COTORAN WASH-OFF FROM COVER CROP RESIDUES AND DEGRADATION IN GIGGER SOIL

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ABSTRACT

Cover crop residues on no-till soil will intercept a portion of applied herbicides. Thus, herbicide efficacy in no-till systems depends, in part, on rainfall to wash the herbicide onto the soil. Tillage and cover crop residue may also influence degradation of a herbicide in soil. This series of studies examined Cotoran (fluometuron, *N,N*-dimethyl-*N*r-[3-(trifluoromethyl)phenyl] urea) wash-off from native vegetation, hairy vetch *(Vicia villosa),* and wheat residue *Triticum aestivum),* related wash-off to sorption on these residues, and compared fluometuron degradation in soil from long-term native, vetch, and wheat cover crop plots used with either conventional or no-till cotton *(Gossypium hirsutum).* A rainfall simulator was used to wash spray-applied fluometuron from plant material. Through-flow was analyzed for fluometuron by HPLC. The most fluometuron was washed off samples of native vegetation. Vetch and wheat residues retained fluometuron about equally. Fluometuron sorption on these residues was determined in a batch study. Sorption was least with native vegetation. There was little difference between vetch and wheat in fluometuron sorption. Fluometuron wash-off could be modeled on the basis of batch sorption data. The degradation of fluometuron in soil from each tillage by cover crop combination was determined by incubating fortified samples for 6, 15, 30, and 60 days. Soil extracts showed that degradation was more rapid in no-till soil than in conventional-till soil. Within either tillage treatment, degradation was slowest in vetch soil. Microbial activity was higher in no-till soil, consistent with faster degradation.

INTRODUCTION

Plant residue management that combines no-tillage with cover crops offers maximal soil coverage with protective residue and, therefore, maximal benefit for reduced erosion and preserved or improved soil quality. Hairy vetch and wheat are winter annuals commonly used as cover crops. These produce large amounts of residue that affect weed populations in no-tillage systems. Weed germination and emergence are suppressed by reduced light and temperature under cover crop residue (Teasdale et al., 1991; Teasdale and Daughtry, 1993). Allelophathy may also enhance weed suppression (White et al., 1989).

These positive effects of cover crop residue on weed suppression, however, are typically insufficient for adequate weed control so herbicides are also needed. Since a portion of applied herbicide is intercepted by the residue (Banks and Robinson, 1982; 1986), this fraction must be washed off the residue before it can contact the soil where it is active. Depending on how strongly the intercepted herbicide is retained by the residue, wash-off may be slow. Gradual transmission to the soil may provide extended weed control. Cover crop residue at the soil surface may also sorb a portion of herbicide dissolved in runoff water before it leaves the

field, thus, offering an additional environmental benefit beyond reduced erosion. On the other hand, strong adsorption may increase persistence with the possibility of crop injury in the next season (Johnson and Talbert, 1993).

Previous research has shown that sorption of chlorimuron (ethyl-2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl]benzo ate) and cyanazine (2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile) on cover crop residues is strong, increases with degree of residue decomposition, and not completely reversible (Reddy et al., 1995; 1997). However, no attempts have been made to directly account for herbicide wash-off on the basis of sorption.

Plant residue at the soil surface or incorporated into the soil may affect the rate of herbicide degradation. The parallel effects of decreasing organic matter and microbial biomass with increasing depth in soil on the degradation of fluometuron were examined by Mueller and Moorman (1992). Fluometuron half life increased from 2½ weeks in the upper 6-inch (7.5-cm) to 21 weeks in the 35- to 47-inch (90- to 120-cm) depth, where organic matter and microbial biomass were less than half that in the surface soil. Effects of increased organic matter due to either long-term no-tillage or hairy vetch cover crop, however, were not reflected in fluometuron degradation rate (Brown et al., 1994). Whereas greater rate of degradation due to enhanced microbial populations may have been expected in the surface no-till, vetch soil than in the surface conventional-till soil without cover crop, the opposite was found. The half life of fluometuron in soil from all treatments in Brown et al. (1994) was longer (average, about 9 weeks) than found in other studies (Rogers et al., 1985; Mueller and Moorman, 1992).

The objectives of the work reported in this paper were to: 1) determine the rate at which fluometuron is washed off three different cover crop residues; 2) relate wash-off rate to fluometuron sorption onto these residues; and 3) determine the effects of tillage and cover crop on fluometuron degradation in soil.

MATERIALS AND METHODS

Plant and Soil Samples

Cover crop residue and surface Gigger (fine-silty, mixed, thermic Typic Fragiudalfs) soil were collected from a long-term cotton tillage (conventional-, ridge-, and no-till) by cover crop (native vegetation, hairy vetch, wheat, and vetch plus wheat) by N fertilization rate (45 and 90 lb/A) field plot study at the Macon Ridge location of the Northeast Research Station, Winnsboro, LA. Duplicate (12 x 12-in area) samples of native, vetch, and wheat biomass were collected from six no-till plots prior to burndown with glyphosate (*N*-(phosphonomethyl)glycine) or paraquat (1,lr-dimethyl-4,4r-bipyridinuim ion). Plant residues were dried at 131°F, chopped into approximately 1-inch pieces and stored until use in the adsorption and wash-off studies described below. Table 1 gives average area densities of native vegetation, vetch, and wheat.

Surface 0- to 1-inch soil samples (2-in diameter, four per plot) from conventional- and no-till, native, vetch, and wheat plots fertilized with 45 lb N/A were collected before planting, application of fluometuron and pendimethalin (N-(1 -ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine), and application of N fertilizer. These were stored at 39°F until use in the fluometuron degradation and microbial assay studies described below. Organic matter and pH of these soils are given in Table 2.

Adsorption of Fluometuron to Cover Crop Residue

Approximately 0.035 oz (oven-dry equivalent) samples of cover crop residue were

placed in 1.0 oz Teflon centrifuge tubes and 0.67 oz of 13.9,3.48, or 0.87 ppm fluometuron in 555 ppm $CaCl_2$ added. Three replicates of each residue by initial concentration were used. Plant material was equilibrated with fluometuron solution by shaking for 24 h, then a 0.33 oz aliquot of solution passed through a conditioned C_{18} solid phase extraction column. Fluometuron trapped on the C_{18} column was then eluted with 0.10 oz of methanol and these concentrated samples analyzed by HPLC (Mueller and Mooman, 1991). Fluometuron sorption was calculated by change in solution concentration. Input concentrations were confirmed by HPLC.

Fluometuron Wash-off from Cover Crop Residues

Approximately 0.14 oz of each residue were uniformly placed on a steel screen in each of three 4-in diameter PVC caps drilled with a drain hole. Fluometuron (nominally, 25.5 ppm, dilute suspension of Cotoran) was spray-applied to each cover crop sample at a rate of 1.0 lb ai/A. Input concentration of fluometuron was confirmed by HPLC. Plant material was allowed to dry and then subjected to a series of three simulated rains (see Gaston and Locke, 1996, for description of rainfall simulator). For each rain, water was applied at a rate of 0.80 in/h for 1 hour using a metering pump. To help ensure uniformity of application, the sprinkler head was periodically rotated. Through-flow from each rainfall was collected as a composite sample. A 1.67-oz aliquot of through-flow was passed through a C_{18} solid phase extraction column and fluometuron trapped on the C_{18} adsorbent was eluted with 0.10 oz of methanol. Fluometuron analyzed by HPLC as previously described. Experimental units were allowed to air-dry between rainfalls.

Tracer Wash-off from Cover crop Residues

To determine whether fluometuron sorption data could be used to predict its rate of wash-off from cover crop residues, a simple mixing-cell model (Eq. 1, below) was used to account for retardation of fluometuron transport through the plant residue.

$$V\,(dC/dt) + m\,(dS/dt) = \beta\, q\, C \qquad [1]$$

where C is solution concentration (ppm solution), S is sorbed concentration (ppm residue), V is volume of water held by the wet residue (oz), m is mass of residue (oz), q is volumetric flow rate (oz/h), t is time (oz), and β is an empirical constant that accounts for flow dynamics in the residue. Least-squares estimates of β were based on measurements of the time-course wash-off of Cl^- applied to duplicate samples of these residue materials. In particular, 0.067 oz of 555 ppm $CaCl_2$ were spray-applied to each experimental unit, the residue sample allowed to dry, then applied salt washed off under simulated rainfall of the same intensity and duration as above. Through-flow was collected in fractions, and these were analyzed for Cl^- concentration using a Cl^- specific electrode.

Fluometuron Degradation in Surface Gigger Soil

Apparent plant residue was removed from soil samples. Approximately 0.70 oz (oven-dry equivalent) of each tillage by cover crop field plot replicate were placed in each of four 8-oz Erlenmeyer flasks (72 experimental units) and 0.033 oz of a 13.0 ppm fluometuron solution uniformly added. Sufficient distilled water was then added to increase water content to field capacity (-0.3 bar, as determined using a pressure plate apparatus). Each flask was covered with pardilm, a small hole pricked in this cover for aeration, and these treated soils allowed to incubate at 77°F for 6, 15, 30, and 60 days in the dark. Weights of flasks and contents were checked weekly for evaporative losses and additional water added if needed to restore -0.3 bar potential.

After prescribed incubation, soils were extracted with 1.34 oz of 80:20 methanol to 555 ppm $CaCl_2$ for 24 h on a wrist-action shaker. The suspensions were vacuum filtered and soil remaining in the flask extracted with a second 1.34-oz portion, which was then quantitatively transferred to the filter. The soil on the filter was washed with an additional 0.67 oz of extractant. The fluometuron extract was then rotary evaporated at 95°F, diluted with 2.5 oz 555 ppm $CaCl_2$, and concentrated by solid phase extraction as previously described. Extracted fluometuron was measured by HPLC.

Microbial Activity and Biomass in Gigger Surface Soil

Microbial activity in the conventional- and no-till, native, vetch, and wheat Gigger surface soils was estimated by the fluorescein diacetate (FDA) hydrolysis method (Schuner and Roswall, 1982). Microbial biomass C was determined on these soils and adjusted to field capacity using the chloroform fumigation method (Voroney and Paul, 1984).

RESULTS

Fluometuron Sorption by Residues

Figure 1 shows sorbed and equilibrium solution concentrations of fluometuron for the three cover crop residues. In all cases, sorption, S (ppm residue), was apparently a linear function of solution concentration, C (ppm solution), and adequately described by $S = K_D C$. Sorption of fluometuron to vetch (K_D = 17) and wheat (K_D = 18) was nearly twice that of sorption to native vegetation (K_D = 11). Therefore, it was expected that fluometuron would be less subject to wash-off from vetch and wheat than from native vegetation.

Fluometuron Wash-off from Cover Crop Residues

Figure 2 shows average cumulative fraction of applied fluometuron removed by each of three simulated rainfalls. Beginning with the first rainfall, more fluometuron was washed off native vegetation residue than from either vetch or wheat. Despite somewhat greater sorption of fluometuron to wheat than vetch (Fig. 1), cumulative wash-off from vetch was not significantly greater than wash-off from wheat, even after the third rainfall.

With the term dS/dt set equal to zero (no sorption), the transport model (Eq. 1) could adequately describe Cl^- wash-off from all residues. Optimized values for the empirical constant, β, were similar regardless of cover crop type (Table 3). Therefore, the average value, 0.19/h, was used in simulations of fluometuron wash-off from the different residues. In order to account for retarded wash-off due to sorption, the term dS/dt was set equal to K_D dC/dt. Predicted removal of fluometuron agreed well with average through-flow concentrations for the first rainfall but exceeded measured wash-off after the third simulated rain. Results for native vegetation (Fig. 3) are typical of those also seen for vetch and wheat residues. Although Eq. 1, together with sorption K_Ds, in general described the slow wash-off of fluometuron and accurately described the amount washed off by the first and second rains, the model consistently over-predicted wash-off by the third simulated rain.

Effects of Tillage and Cover Crop on Fluometuron Degradation

Table 4 gives average extractable fluometuron remaining after 6, 15, 30, and 60 days incubation. In general, fluometuron degradation was faster in the no-till than in the conventional-till Gigger soil. This difference was clear by 15 days incubation. Within each tillage treatment, differences due to type of cover crop also occurred. Fluometuron degradation was significantly faster in the native vegetation and wheat soils than in the vetch soil. There was no difference in the rate of fluometuron

degradation in the native vegetation and wheat soils. The greatest difference among all treatments, therefore, was between no-till, non-vetch soil and conventional-till, vetch soil. By 60 days incubation, negligible fluometuron was recovered from no-till, native, and wheat soils, whereas about half of the fluometuron initially applied was recovered from the conventional-till, vetch soil.

In all cases, fluometuron degradation was adequately described by first-order kinetics (Eq. 2)

$$dM / dt = -k_d M \qquad [2]$$

where M is mass of substrate remaining after t (d) of incubation and k_d is the degradation rate coefficient (d^{-1}) Table 5 gives best-fit values of K_ds for these soils. Figure 3 shows typical agreement between decreasing fluometuron recovery with time and first-order degradation lunetics.

Effects of Tillage and Cover Crop on Microbial Activity

Average FDA hydrolytic activity and microbial biomass C for the different soils are given in Table 6. Variability was high in both FDA and biomass measurements. This precluded significant differences due to type of cover, either in FDA hydrolytic activity or microbial biomass. However, FDA hydrolytic activity was significantly greater in the no-till samples. This result was consistent with more rapid fluometuron degradation in the no-till soils than in the conventional-till soils.

DISCUSSION

Interception of spray-applied fluometuron by cover crop residues and subsequent slow release to soil may affect herbicide efficacy, persistence, and fate. Results indicate that fluometuron is not readily washed off either native vegetation, vetch, or wheat residue and that the type of residue has some bearing on how fast wash-off occurs. Furthermore, the amount of fluometuron washed off residue can be predicted on the basis of sorption K_Ds However, over-predictions of the amount of fluometuron washed off by continued simulated rains suggest that sorption K_Ds may not have been constant but instead increased during the course of the study. Reddy et al. (1995) found that an increasing degree of decomposition of hairy vetch and rye *(Secale cereale)* increased sorption of chlorimuron ethyl. Similar results were reported for cyanazine sorption on ryegrass *(Loliurn multiflorum* residue (Reddy et al., 1997).

Applied fluometuron that is not intercepted by crop residue in the field or that is washed off residue comes in contact with soil. In the Gigger soil, fluometuron degradation rate was affected both by tillage and cover crop. Average half-live for degradation in the no-till soils was approximately one-third of that in the conventional-till soils (Table 5). Furthermore, degradation was much faster in the native vegetation and wheat soils than in the vetch soils. These results are in contrast to those of Brown et al. (1994) who found no differences in fluometuron degradation due either to tillage or cover crop.

Native vegetation produced much less biomass than vetch or wheat. Therefore, potential interception of applied fluometuron is less than potential interception by vetch or wheat. Furthermore, interception by wheat would depend on whether it was standing or flattened. In contrast, a close, dense residue of vetch is expected to intercept a high fraction of applied fluometuron. In Gigger soil under native or wheat cover, fluometuron is quickly degraded with less than one-tenth remaining 4 weeks after application. Interception by vetch residue, coupled with slow release by wash-off and slow degradation in the soil (more than one-half remaining 4 weeks after application), may provide longer weed control. Also, any prolonged susceptibility to loss of fluometuron in

runoff would be likely counterbalanced by the high sorptive capacity of vetch residue.

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Table 1. Cover crop biomass.

Native Vegetation	Vetch	Wheat
---------- tons/A----------		
0.33 (0.26†)	0.97 (0.14)	2.25 (0.72)

† Standard error.

Table 2. Chemical properties of Gigger soil as affected by tillage and cover crop.

	Conventional-till			No-till		
Property	Native	Vetch	wheat	Native	Vetch	wheat
pH†	5.70 ab¶	5.53 ab	5.80 a	5.17 b	5.50 ab	6.07 a
Organic matter‡ %	0.34 d	0.46 cd	0.49 c	0.72 b	0.91a	0.92 a

† 1:2, soil to water.

‡ Nelson and Sommers (1982).

Means within a row followed by the same letter are not significantly different (Fisher's LSD, " = 0.05).

Table 3. Best-fit values of the through-flow parameter, β, (Eq. 1) for different cover crop residue materials.

Replicate	Native	Vetch	Wheat
	(1/h)		
1	0.17 (0.03†)	0.26 (0.05)	0.22 (0.04)
2	0.22 (0.03)	0.10 (0.01)	0.16 (0.04)

† Standard error.

Table 4. Fraction of applied fluometuron recovered from conventional- and no-till soils under native, vetch and wheat vegetation after different periods of incubation.

Incubation	Conventional-till			No-till		
(d)	Native	Vetch	Wheat	Native	Vetch	Wheat
6	0.699 cd¶	0.884 a	0.761 bc	0.586 e	0.810 ab	0.594 de
15	0.630 a	0.681 a	0.553 a	0.208 b	0.556 a	0.265 b
30	0.460 b	0.670 a	0.328 b	0.058 c	0.467 b	0.141 c
60	0.313 bc	0.506 a	0.186 c	0.022 d	0.368 ab	0.000 d

¶ Means with a row followed by the same letter are not significantly different (Fisher's LSD, P = 0.05).

Table 5. Influence of tillage and cover crop on fluometuron degradation in Gigger soil.

	Conventional-till			No-till		
Parameter	Native	Vetch	Wheat	Native	Vetch	Wheat
Rate constant, k_d (1/d)	0.026(0.004†)	0.014(0.002)	0.036(0.003)	0.097(0.004)	0.022(0.003)	0.083(0.005)
Half life (d)	27	51	19	7	31	8

† Standardemor.

Table 6. Means for FDA hydrolytic activity and microbial biomass.

	Conventional-till			No-till		
Property	Native	Vetch	Wheat	Native	Vetch	wheat
FDA†	0.190 b¶	0.228 ab	0.257 ab	0.273 ab	0.376 a	0.332 ab
Biomass C‡	0.899 a	0.760 a	1.154 a	1.351 a	1.487 a	0.726 a

† Increase in optical density at 490 nm/g-h.

‡ ppm C.

¶ Means with a row followed by the same letter are not significantly different (Fisher's LSD, P = 0.05).

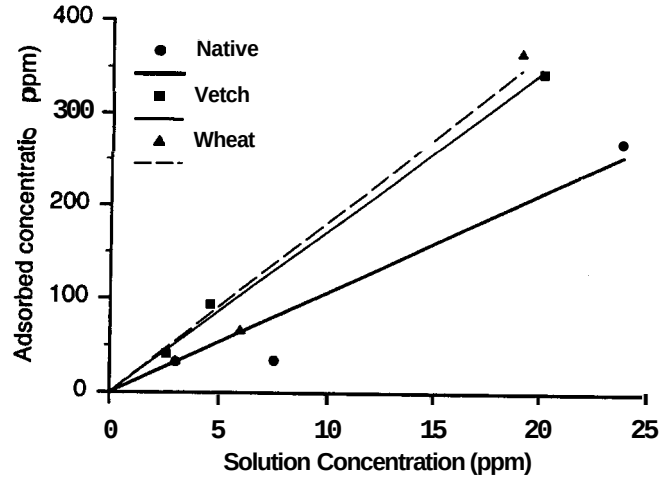

Figure 1. Isotherms for fluometuron sorption on native vegetation, vetch, and wheat residues.

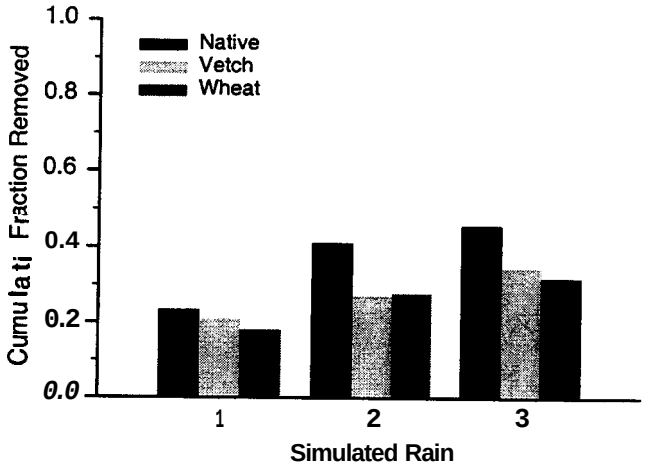

Figure 2. Cumulative fluometuron washed off cover crop residues by three simulated rains.

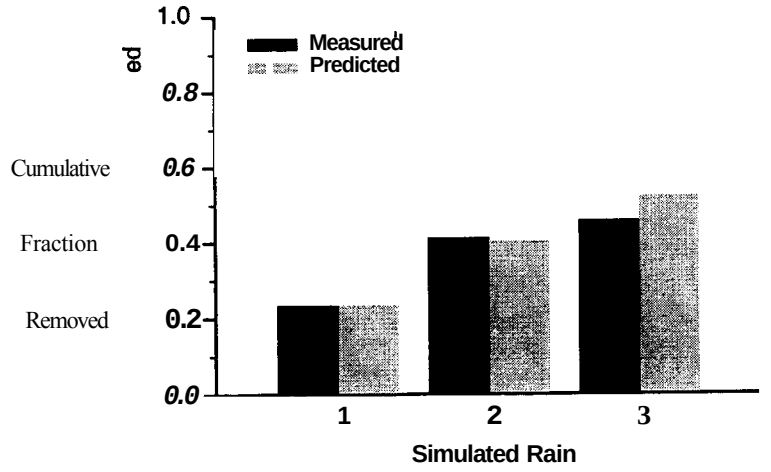

Figure 3. Measured and predicted fluometuron wash-off from cover crop residues.

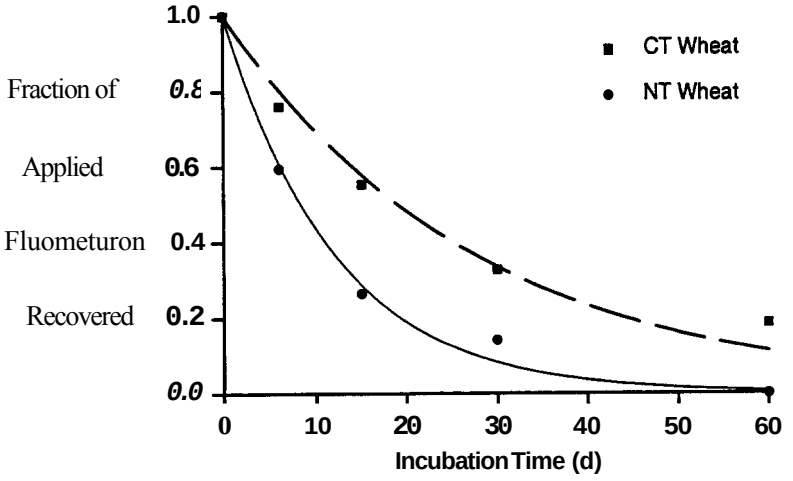

Figure 4. Fluometuron degradation in conventional-till (CT) and no-till (NT) Gigger soil with wheat cover crop. Smooth curves show degradation described by first-order kinetics.