	2,4-D	99 (0)	100 (0)	98 (1)
	Mow	95 (0)	–	–
	Chop	–	100 (0)	97 (1)
	Light disk	66 (2)	98 (3)	96 (1)
	Heavy disk	29 (2)	16 (1)	18 (3)

[1] The standard error of the mean is shown in parentheses.
[2] Operations were conducted when hairy vetch was vegetative (early May) or flowering (late May).
[3] More than 60% of hairy vetch was live. Hairy vetch in all other treatments was predominantly desiccated residue.

vines covered corn plants and became entangled in cultivator equipment, making it impossible to effectively cultivate this treatment. The flail mower killed hairy vetch and provided high residue cover when hairy vetch was treated at flowering (Table 1). However, final weed cover was higher in this treatment than all others in the 1997 late planting (Table 2), probably because the shredded hairy vetch residue resulting from flail mowing decomposed faster than residue left by the other treatments. Consequently, this treatment was discontinued after 1997, and was replaced with a corn stalk chopper that rolled over hairy vetch, but left it intact. The stalk chopper killed only flowering hairy vetch, but left high residue levels (Table 1). Mowing and rolling during the vegetative stage have been shown to be ineffective for killing several cover crops in several investigations (Creamer and Dabney, 2002).

The light disk was set too aggressively during early operations in 1997 and 1998, resulting in good kill but burial of over half of the hairy vetch residue (Table 1). Heavy rain on bare soil following disking in 1998 required a second operation, which reduced residue cover to a very low level. The light disk was set less aggressively in 1999, resulting in high residue cover but failure to kill vegetative hairy vetch. The light disking killed hairy vetch when performed at flowering in all years, and provided greater than 95% residue cover in 1998 and 1999 (Table 1). The heavy disk incorporated most residue at both stages in all years.

Table 2. Percentage of the soil covered by weeds, primarily yellow foxtail [*Setaria glauca* (L.) Beauv.], on September 1 of the 1997 experiment.

	Weed cover (%)[1]	
Pre-plant treatment	Early planting	Late planting
2,4-D + paraquat + atrazine + metolachlor	2 b	2 c
2,4-D	1 b	2 c
Mow	41 a	29 a
Light disk	65 a	12 b
Heavy disk	32 a	13 b

[1] Values followed by the same letter in the same column are not significantly different ($P = 0.05$).

Weed management

Annual broadleaf weeds and yellow nutsedge (*Cyperus esculentus* L.) combined to make up 82% and 93% of the total weeds emerging in the early and late planted 1998 experiments, respectively. Annual broadleaf weeds made up 93% and 82% of the weeds emerging in the early and late planted 1999 experiments, respectively. Therefore, presentation of weed populations will focus on annual broadleaf and yellow nutsedge populations in 1998, and annual broadleaf populations in 1999. Smooth pigweed was the dominant annual broadleaf species in both years.

Annual broadleaf weeds emerged in higher numbers following pre-plant treatment with a heavy disk that buried residue, than following other pre-plant treatments that left hairy vetch residue on the soil surface (see earliest population assessment date in Tables 3–6). The light disk in the early 1998 experiment left little residue on the soil surface (Table 1), permitting similar broadleaf weed emergence as that observed in the heavy disk treatment (Table 3). These results agree with earlier research that shows small-seeded broadleaf weeds to be sensitive to suppression by cover-crop residue (Teasdale and Mohler, 2000). Yellow nutsedge, with larger tuber reserves to sustain emergence, was not affected by the presence or absence of hairy vetch residue (see the earliest population assessment date in Tables 3 and 4). The metolachlor component of the pre-plant herbicide treatment was probably responsible for lower yellow nutsedge populations in the late 1998 planting (Table 4).

Sufficient weed populations developed in all treatments (except the late 1998 pre-plant treatment that included atrazine and metolachlor) to require a post-emergence weed control treatment. In the mechanical treatments, weed populations usually exceeded the threshold levels at the

Table 3. Effect of pre-plant hairy vetch management and post-emergence weed management on populations of annual broadleaf weeds and yellow nutsedge during the 1998 early planted crop.

		Annual broadleaf population (number m^{-2})[1]			Yellow nutsedge population (number m^{-2})[1]		
Pre-plant treatment	Post-emergence operation	6/22	7/6	Percent reduction[2]	6/22	7/6	Percent reduction[2]
2,4-D+ paraquat + atrazine + metolachlor	Dicamba on 6/26	1.0 c	0.04 c	96	3.7 a	5.2 b	+42
2,4-D	Dicamba on 6/26	4.9 b	0.59 b	88	6.9 a	15.2 a	+119
Light disk	Cultivation on 6/22	10.4 ab	1.92 a	82	6.8 a	5.2 b	24
Heavy disk	Cultivation on 6/22	13.3 a	1.72 a	87	6.2 a	2.7 b	56

[1] Values within columns followed by the same letter are not significantly different ($P = 0.05$).
[2] Reduction of weed density on July 6 relative to that on June 22 by post-emergence operations on June 22 or 26.

time corn reached the four-leaf stage and became large enough for cultivation. In both plantings in 1999, weeds exceeded the threshold sooner in the heavy disk than in the other treatments (Tables 5 and 6), but corn also developed faster in the heavy disk treatment. As a result, corn was at the same leaf stage (approximately four leaves) when all mechanical treatments exceeded threshold weed levels. The only exception was the late 1998 planting, where weed emergence on June 22 exceeded the threshold when corn was only in the two- to three-leaf stage. In this situation, the soil previously tilled by the heavy disk permitted an early cultivation without disrupting the small corn plants;

Table 4. Effect of pre-plant hairy vetch management and post-emergence weed management on populations of annual broadleaf weeds and yellow nutsedge during the 1998 late planted crop.

		Annual broadleaf population (number m^{-2})[1]				Yellow nutsedge population (number m^{-2})[1]			
Pre-plant treatment	Post-emergence operation	6/22	6/29	7/13	Percent reduction[2]	6/22	6/29	7/13	Percent reduction[2]
2,4-D+ paraquat + atrazine + metolachlor	None	0.0 d	0.2 c	0.2 b	–	0.1 b	0.1 c	0.7 b	–
2,4-D	Dicamba on 7/2	0.1 c	1.5 b	0.1 b	97	1.3 a	1.9 b	2.1 a	+13
Chopper	Cultivation on 6/29 and 7/7	3.1 b	5.7 a	3.5 a	38	2.6 a	8.7 a	2.6 a	69
Light disk	Cultivation on 6/29 and 7/7	2.7 b	11.7 a	3.6 a	69	1.1 a	2.6 b	0.8 b	70
Heavy disk	Cultivation on 6/22, 6/29 and 7/7	70.5 a	10.1 a	3.5 a	95	1.5 a	1.0 bc	0.2 b	87

[1] Values within columns followed by the same letter are not significantly different ($P = 0.05$).
[2] Reduction of weed density on July 13 relative to that on June 22 (heavy disk treatment) or June 29 (other treatments) by post-emergence operations on June 22 through July 7.

Table 5. Effect of pre-plant hairy vetch management and post-emergence weed management on populations of annual broadleaf weeds during the 1999 early planted crop.

		Annual broadleaf population (number m^{-2})[1]			
Pre-plant treatment	Post-emergence operation	6/1	6/7	6/14	Percent reduction[2]
2,4-D + paraquat + atrazine + metolachlor	Dicamba on 6/11	0.4 b	12.5 a	0.5 ab	96
2,4-D	Dicamba on 6/11	0.1 b	3.1 b	0.1 b	97
Heavy disk	Cultivation on 6/3 and 6/11	3.5 a	9.3 ab	0.6 a	94

[1] Values within columns followed by the same letter are not significantly different ($P = 0.05$).
[2] Reduction of weed density on June 14 relative to that on June 7 by post-emergence operations on June 11.

Table 6. Effect of pre-plant hairy vetch management and post-emergence weed management on populations of annual broadleaf weeds during the 1999 late planted crop.

		Annual broadleaf population (number m^{-2})[1]				
Pre-plant treatment	Post-emergence operation	6/14	6/24	6/29	7/6	Percent reduction[2]
2,4-D + paraquat + atrazine + metolachlor	Dicamba on 7/3	0.2 b	0.3 a	12.9 ab	0.4 c	97
2,4-D	Dicamba on 7/3	0.2 b	0.3 a	8.5 bc	0.3 c	96
Chopper	Cultivation on 6/25 and 7/2	0.0 b	1.0 a	4.1 c	1.5 b	65
Light disk	Cultivation on 6/25 and 7/2	0.4 b	1.7 a	9.8 bc	3.9 a	60
Heavy disk	Cultivation on 6/19 and 7/2	2.3 a	0.7 a	25.1 a	2.9 ab	88

[1] Values within columns followed by the same letter are not significantly different ($P = 0.05$).
[2] Reduction of weed density on July 6 relative to that on June 29 by post-emergence operations on July 2 or 3.

however, this was not possible in the untilled soil with high residue levels left by the stalk chopper and light disk.

At the conclusion of post-emergence operations, there were more annual broadleaf weeds in treatments receiving cultivation than in those receiving herbicides (Table 2 and last population assessment date of Tables 3–6). Following cultivation, there were few differences in final broadleaf populations between pre-plant treatments with heavy disk, light disk or chopper. Broadleaf populations following pre-plant and post-emergence herbicide applications were usually less than 0.5 plants m^{-2}, whereas broadleaf populations following pre-plant and post-emergence mechanical operations exceeded the 2.3 plants m^{-2} threshold for corn yield loss in two of the four experiments.

Percentage reduction of weed populations by post-emergence operations, based on populations before and after operations, are shown in Tables 3–6. Annual broadleaf populations were reduced by 96–97% by dicamba, except in the early 1998 experiment, where control was only 88% for annual broadleaf weeds following a pre-plant treatment of 2,4-D alone. In this case, some smooth pigweed plants exceeded the maximal size for control by dicamba. Dicamba would not be expected to control yellow nutsedge; populations of this weed increased in all herbicidal treatments in 1998 (Tables 3 and 4).

Cultivation following the heavy disk reduced annual broadleaf populations by 87–95% (Tables 3–6). Cultivation following the light disk which left minimal residue on the soil surface, in the early 1998 experiment, reduced broadleaf weeds by 82%, comparable with that following the heavy disk treatment (Table 3). Cultivation of untilled soil following the light disk in the late 1998 and 1999 experiments reduced annual broadleaf populations by 60–69%, and cultivation following the stalk chopper reduced broadleaf weeds by 38–65% (Tables 4 and 6). Thus, broadleaf weed reduction by cultivation of soil already loosened by the heavy disk was higher than that when cultivation of untilled soil followed the light disk or stalk chopper. Similar levels of control have been reported by others for cultivation in no-tillage systems. Hanna et al. (2000) reported weed population reductions of 67–79% for cultivation of no-tillage corn. Cultivating no-tillage corn without herbicides provided 62–79% weed control when following a previous corn crop (Buhler et al., 1995). Two cultivations without herbicide provided 63–82% control of broadleaf populations, but one cultivation gave 36–56% broadleaf control for no-tillage corn following a previous alfalfa crop (Buhler et al., 1994).

At the time cultivations began, smooth pigweed sizes ranged from seedlings of 2.5 cm to more established plants of 7.5–15 cm in height. Apart from small and fragile (<5 cm) smooth pigweed plants, the majority of in-row plants survived cultivation (Fig. 1). A rectangular hyperbola model predicted survival of 30, 50 and 92% for pigweed 2.5, 5 and 15 cm high, respectively. In contrast, only 6% of 11 cm high pigweed plants survived when treated with dicamba (data not shown). Since there were many plants more than 5 cm high at the time of post-emergence operations in these experiments, a higher proportion of broadleaf weeds would be expected to be controlled by herbicide than by cultivation.

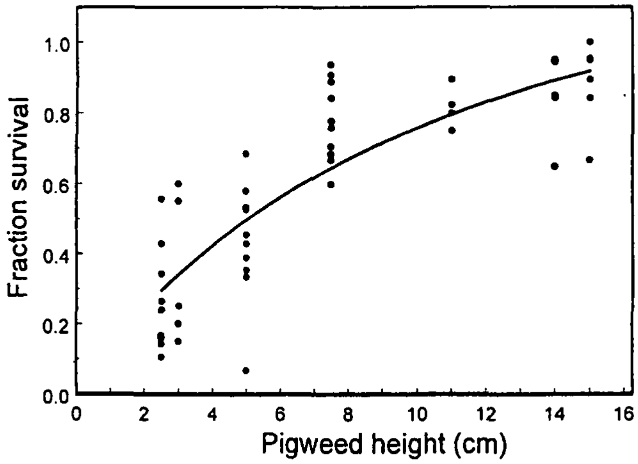

Figure 1. Survival of smooth pigweed within the corn row as a function of smooth pigweed height at the time of cultivation. The regression equation is $y = 0.144x/(1 + 0.0901x)$, where y is the fraction of smooth pigweed surviving and x is the height of smooth pigweed at cultivation ($R^2 = 0.73$).

Discussion

No-tillage crop production typically relies on a mixture of 'knock-down' herbicides, such as paraquat or 2,4-D, for killing existing vegetation, and 'residual' herbicides, such as atrazine and metolachlor, for preventing emergence of weeds later in the season. However, recent research has shown that use of residual herbicides with a hairy vetch cover crop is often ineffective, because the dense layer of residue on the soil surface adsorbs herbicide, thereby decreasing the soil solution concentration (Teasdale et al., 2003). Smooth pigweed and yellow nutsedge should have been controlled by the residual herbicides used in this pre-plant treatment, but were not, in all but the late planted 1998 experiment, probably because of interception of metolachlor by hairy vetch residue and resistance of smooth pigweed to triazine herbicides. The approach of killing hairy vetch with 2,4-D without residual herbicides, followed by a post-emergence herbicide as needed, was as effective as that with residual herbicides for controlling annual broadleaf weeds. However, the presence of perennial weeds, such as yellow nutsedge in 1998, can become a problem associated with the sole reliance on post-emergence herbicides, unless effective herbicides are available for their control. Also, paraquat rather than 2,4-D would have been an option for initial burndown if volunteer grains and/or other winter weeds had been present. Thus, use of a cover crop for suppressing early weed emergence, plus post-emergence herbicides for controlling later emerging weeds, can eliminate the need for residual herbicides.

These results confirm that killing hairy vetch with mechanical treatments depends on the growth stage of hairy vetch. Pre-plant treatment with various mechanical implements could not both kill hairy vetch and leave high residue levels when hairy vetch was treated in the vegetative stage. Operations by the flail mower, corn stalk chopper or light disk which left high soil residue coverage usually resulted in hairy vetch regrowth. At the vegetative stage, the only effective means of managing hairy vetch without herbicides was incorporation. However, when performed while hairy vetch was flowering, these mechanical implements gave good hairy vetch kill and left high residue levels, comparable to those achieved by the herbicide treatments. Flail mowing required slower speeds of operation than the light disk and stalk chopper, and left the residue shredded, resulting in faster decomposition. The light disk treatment was less consistent, but performed well if set to skim the surface of the hairy vetch vines and to avoid burying residue. The stalk chopper offers good potential for hairy vetch management. More research and development is needed to design equipment with more aggressive cutting action, to kill both vegetative and flowering stands of hairy vetch and other important cover crops (Creamer and Dabney, 2002).

In these experiments, it was possible to control weeds without herbicides in minimum-tillage systems, although not with the same consistency as with herbicides. Keeping hairy vetch residue on the soil surface by pre-plant treatment with a stalk chopper or light disk in the late planted experiments suppressed early weed emergence, compared to incorporation of most residue with a heavy disk. However, weeds of large size, which could not be controlled by the time cultivation began, developed within the rows in all systems. The efficiency of reducing weed populations by cultivation was lower following the stalk chopper (38–65%) or light disk (60–69%) than following the heavy disk (87–95%). It is likely that the initial loosening of soil by the heavy disk led to more efficient uprooting of weed seedlings during the cultivation operations and enabled work to be carried out closer to the row. Thus, although maintaining surface cover-crop residue without tillage initially reduced weed emergence, it also reduced the efficiency of cultivation, leading to similar final weed populations in all mechanical-based, pre-plant treatments. These results suggest a number of areas requiring future research. Current cultivation equipment is designed primarily for operation in tilled soil. New equipment designs are needed to permit efficient cultivation in no-tillage soils. In particular, more effective methods for controlling weeds within the rows are needed for minimum-tillage systems. This could be accomplished either by delaying weed emergence relative to crop development, perhaps by increasing mulch rates within row, or by developing systems that allow more precise control of weeds in the row at an earlier stage. Finally, research is needed to determine whether weed population thresholds for crop yield loss in organic and/or reduced-input systems may be different than in conventional systems. Perhaps more weeds can be sustained without crop yield loss in organic systems because of differences in resource availability. Perhaps more weeds can be sustained without increasing weed seedbanks in organic systems because seed predation and decomposition rates may be higher. Research on any specific weed management strategy for organic systems must be conducted within a more complete understanding of weed population dynamics in these systems in order to develop a comprehensive strategy for long-term weed control.

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