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Author(s): John R. Teasdale, Parthan Pillai, Ronald T. Collins

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Synergism between cover crop residue and herbicide activity on emergence and early growth of weeds

John R. Teasdale

Corresponding author. U.S. Department of Agriculture–Agricultural Research Service (USDA–ARS) Sustainable Agricultural Systems Lab, Building 001, Room 245, Beltsville, MD 20705; teasdale@ba.ars.usda.gov

Parthan Pillai

USDA-ARS Sustainable Agricultural Systems Lab, Beltsville, MD 20705

Ronald T. Collins

USDA-ARS Sustainable Perennial Crops Lab, Beltsville, MD 20705

Cover crop residues and other biologically based approaches often provide incomplete and inconsistent weed control. This research was conducted to evaluate interactions between hairy vetch residue on the surface of soil and the herbicide metolachlor. Herbicide was applied and incorporated with simulated rainfall before residue placement, residue was applied to the soil surface at precise rates, and potentially confounding variables such as nitrogen and soil moisture were controlled in a greenhouse experiment. Emphasis was placed on the use of suboptimal rates of both residue and metolachlor to explore the potential synergistic interactions between these factors. Deviation from a multiplicative model that included a quadratic response to hairy vetch residue and a log-logistic response to metolachlor was used to demonstrate the presence or absence of synergism. This model effectively showed that emergence of smooth pigweed, common lambsquarters, giant foxtail, and velvetleaf and early growth of smooth pigweed and common lambsquarters were reduced synergistically by the combination of hairy vetch residue and metolachlor. For example, smooth pigweed emergence was reduced 13% by 500 g m⁻² of hairy vetch residue alone and was reduced 16% by 10 g ha⁻¹ of metolachlor alone, but together, they reduced smooth pigweed emergence by 86%. This model could be used to determine synergistic interactions between any combination of a phytotoxin and a biologically based weed management approach that could be expressed in quantitative units.

Nomenclature: Metolachlor; common lambsquarters, *Chenopodium album* L. CHEAL; giant foxtail, *Setaria faberi* Herrm. SETFA; smooth pigweed, *Amaranthus hybridus* L. AMACH; velvetleaf, *Abutilon theophrasti* Medic. ABUTH; hairy vetch, *Vicia villosa* Roth.

Key words: Allelopathy, biologically based weed management, multiplicative model, phytotoxin, sustainable agriculture.

Biologically based management of weeds has become an objective for many farmers and researchers in recent years. Liebman and Gallandt (1997) have speculated that there could be advantages to reliance on multiple tactics for controlling weeds in an ecologically managed system. This approach focuses on using inherent natural components of the cropping system such as rotation, cultivars, planting arrangement, and fertility practices as preventive measures to reduce weed populations. Although many biologically based strategies have been shown to suppress weed populations to some degree, most, by themselves, have not provided consistently acceptable weed control. Also, combinations of marginally successful control tactics have not provided improvement over each tactic used separately. For example, the combination of a phytopathogenic bacterium and a competitive cultivar of soybean [*Glycine max* (L.) Merr.] did not result in improved weed control over that of the biocontrol alone (Hoeft et al. 2001). Control by intrarow brush weeding was not improved by the addition of night soil cultivation that had a weak effect when used alone (Fogelberg 1999).

Research during the past decade has explored the potential of cover crop residue for suppressing weeds. Cover crops are grown during a period preceding planting a cash crop. Typically, winter annual species are grown during the off-season before planting cash crops in the spring. Cover crops are killed and residue is left as a mulch on the surface of

the soil in reduced-tillage cropping systems. This surface residue can suppress weed emergence at an exponentially declining rate as a function of residue biomass and other related properties (Teasdale and Mohler 2000). The competitive fitness of weeds relative to that of crops also can be reduced in the presence of cover crop residue (Williams et al. 1998). However, most research has shown that cover crop residue, as with other biologically based practices, is inadequate alone for consistently controlling weeds. Consequently, much research has been performed to determine whether cover crops in combination with other control practices, particularly herbicides, can enhance weed management.

Research that has explored interactions between cover crops and herbicides, other management practices, or a combination of these factors has shown mixed results ranging from no interactions to antagonism to potential synergism. No interactions were found between cover crops and herbicide and management systems for lettuce (*Lactuca sativa* L.) production in southern California (Ngouajio et al. 2003), soybean production in Mississippi (Reddy 2001), and corn (*Zea mays* L.) and soybean production in Ohio (Gallagher et al. 2003). Performance of several herbicides applied at both recommended or reduced rates were often similar with or without a hairy vetch cover crop regardless of cover crop management (Curran et al. 1994; Gallagher et al. 2003; Teasdale 1993). In some instances, however,

cover crops have been shown to antagonize the activity of herbicides. Although a hairy vetch cover crop suppressed weed emergence compared with a control without cover crop in herbicide-free plots, emergence of selected weeds in some years was higher with a vetch cover crop than without a cover crop in plots receiving reduced rates of atrazine plus metolachlor (Burgos and Talbert 1996; Teasdale 1993). This was explained by interception of herbicide by hairy vetch residue and by maintenance of soil moisture conditions more favorable to emergence under cover crop residue vs. bare soil. Additional research has shown that despite increased interception of herbicide by cover crop residue, weed control can still be improved by combining herbicides with high rates of surface residue. Prihar et al. (1975) showed that a combination of atrazine and straw mulch was more effective than their application singly. Crutchfield et al. (1986) explored a complete factorial of residue and metolachlor rates and determined that weed control was increased with increasing levels of wheat straw despite increased interception of metolachlor. Teasdale et al. (2003) showed evidence that, although metolachlor concentration in the soil solution was reduced by hairy vetch residue, a 10-fold lower metolachlor concentration was required to prevent weed emergence with a hairy vetch cover crop than without a cover crop. This research suggested that there could be a potential synergism between cover crops and herbicides.

Because soil herbicide concentrations, residue rates, and soil moisture conditions were confounded in many of these field experiments, the exact nature of the interactions between herbicides and cover crops could not be determined precisely. Research was needed under controlled conditions to determine the interactions between cover crop and herbicide at a range of suboptimal rates that would permit detection of deviations from expected responses. A model also was needed that could accurately predict dose responses to combinations of cover crop residue and herbicide rates but that also would permit a clear identification of synergistic responses. Therefore, the purposes of this research were (1) to develop an adequate dose–response model for testing synergism between cover crop residue and herbicide rates and (2) to determine whether there was a synergistic interaction between hairy vetch residue and metolachlor on emergence and early growth of common annual weed species.

Materials and Methods

Research was conducted under controlled greenhouse conditions to remove as many confounding influences as possible. Metal flats (32- by 22- by 8-cm inside dimensions) were filled with a sterilized greenhouse soil mix analyzed as 81% sand, 10% silt, 9% clay, and 2.2% organic matter. This soil was determined to have high nitrate nitrogen (approximately 150 kg ha⁻¹) and to have “excess” levels of other macronutrients by the University of Maryland Soil Testing Lab. One hundred seeds each of velvetleaf, giant foxtail, common lambsquarters, and smooth pigweed were planted 0.5 cm deep in rows across each flat. S-metolachlor (hereafter designated as metolachlor) formulated as Dual II MAGNUM¹ (82.4% active ingredient) was applied at 0, 1.12, 11.2, 112, and 1,120 g ai ha⁻¹ in 281 L ha⁻¹ of water with a stationary belt-driven Mandel Scientific RC-5000-500EP spray chamber with a TJ8003E nozzle² at 276 kPa

and a carriage speed of 4.8 km hr⁻¹. Treated flats then received 13 mm of simulated rain to incorporate the herbicide with a rainfall simulator designed and built by the USDA-ARS Sedimentation Laboratory, Oxford, Mississippi. Flats were covered with dried hairy vetch residue at 0, 15, 30, and 60 g per flat, spread slightly beyond the soil margins of each flat. The area covered was approximately 0.1 m², resulting in residue rates of 0, 150, 300, and 600 g m⁻². Flats were placed in a hoophouse with 14/10 h day/night and a temperature range of 25 to 30 C. Flats were subirrigated as needed to maintain adequate soil moisture conditions. When the first flush of seedlings of a given species in the control treatment (no metolachlor or vetch residue) became established approximately 2 wk after planting, emerged seedlings of that species were counted and then thinned to five uniformly vigorous plants. Any seedlings emerging after this and before harvest were counted and eliminated. When the canopy closed at approximately 4 wk after planting, the aboveground portion of the five plants was harvested, dried, and weighed. Flats were arranged in a completely randomized design with four replications per experiment, and two duplicate experiments were performed. Results were similar for each experiment, and data were combined for analysis.

Hairy vetch residue rates were chosen that represented residue levels typically encountered under natural conditions and that previous experience showed would provide only partial suppression of weed emergence at the highest rate. These rates were chosen so that response to metolachlor could be determined at all rates of vetch residue. Because emergence and growth of weeds were only partially suppressed, a simple quadratic model could adequately describe weed response to hairy vetch residue rate. Thus, weed response to hairy vetch in the absence of metolachlor was determined with a quadratic model with PROC GLM.³ When quadratic or linear coefficients were not significant, they were removed from the model.

Metolachlor rates were chosen that ranged from a registered rate for controlling weeds in corn on a coarse-textured soil (as the highest rate) to sublethal rates that could detect synergistic activity in combination with hairy vetch residue, if present. A log-logistic model (Seefeldt et al. 1995) was used to describe the dose–response relationship to an herbicide with PROC NLIN.³ A response, Y , was related to a dose, X , by the model

$$Y = \frac{a}{1 + \left(\frac{X}{I_{50}}\right)^c}, \quad [1]$$

where a is the response in the absence of herbicide, c is a slope parameter, and I_{50} is the dose giving a 50% response. Response data were expressed as a fraction of the control, thereby reducing parameter a to a value of 1.0. To model weed response to a combination of metolachlor and hairy vetch, these factors were assumed to have different, independent modes of action; thus, responses to these factors were assumed to be multiplicative (Morse 1978). Therefore, the model for estimating the response to metolachlor and vetch residue was the product of the quadratic response model to hairy vetch (V) and the log-logistic model to metolachlor (M),

TABLE 1. Coefficients for the regression of weed emergence and weight as a function of hairy vetch residue biomass in the absence of metolachlor.

Variable	Species	Model ^a			<i>R</i> ²	Maximum ^b
		<i>b</i> ₀	<i>b</i> ₁	<i>b</i> ₂		
Emergence	AMACH	0.983	0.00299	−0.00000600	0.60	1.35*
	CHEAL	0.924	0.00240	−0.00000579	0.69	1.17*
	SETFA	1.008	0.00090	−0.00000248	0.80	1.09*
	ABUTH	0.988	0.00066	−0.0000191	0.65	1.04
Weight	AMACH	0.917	NS	NS	—	—
	CHEAL	1.014	0.00107	−0.00000359	0.71	1.09*
	SETFA	1.056	NS	−0.00000177	0.64	—
	ABUTH	1.037	NS	−0.00000074	0.23	—

^a Quadratic regression model $Y = b_0 + b_1V + b_2V^2$ where *Y* is the emergence or weight as a fraction of control and *V* is hairy vetch residue biomass (g m^{−2}). NS, the coefficient was not significant (*P* < 0.05).

^b The maximum fraction predicted by the model when the maximum occurred at a value of vetch residue > 0. * Indicates that the lower 95% confidence limit of the maximum value is >1.

$$Y = (b_0 + b_1V + b_2V^2) \left[\frac{1}{1 + \left(\frac{M}{I_{50}} \right)^c} \right], \quad [2]$$

where *b*₀, *b*₁, and *b*₂ are quadratic coefficients. This multiplicative model provided an estimation of weed response to hairy vetch and metolachlor if there were no synergistic or antagonistic effects.

To describe a potential synergistic response, another parameter was added to the model. Preliminary inspection of the data showed that the *I*₅₀ value declined exponentially as hairy vetch rate increased. Thus, the final model that was capable of describing a synergistic effect was

$$Y = \frac{(b_0 + b_1V + b_2V^2)}{1 + \left(\frac{M}{I_{50}e^{-sV}} \right)^c}, \quad [3]$$

where *s* is a parameter defining the strength of the deviation from the multiplicative model (Equation 2). If parameter *s* is positive, then this parameter indicates a synergistic effect.

Modeling was performed in a four-step iteration process because of difficulty obtaining convergence without having good initial parameter estimates. First, the quadratic model of weed response to hairy vetch residue in the absence of metolachlor was determined by PROC GLM. Second, the quadratic coefficients determined from this analysis were then entered into Equation 3 as fixed values, and *I*₅₀, *c*, and *s* were determined by PROC NLIN. Third, the coefficients determined in the first two steps were used as initial starting values, and the full six-parameter model was run with PROC NLIN. Fourth, the coefficients from the third step were used as starting values, and the full six-parameter model was run again. If there was no change in parameter estimates between steps three and four, it was concluded that convergence had been achieved and no further iterations were necessary (this occurred in every case). The same model without parameter *s* (Equation 2) was also determined. The significance of inclusion of the synergistic parameter *s* in the model was determined in two ways. First, if the 95% confidence interval of parameter *s* did not include 0, it was considered significant. Second, the models with and without parameter *s* were compared by an *F* test (Seefeldt et al.

1995), and the model with parameter *s* was considered a significant improvement over the model without parameter *s* if the *F* value was significant.

The response of velvetleaf to metolachlor was insufficient at the rates used in this experiment to determine an *I*₅₀ value. Thus, velvetleaf was modeled by the quadratic response surface

$$Y = a + b_1V + m_1M + b_2V^2 + m_2M^2 + sVM, \quad [4]$$

where *a* is the intercept, *b*₁ and *b*₂ are coefficients for hairy vetch, *m*₁ and *m*₂ are coefficients for metolachlor, and *s* is the parameter for the interaction of hairy vetch and metolachlor. A stepwise parameter reduction was used to arrive at a model with entirely significant coefficients. This iterative process involved removing the coefficient with the highest *P* value until all coefficients had a *P* < 0.05. Synergism was confirmed if parameter *s* was negative and was retained in the model during this stepwise process. In addition, an *F* test comparing the model with and without parameter *s* was conducted as described above.

Results and Discussion

Emergence of all four species exhibited a significant quadratic response to increasing hairy vetch residue up to 600 g m^{−2} (Table 1). Emergence of smooth pigweed, common lambsquarters, and giant foxtail was stimulated at intermediate levels of hairy vetch. Maximum stimulation of smooth pigweed, common lambsquarters, and giant foxtail emergence was 35% at 249 g m^{−2}, 17% at 207 g m^{−2}, and 9% at 181 g m^{−2} of vetch residue, respectively. Previous research has also demonstrated occasional stimulation of emergence of pigweed species by legume residue (Gallagher et al. 2003; Teasdale and Mohler 2000). Nitrates (Gallagher and Cardina 1998) and ammonium (Teasdale and Pillai 2005) have been shown to interact with several factors to break dormancy and enhance germination of pigweed species. However, nitrate levels were initially high in this soil, so stimulation of emergence by hairy vetch residue in these experiments also could be attributed either to additional stimulatory compounds released from vetch residue or to maintenance of more favorable soil moisture conditions by residue.

The nonlinear regression model (Equation 3) provided a

TABLE 2. Coefficients for the nonlinear regression of smooth pigweed, common lambsquarters, and giant foxtail emergence and weight as a function of metolachlor concentration and hairy vetch residue biomass.

Variable	Species	Model ^a						<i>R</i> ²
		<i>b</i> ₀	<i>b</i> ₁	<i>b</i> ₂	<i>c</i>	<i>I</i> ₅₀	<i>s</i>	
Emergence	AMACH	1.085	0.00255	−0.00000565	0.661	121	0.0099	0.80
	CHEAL	1.056	0.00122	−0.00000413	0.470	47	0.0189	0.77
	SETFA	1.039	0.00025	−0.00000170	0.729	132	0.0064	0.79
Weight	AMACH	0.960	—	—	0.399	182	0.0160	0.45
	CHEAL	0.886	0.00366	−0.0000110	0.255	88	0.0250	0.71
	SETFA	1.044	—	−0.00000165	0.338	1	NS	0.65

^a Nonlinear model $Y = (b_0 + b_1V + b_2V^2) / \{1 + [M/(I_{50}\exp[-sV])]^c\}$, where *Y* is emergence or weight as a fraction of control; *M* is metolachlor concentration (g ha^{−1}); *V* is hairy vetch residue biomass (g m^{−2}); and *b*₀, *b*₁, *b*₂, *I*₅₀, *c*, and *s* are parameters. NS indicates that parameters were not significantly different from 0 according to the 95% confidence intervals.

reasonably good fit to emergence and weight of smooth pigweed, common lambsquarters, and giant foxtail (Table 2); likewise, the response surface of Equation 4 provided a significant fit to velvetleaf emergence and weight (Table 3). When these models were fit to the means of the data, an excellent fit was obtained in most cases (*R*² = 0.90 to 0.92 for emergence and 0.65 to 0.87 for weight), indicating that the majority of unexplained variation was due to variability around the means rather than to lack of fit of the model. Parameter *s*, which designated the presence of synergism, was significant for all models except giant foxtail weight (Table 2) and velvetleaf weight (Table 3). In addition, comparison of *F* values for models with and without parameter *s* indicated that it provided a significant improvement to the model for all variables except giant foxtail and velvetleaf weight (Table 4). These results demonstrate that there was synergistic activity of hairy vetch and metolachlor on emergence of all species and on smooth pigweed and common lambsquarters weight.

The nature of this synergism can be seen in Figure 1, which shows predicted values of smooth pigweed emergence in response to hairy vetch residue at selected metolachlor rates (Figure 1A) and in response to metolachlor rate at selected levels of hairy vetch residue (Figure 1B). In the absence or at low rates of metolachlor, Figure 1A shows a stimulation of emergence at intermediate rates of hairy vetch residue followed by a decline in emergence at higher rates. This same figure shows that as metolachlor rate increased, there was a more rapid rate of decline in emergence as the level of hairy vetch increased. Figure 1B shows that in the absence of hairy vetch, smooth pigweed emergence was reduced substantially only at the highest metolachlor rate. However, as hairy vetch rates increased, smooth pigweed emergence was reduced by metolachlor at progressively lower rates. For example, 500 g m^{−2} of vetch residue reduced smooth pigweed emergence by 13% alone, and 10 g ha^{−1}

of metolachlor reduced pigweed emergence by 16% alone, but they reduced smooth pigweed by 86% together. The graphs of the predicted responses of common lambsquarters and giant foxtail emergence and of smooth pigweed and common lambsquarters weight showed a similar pattern of response to that of smooth pigweed emergence, as shown in Figure 1.

Velvetleaf emergence was relatively unaffected by hairy vetch residue except at 600 g m^{−2} (Figure 2A) and was minimally affected by any rate of metolachlor in the absence of hairy vetch residue (Figure 2B). Previous research has shown that the relative tolerance of velvetleaf to cover crops is correlated with its relatively larger seed size and greater seed reserves than most other annual species (Teasdale and Mohler 2000). Curves exhibiting velvetleaf emergence response to hairy vetch at metolachlor rates of 1 to 100 g ha^{−1} were almost identical to the curve without metolachlor, and the responses to metolachlor at intermediate hairy vetch rates were almost identical to the curve without hairy vetch (curves not shown on Figure 2). The synergism between hairy vetch residue and metolachlor occurred primarily at the highest rate of both hairy vetch and metolachlor, at which rate velvetleaf emergence was reduced 70% by the combination compared with 33% by the high rate of vetch or 8% by the high rate of metolachlor.

The magnitude of the synergism between hairy vetch residue and metolachlor can be observed by displaying the response of metolachlor *I*₅₀ values to hairy vetch residue (Figure 3). Because the *I*₅₀ value was modeled as an exponential decay function of hairy vetch residue, the magnitude is determined by parameter *s* in the model. Both smooth pigweed emergence and weight required > 100 g ha^{−1} of metolachlor for a 50% reduction in the absence of hairy vetch but required only 6 and 1 g ha^{−1} for a 50% reduction at 300 g m^{−2} of hairy vetch (Figure 3), representing a 20-fold and 120-fold increase in metolachlor activity on emergence

TABLE 3. Coefficients for the regression of velvetleaf emergence and weight as a function of hairy vetch residue biomass and metolachlor concentration.

Variable	Model ^a					<i>R</i> ²
	<i>a</i>	<i>b</i> ₁	<i>m</i> ₁	<i>b</i> ₂	<i>s</i>	
Emergence	0.917	0.000788	−0.0000725	−0.00000215	−0.00000044	0.57
Weight	0.932	NS	−0.000309	−0.00000072	NS	0.43

^a Quadratic response surface $Y = a + b_1V + m_1M + b_2V^2 + sVM$, where *Y* is emergence or weight as a fraction of control; *V* is hairy vetch residue biomass (g m^{−2}); *M* is metolachlor concentration (g ha^{−1}); and *a*, *b*₁, *b*₂, *m*₁, and *s* are coefficients. NS, the coefficient was not significant (*P* < 0.05).

TABLE 4. *F* test for comparison of the multiplicative model plus a synergistic parameter *s* compared with the same multiplicative model without the synergistic parameter. Models are defined in Tables 2 and 3.

Variable	Species	<i>F</i> value	Probability <i>F</i> > 1
Emergence	AMACH	35.64	<0.0001
	CHEAL	62.94	<0.0001
	SETFA	18.09	<0.0001
	ABUTH	10.20	0.0017
Weight	AMACH	15.95	0.0001
	CHEAL	20.73	<0.0001
	SETFA	3.69	0.0571
	ABUTH	2.36	0.1268

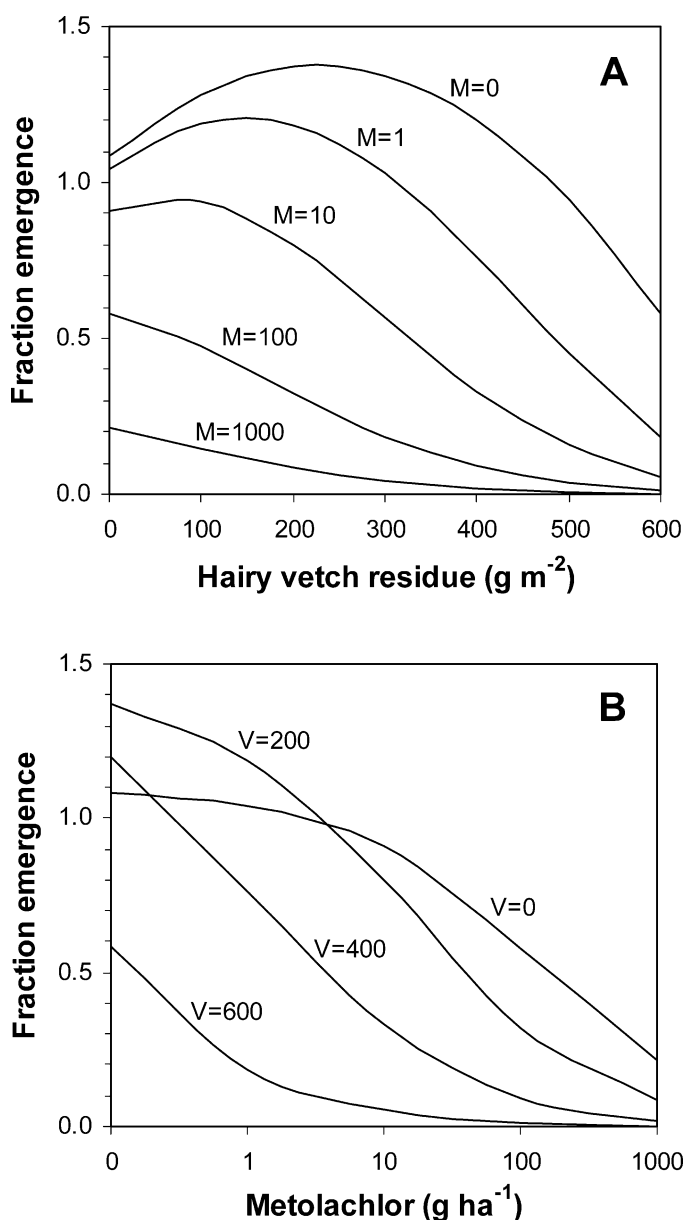


FIGURE 1. Predicted smooth pigweed emergence as a function of (A) hairy vetch residue biomass at metolachlor rates of 0, 1, 10, 100, and 1,000 g ha⁻¹ and (B) as a function of metolachlor concentration at hairy vetch rates of 0, 150, 300, 450, and 600 g m⁻². Model is defined in Table 2.

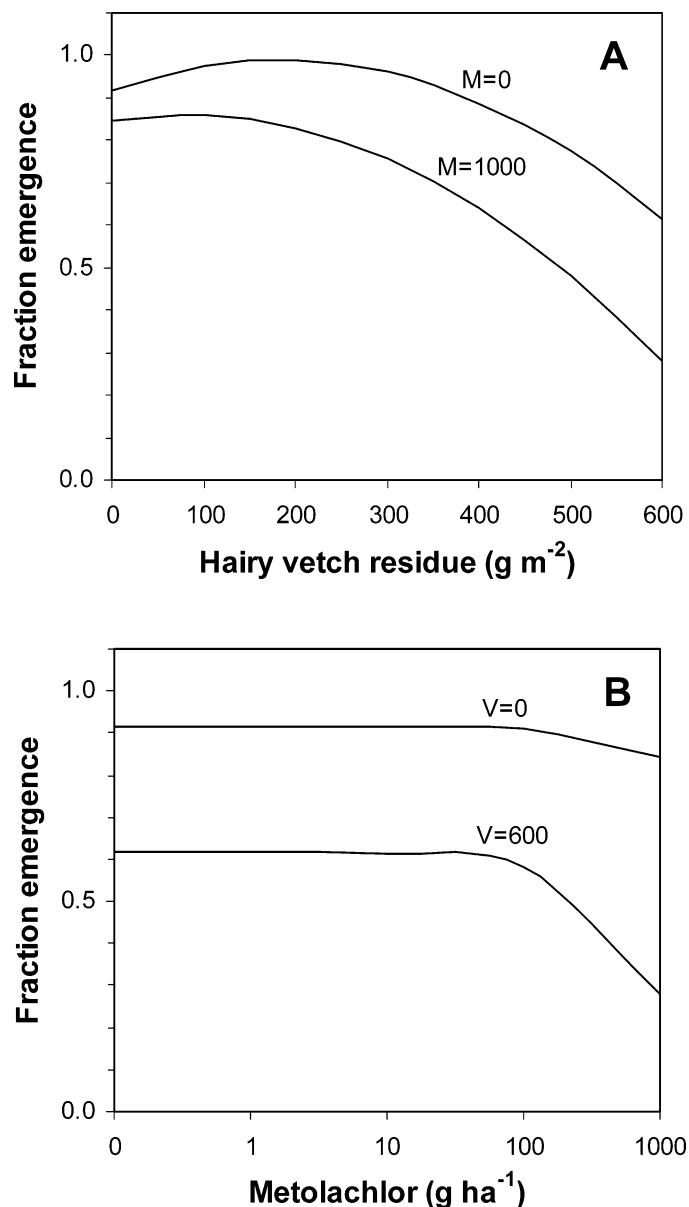


FIGURE 2. Predicted velvetleaf emergence as a function of (A) hairy vetch residue biomass at metolachlor rates of 0 and 1,000 g ha⁻¹ and (B) as a function of metolachlor concentration at hairy vetch rates of 0 and 600 g m⁻². Model is defined in Table 3.

and weight, respectively. Common lambsquarters emergence and weight exhibited an even stronger synergism where metolachlor activity was increased 40- and 150-fold, respectively, by 200 g m⁻² of vetch residue.

Enhancement of metolachlor activity by hairy vetch residue can be explained by the etiolating effect of residue on emerging seedlings. Teasdale and Mohler (2000) showed that light extinction by mulching materials made a significant contribution to a model that described emergence of the same weed species used in this experiment. An emerging seedling must expend more resources into growth around and through mulching materials to access radiation before seed reserves are exhausted than a seedling emerging from bare soil. Bruce (2003) showed that hypocotyl elongation of canola seedlings in response to reduced light by wheat stubble led to reallocation of carbon and nutrient resources away

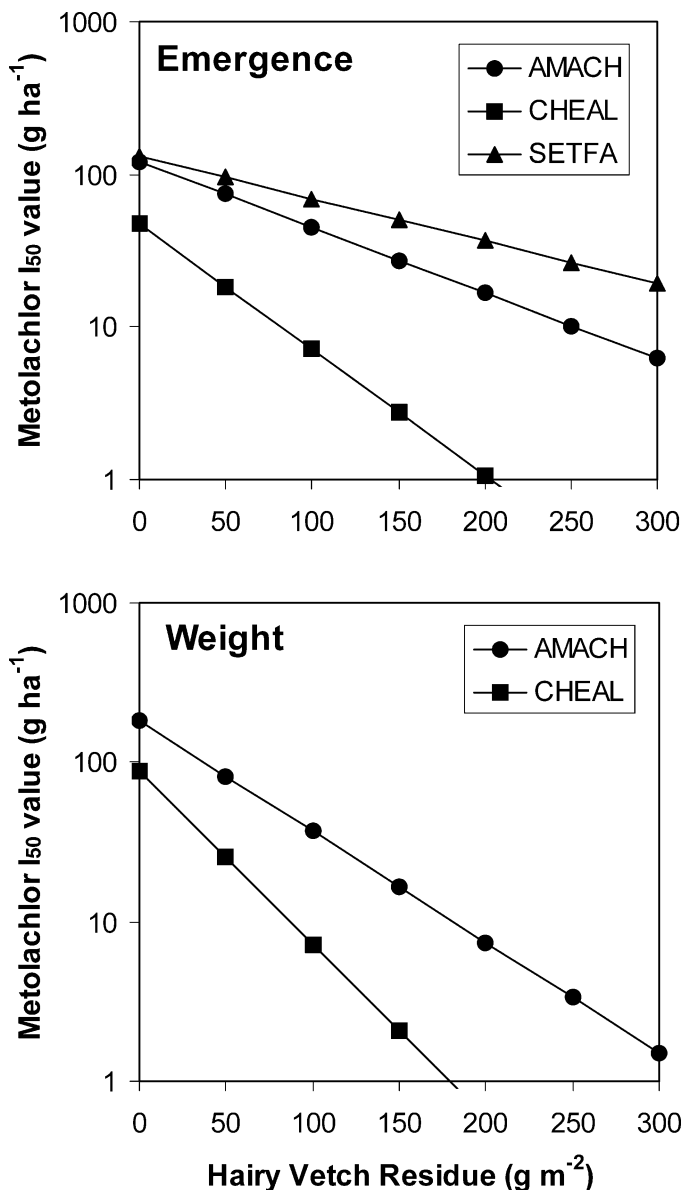


FIGURE 3. Predicted 50% inhibition concentrations (I_{50}) of metolachlor as a function of hairy vetch residue from the models presented in Table 2.

from roots and leaves, thereby reducing the subsequent relative growth rate of plants. Metolachlor is absorbed from the soil and is transported by the xylem to the growing points of the plant (Anonymous 2002; Böger et al. 2000). Activity against many physiological targets has been reported, but the primary activity of metolachlor seems to be associated with inhibition of the formation of very long chain fatty acids (Böger et al. 2000). Plants can detoxify metolachlor by conjugation with glucose or glutathione (Anonymous 2002), a step that would require an adequate supply of carbohydrate within the growing seedling. It seems reasonable that seedlings that must partition carbohydrate to hypocotyl elongation in response to light deprivation within a mulch would have diminished capacity to detoxify a phytotoxin such as metolachlor. The synergism between hairy vetch residue and metolachlor observed in this experiment could be explained by carbohydrate deprivation of etiolated seedlings that prevented sufficient detoxification of metolachlor at low rates.

Research conducted under field conditions provides practical information on the efficacy of weed management by cover crops and herbicides but has limited capacity to control conditions to determine interactions precisely. The most notable limitations of most field studies are that cover crops do not grow uniformly across field sites, resulting in uneven residue rates; surface cover crop residues can influence many confounding variables, such as soil moisture and nutrient status; and residues can significantly impede herbicide delivery to the soil surface. The design of this greenhouse experiment provided the following controls on these variables: (1) weighed amounts of residue were uniformly applied; (2) the same amount of herbicide was applied to the soil surface for any given rate; (3) herbicide was incorporated to the same degree by simulated rainfall; (4) initial soil nitrogen levels were high, minimizing differential soil nitrogen effects by vetch residue; and (5) soil moisture was maintained relatively uniform across all treatments through subirrigation. Given this level of precision, a high degree of synergy could be detected between hairy vetch residue and metolachlor.

This research suggests that the synergistic combination of cover crop residue plus low rates of metolachlor, or perhaps any phytotoxin requiring metabolic detoxification, could provide an effective biologically based system. Although use of cover crop residues in combination with herbicides might have limited usefulness for the production of field crops because of the inability to make applications beneath a surface residue layer, there could be applications in the ornamental industry, in which mulches are routinely added from an external source. In addition, phytotoxic natural products might act in a similar way in combination with cover crop residue. Any compound that requires metabolic detoxification could be synergized by surface residue that etiolates emerging weed seedlings and deprives them of the carbon resources needed for detoxification of that compound. These toxins could be allelochemicals produced by a cover crop itself or chemicals produced by microorganisms associated with decomposing cover crop residue. As a general strategy for developing effective biologically based weed management systems, this research suggests that the targeted identification of synergistic interactions should become a priority.

Sources of Materials

¹ Dual II MAGNUM, Syngenta Crop Protection, 410 South Swing Road, Greensboro, NC 27419.

² Mandel Scientific RC-5000-500EP spray chamber with a TJ8003E nozzle, Mandel Scientific, 2 Admiral Place, Guelph, ON N1G 4N4, Canada.

³ PROC GLM and NLIN, SAS Version 8.2, SAS Institute, Cary, NC 27513.

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